ENERGY POLICIES OF IEA COUNTRIES

Denmark

2017 Review

International Energy Agency
Secure
Sustainable
Together

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INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate was – and is – two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 29 member countries and beyond. The IEA carries out a comprehensive programme of energy co-operation among its member countries, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency's aims include the following objectives:

- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations and other stakeholders.

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Foreword

The International Energy Agency (IEA) has been conducting in-depth country reviews since 1976. A core activity, the process of review by peers, not only supports member countries' energy policy development and mutual learning, but it also encourages the exchange of international best practice and experience. In short, by seeing what has worked – or not – in the "real world," these reviews help to identify policies that achieve objectives and bring results.

In 2016, the IEA decided to modernise the reviews by shifting their focus to key energy security challenges in fast-changing global energy markets, and to the transition to a clean energy system.

This report on Denmark offers insights into two special focus areas, which were chosen by the Danish government: integrating variable renewable energy into the electricity system and making the heating sector more sustainable. These two areas are critical for advancing decarbonisation in Denmark and, because they are intertwined, they also offer an attractive potential for energy system integration.

Wind power today provides more than 40% of the electricity generated in Denmark. This is the highest share in the world, and tapping into the large offshore resource will help the country raise this portion even higher. In regard to heating, Denmark is already switching from coal to biomass in district heating and favouring renewables over oil and natural gas in individual heating. These trends will have to continue for the country to meet its goals to increase the share of renewables and, by 2050, to discontinue its reliance on fossil fuels altogether. Smart policies and measures are essential to accomplishing this at least cost.

The primary aim of this report is to support Denmark in its quest for a secure, affordable and environmentally sustainable transformation of its energy sector and economy. It is my hope that this country review will guide Denmark in its energy transition and support its contribution to a cleaner, more sustainable and secure global energy system.

Dr. Fatih Birol

Executive Director

International Energy Agency

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ENERGY SYSTEM TRANSFORMATION

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Overview

Since the previous in-depth review in 2011, Denmark has made impressive progress towards decarbonising its energy sector while maintaining robust security of supply. Denmark's energy intensity and carbon intensity are among the lowest of all IEA member countries. The country has also become a world leader in system integration of variable renewable energy (VRE); it has the highest share of wind power in electricity generation and electricity supply is stable and secure at both transmission and distribution levels. Denmark is also among global leaders in using energy-efficient technologies, including combined heat and power (CHP), which provides half the electricity and two-thirds of heat sold in the country.

The growing shares of wind and solar power create new challenges and opportunities for the Danish electricity and heating sectors, as well as for end-use sectors such as transport, buildings and industry. This review of Denmark's energy policy has a special focus on two interrelated issues: how to increase the share of VRE in the power system even further, and how to transform the heating sector into a low-carbon sector.

The current decoupling of gross domestic product (GDP) from energy consumption and greenhouse gas emissions partly results from the ambitious national decarbonisation targets as in the Energy Agreement for 2012-20 and the effective implementation of policies and measures to meet them. The Danish tradition of broad energy agreements has provided predictability and continuity in energy policy (thus creating a good environment for investors). The new Energy Agreement for the period 2020-30 is being prepared in 2017 in open and transparent consultation with many stakeholders, which is a very constructive approach. This new agreement can offer a good foundation for a low-carbon, efficient and secure energy policy, while at the same time continuing to provide stability to the energy sector and its stakeholders.

As part of the preparations for the 2020-30 Energy Agreement, an independent Energy Commission published its recommendations in April 2017. The IEA generally supports the Energy Commission's conclusions and recommendations, including the importance of a regional approach, market-based solutions, energy system integration across sectors, increased flexibility, further improvements in energy efficiency and the need to launch, as early as possible, cost-effective emissions reduction initiatives in sectors not covered by the European Union (EU) Emissions Trading Scheme (ETS).

The IEA praises Denmark for its efforts to develop energy and climate policies and measures based on sound socio-economic analysis and forecasts. The Danish government is also to be commended for its willingness to address energy issues in a holistic manner, with great attention paid to interactions and synergies between: *i)* the demand side (energy efficiency) and the supply side (expansion of renewable energy capacity); *ii)* different sectors (electricity generation, heating, transport, buildings, etc.); and *iii)* various policies and regulatory instruments, including taxation.

Low-carbon transition

In addition to its international and EU-specific commitments, Denmark has very ambitious national targets: meeting at least 50% of energy demand with renewable energy in 2030; and becoming a low-emission society independent of fossil fuels by 2050. Effective policies and measures have been put in place to support energy efficiency improvements and switching from fossil fuels to renewable energy. Denmark is to be commended, in particular, for organising successful offshore wind tenders that have resulted in record-low prices. The existing measures will enable Denmark to meet most of its short-term targets (to 2020) without any additional efforts, with the exception of its 10% renewable target in the transport sector. However, meeting the 2030 and 2050 objectives would require new policies because most of the existing support schemes expire around 2020. When planning measures for the short and medium term, the government should also consider the long term to avoid costly lock-in effects. For example, the current support framework encourages replacing coal-fired generation with biomass, which is a viable solution in the short term. However, an integrated, electrified system based on even larger shares of wind power represents many more advantages in the longer term. Therefore, the new Energy Agreement should facilitate solutions that would be sustainable not only in the period 2020-30 but also in the longer run.

As several of the energy and climate targets are interlinked (for example, increasing the share of renewables also reduces GHG emissions), the government should closely co-ordinate the preparation of the Energy Agreement, the Climate Plan and the strategy for reducing emissions in the non-ETS sector in 2030 and beyond.

To continue its transition towards a low-carbon society, Denmark will need to address several challenges, including:

- **Achieving further decarbonisation in a cost-efficient manner.** In recent years, the growth in renewable energy generation and improvements in energy efficiency have been impressive, but the costs of the related support policies have increased significantly. In designing future policies, the government should pay even greater attention to market-based, cross-cutting solutions, building upon the Danish experience with energy efficiency schemes and competitive mechanisms to reduce the costs of renewable energy projects (offshore wind and solar photovoltaic tenders). For example, competitive auctions could be further aligned with transmission and distribution planning to ensure that new generation is built where it has the most value to the system. Market-based instruments are beneficial because they give private-sector actors freedom to innovate and use the most optimal technologies and delivery routes. High-quality monitoring, verification and evaluation of market-based instruments will be needed so that the participants cannot "game" the system or deliver suboptimal outcomes.

- **Electrification and sector coupling** (linking the electricity sector with the heating, transport and other sectors). Further expansion of electricity produced from renewables, particularly from wind, helps reduce or eliminate the use of fossil fuels in district heating, transport and other sectors. In addition, electrification can reduce total energy consumption because it enables highly efficient technologies, such as heat pumps and electric cars. The value of increased electrification is already well understood in Denmark; therefore, the key next steps include developing a sound strategy and ensuring cross-sector co-ordination. In particular, incentives will need to be aligned across the economy. For example, digitalisation of energy equipment, processes, data and communications across different sectors can effectively contribute to the low-carbon transition by offering opportunities for enhanced efficiencies and performance. The government and other stakeholders rightly put increasing focus on digitalisation.

- **Amending energy taxation** to support the energy and climate policies of Denmark, while maintaining budget revenue. Very high electricity taxation for households, while encouraging energy savings, is a barrier to the increased use of heat pumps and efficient electric boilers, as well as of electric vehicles. This limits the potentially cost-efficient sector coupling and encourages self-generation, also where this is inefficient from a socio-economic perspective. The zero tax on biomass, the double taxation of electricity stored in batteries (when purchased and when resold) and the registration tax on cars also need to be evaluated by the government. The IEA encourages the government to reconsider its taxation policy to steer producers' and consumers' choices towards more sustainable low-emission solutions. For example, reducing the electricity tax for heating, as is already done, is a step in the right direction that could be taken further. Heating consumption could be defined more robustly – in particular as smart meters are rolled out – by separately metering electric heat. Similar steps should also be considered for new uses, such as electric vehicles and batteries.

- **Reducing emissions in the sectors not covered by the EU Emissions Trading Scheme (ETS).** By 2020, emissions in the non-ETS sectors, particularly in transport, are expected to represent around 70% of the overall GHG emissions. Although energy-related carbon dioxide emissions in transport have declined over the last decade, the pace has been slower than in other sectors. Denmark is encouraged to speed up the decarbonisation of transport by stimulating more aggressively the penetration of electric vehicles as well as the use of sustainable liquid biofuels and biogas, increasing further electrification of rail transport and, at the EU level, introducing more stringent efficiency standards for vehicles. Additionally, increasing the efficiency of the transport system, e.g. through promoting public transport, digitalisation, optimising speed limits and managing flows in the road networks, can further improve decarbonisation in the sector.

- **Effective strategy for the sectors covered by the ETS while supporting the EU-ETS reforms**. Because of the surplus of emission allowances, the EU-ETS currently is not a sufficiently effective decarbonisation tool. Emissions reductions in the Danish sectors covered by the ETS have been largely the result of renewable energy and energy efficiency policies rather than the effect of the ETS itself. Therefore, the Danish government is encouraged to continue its support for structural reforms of the ETS to reduce the amount of allowances and ensure stronger price signals. As long as the EU-ETS prices are not adequate to drive a structural shift towards low-carbon options, the Danish government will need an effective strategy for the sectors covered by the ETS (especially industry).

Energy security

Security of supply is a priority of the Danish energy policy. Thanks to competent planning, timely investments and efficient maintenance, the supply of electricity, heating, gas and oil has been quite stable and without major interruptions in recent years. The electricity sector, in particular, has achieved a remarkable level or flexibility, resource adequacy and overall system reliability in the context of growing shares of variable renewable energy. The security of electricity supply is very high compared to other countries and is expected to remain high according to the projections of the transmission system operator (TSO) Energinet.dk. Efforts to ensure security of oil supply are also commendable: Denmark holds emergency stocks 20% higher than the EU requirement,[1] corresponding to 73 days of average daily inland consumption. The government, the system operator, the utilities and the regulator should maintain their commendable efforts to ensure secure energy supply. Particular attention should be given to gas supply security during the temporary closure of Tyra, the major producing field, from 2019 to 2022.

Denmark has been an oil and gas producer since the 1970s. Although production has been declining steadily since 2004, it has been sufficient to meet internal demand. In 2013, the terms and conditions for hydrocarbon production in the North Sea were revised. Following a wide national debate, the government, in co-operation with the industry, prepared a strategy with the aim to ensure that the North Sea oil and gas resources are exploited efficiently.

While Denmark is expected to remain a net gas producer in the coming decades, the prospects for the future functioning of the Danish internal gas infrastructure are unclear. It is welcome that the government has addressed gas system development in the strategy “Utilities for the Future” but a longer-term perspective seems needed in light of Denmark’s low-carbon aspirations. The government should assess possible strategies for the gas infrastructure and ensure optimal use and maintenance of the existing and remaining gas infrastructure.

In terms of electricity supply security, Denmark provides a very successful example. In a relatively short timeframe, Denmark’s power system has been transformed from a fossil fuel-based one to one with more than half of generation coming from renewable sources, without sacrificing system reliability in the meantime. This has been supported in large part by effective grid management and strong regional co-operation with the other Nordic countries. However, security of supply may soon become a pressing issue.

In pure capacity terms, Denmark has a significant surplus to meet its peak demand, even when discounting its weather-dependent VRE and before taking into account its (growing) interconnector capacity. However, there are reasons to be concerned that this situation will not last. First, a significant portion of the natural gas fleet lies idle, and only remains in the market because of a subsidy that will expire in 2019. Second, the medium- and long-term goals to increase the share of renewables in the power system imply that the share of VRE in the generation mix will only increase.

[1] As a net oil exporter, Denmark has no IEA obligation to hold oil emergency stocks, but it has a stockholding obligation as an EU member state.

Denmark's grid is unique in Europe in that it is divided into two non-synchronised areas: western Denmark (DK.1) and eastern Denmark (DK.2). The two grids are connected by a 600 megawatt (MW) high-voltage direct current line named the Great Belt Interconnector. Energinet.dk regularly evaluates whether the capacity of this interconnector should be increased. At present there does not appear to be a clear economic rationale for doing so. It is worth asking, however, whether a possible increase in capacity between DK.1 and DK.2 should wait for an economic rationale to emerge, or if security concerns are sufficient to warrant investment in the near term.

Increasing interconnector capacity with neighbouring countries is another important step. For example, increasing interconnector capacity to Sweden could also be considered. Given ongoing internal capacity issues in the German grid, it is not clear how much increased transmission capacity between DK.2 and Germany will help. Today, internal constraints in Germany prevent Denmark from fully taking advantage of the interconnection capacity that already exists between the countries. Increased collaboration between Energinet.dk and the German TSO TenneT is an important step, but it is a second-best solution to resolving the grid constraints in Germany.

Competition and energy sector regulation

Denmark's electricity and gas sectors have been unbundled and liberalised since 2004, in line with European Union law. There are a large number of active retailers, and consumers have a wide range of electricity products to choose from, suggesting a good deal of competition in the retail sector. However, there is room for improving retailer switching rates to better grasp the multiple benefits of competition. Despite available choices, switching rates remain low, especially among small-size consumers (6.3% in 2016). In the gas sector, retail market competition is an even larger concern (only around 4% changed supplier in 2015). Consumers do not have sufficient incentives to choose a supplier or a product. In both sectors, regulated prices still exist and customers are not encouraged to enter into the market. Regulated prices hinder competition. The regulated price for the supply obligation product can be so low that it is difficult for independent suppliers to compete.

It is positive that Denmark started phasing out the price-regulated supply obligation products in both electricity and gas sectors. Another step in the right direction is giving the supplier complete control over the billing and support process, as was done with the introduction of the supplier centric model in the electricity sector. Denmark has also recently taken steps to eliminate the potential for confusion over who is actually providing retail services, for example by requiring that incumbent retailers use a different name and branding from the monopoly electricity and gas distribution business.

Denmark participates in the Nordic electricity market and relies on imports from that market for a large share of its electricity supply. Low wholesale prices in the Nordic market area in recent years have reduced the profitability of power generators. Denmark and the other governments in the Nordic electricity market area should co-ordinate and harmonise their renewable energy subsidies and policies to avoid creating an oversupply of power that leads to wholesale prices too low to trigger investments in an otherwise profitable low-carbon electricity capacity.

The district heating market is more regulated than the electricity and gas markets, through a non-profit regulatory framework. Denmark is planning to change this framework into a system based on revenue regulation, supported by benchmarking and standardised accounting principles, which will be used to increase efficiency incentives to the district heating operators. Focus on efficiency improvements is a useful addition to a regulated market.

The electricity, gas and district heating sectors are regulated by the Danish Energy Regulatory Authority (DERA). The IEA welcomes DERA's efforts to carry out competition inquiries regularly and stresses the need to monitor closely the implementation of recommendations, as the electricity and gas retail market remains highly concentrated. DERA's other responsibilities include supervising the energy efficiency obligation and co-operating with the Nordic and EU regulators. Given the increasing role of the electricity sector in the low-carbon transition, DERA may require additional competent staff with specific expertise. Encouragingly, DERA's staffing was recently increased. It is important to ensure that the regulatory authority continues to have sufficient funding and human resources.

Variable renewable energy (VRE) integration

Denmark, supported by a flexible domestic power system and a high level of interconnection, has already done more than most countries to integrate VRE. Wind, and to a lesser extent solar PV, account for nearly half the total generation, which is a unique achievement. Pushing the limits of VRE integration even further will require increased innovation and co-ordination across the entire energy sector.

The IEA has identified five broad strategies for supporting the integration of VRE, all of which Denmark is already following, albeit to varying degrees.

The first and possibly most complex strategy is to encourage system-friendly deployment of VRE. This means, among other things: allowing VRE to contribute to the provision of power system services; optimising the location of VRE deployment; optimising the generation profile to maximise its value to the system; and utilising integrated resource planning.

The second strategy is to maximise the flexibility of the non-VRE generating fleet. Denmark's generation fleet is already flexible, but it is critical that this flexibility be maintained as the power system continues to evolve. For example, a large portion of the natural gas fleet is expected to be retired when the natural gas capacity subsidy expires, resulting in a net loss of potential flexibility options.

Leveraging demand-side flexibility is also important to VRE integration. Demand-side flexibility refers to a suite of solutions, and so there is no single strategy for increasing its deployment. Rather, Denmark needs to address a range of issues, such as giving consumers the right market signals to encourage more flexible consumption patterns. The roll-out of tools such as smart meters and the DataHub and the development of Denmark's Digital Strategy are important steps in the right direction.

Increased electrification will also allow more opportunities to consume VRE generation as the penetration of wind and solar increases. Tariff reform, already to some extent under way, will certainly help in this area.

Finally, VRE integration is made easier by the efficient utilisation of interconnectors. Having access to neighbouring markets improves Denmark's ability to balance its domestic VRE resources while also allowing it to export VRE generation in those hours when it produces more than it can consume domestically.

To truly push the limits of VRE integration, Denmark's focus must be on improving the way each strategy is implemented. Moreover, effectively integrating large shares of VRE into the power system requires the implementation of multiple strategies simultaneously. This will require co-ordination across multiple government agencies to ensure that policies are developed and implemented in a manner consistent with long-term objectives.

Heating sector

The heating sector will play a key role in meeting Denmark's ambition of being independent of fossil fuels by 2050. Denmark has put considerable efforts into using renewable energy for heating – both in district heating networks and individual heating systems. District heating (DH) is the most important heating source in the residential and commercial sectors, providing almost half the total heat supply in buildings, which is among the highest shares in the IEA. The DH production mix has shifted from being largely based on fossil fuels to a clear dominance of biomass (surplus straw, woodchips and wood pellets) and municipal waste. This shift forms an important part of the energy transition in Denmark, and needs to continue for the country to meet its ambitious energy and environmental targets.

The rapid increase in biomass-based DH has made Denmark a large importer of wood pellets. As the conversion of existing coal-fired combined heat and power (CHP) plants continues, fuel availability and import diversity need to be considered to guarantee security of supply. Denmark should assess the future for biofuels and municipal waste as fuels, in the light of sustainability requirements. With new data centres being established in Denmark, the potential for using surplus heat increases, and regulations and policy should support this development.

Denmark's world-leading deployment of variable wind power and large utilisation of CHP plants with heat storage capacity in district heating systems form ideal conditions for the efficient integration of heat and electricity systems. To this end, policy and regulation need to be aligned to support sector coupling and achieve potential synergies. The boom in biomass combustion and a slow uptake of other sustainable technologies, particularly heat pumps, have been driven by distorted price signals due to zero taxation for biomass and high electricity taxes. Taxation should be adjusted to improve integration between the electricity and heat systems, so that CHP producers can further utilise times of excess power in the system and contribute to balancing the power and heat systems.

Taxation and eventual other measures should further be adjusted to optimise the use of DH and individual heating options. Fossil fuels in individual boilers and very small DH networks can be replaced directly by advanced heating technologies, such as heat pumps, without converting fossil-fired boilers into biomass use. Increased use of individual heat pumps may, however, increase the electricity demand in times of peak consumption and thus cause stress on the electricity grid. Smart technology for monitoring energy consumption on an aggregated level can improve integration between the heat and electricity sectors, also in a more decentralised system. Policy should support the utilisation of new technology and business models that can further improve sector coupling.

Another challenge for Denmark is to promote and improve the efficiency of DH systems – which are often natural monopolies − while maintaining a good business environment. There is potential for significant productivity gains in the sector, and the government is developing a new regulatory framework to this end. Opening up DH networks for third-party access can further increase market competition and utilisation of industrial surplus heat. The government is also considering removing the DH and gas network connection mandate as a way to increase competition between individual and collective heat supply. If it decides to do so, it should take into account the need for a "critical mass" in smaller DH systems for them to remain economically viable.

Key recommendations

The government of Denmark should:

- ☐ Consider energy and climate issues as a whole when deciding upon policy measures for reaching the different energy and climate targets set by the government as well as the targets adopted internationally and in the European Union. Prioritise measures that are the most cost-effective and suitable for meeting multiple targets and socio-economic objectives.
- ☐ Ensure that policy measures for reaching medium-term energy and climate targets (2030) are dimensioned and directed so that they are consistent with possible paths towards long-term objectives (to 2050).
- ☐ Assess current energy taxation principles, structure and levels in light of the energy and climate policy objectives, and adjust them to ensure that taxation is not a barrier and does not undermine current or intended policy.
- ☐ Ensure that the Danish Energy Regulatory Authority has sufficient resources to continue to perform in a competent manner as its duties expand.

1. General energy policy

Key data

(2016 provisional)

TPES: 16.5 Mtoe (oil 35.6%, biofuels and waste 25.1%, natural gas 17.4%, coal 11.9%, wind 6.7%, solar 0.7%, geothermal 0.1%, electricity imports 2.7%), -18% since 2006

TPES per capita: 2.9 toe (IEA average: 4.4 toe)

TPES per unit of GDP: 65 toe/USD million PPP (IEA average: 109 toe/USD million PPP)

Energy production: 14.9 Mtoe (oil 47.6%, natural gas 27.1%, biofuels and waste 17.1%, wind 7.4%, solar 0.7%, geothermal 0.1%) -50% since 2006.

Exchange rate: 1 DKK = USD 0.149 = EUR 0.134

Country overview

Denmark is a Scandinavian country, member of the European Union (EU). It has an area of 43 000 square kilometres, a coastline of 8 500 km and a population of 5.7 million in January 2017, of which almost 88% lives in urban settlements. The capital of the country is Copenhagen, with 1.28 million inhabitants; other major cities include Aarhus, Odense and Aalborg. The official language is Danish and the currency is the Danish krone (DKK).

The bulk of Denmark is located on the peninsula Jutland and the rest of the country consists of 406 islands, the largest of which are Zealand and Funen. Denmark shares a small land border with Germany and is connected to Sweden by bridge. The Kingdom of Denmark also includes the autonomous self-governing areas of the Faroe Islands in the North Atlantic, and Greenland, which is part of the North American continent.

Denmark is a constitutional monarchy, with a full parliamentary democracy. Its Head of state is the Monarch – since 14 January 1972 Queen Margrethe II. The government, headed by the prime minister, exercises executive power. The current government was formed in 2016 as a three-party, centre-right coalition led by the Liberal Party (Venstre) and backed by the Liberal Alliance (LA) and the Conservative People's Party (KF). The coalition does not have a parliamentary majority, leaving it dependent on the support of the right-wing Danish People's Party (DF). The head of government since 28 November 2016 is Lars Løkke Rasmussen.

Denmark is a member of the United Nations (UN), the Organisation for Economic Co-operation and Development (OECD), the North Atlantic Treaty Organization (NATO), the Organisation for the Security and Co-operation in Europe (OSCE), the International Monetary Fund (IMF), the World Trade Organization (WTO) and other major international organisations.

Figure 1.1 Map of Denmark

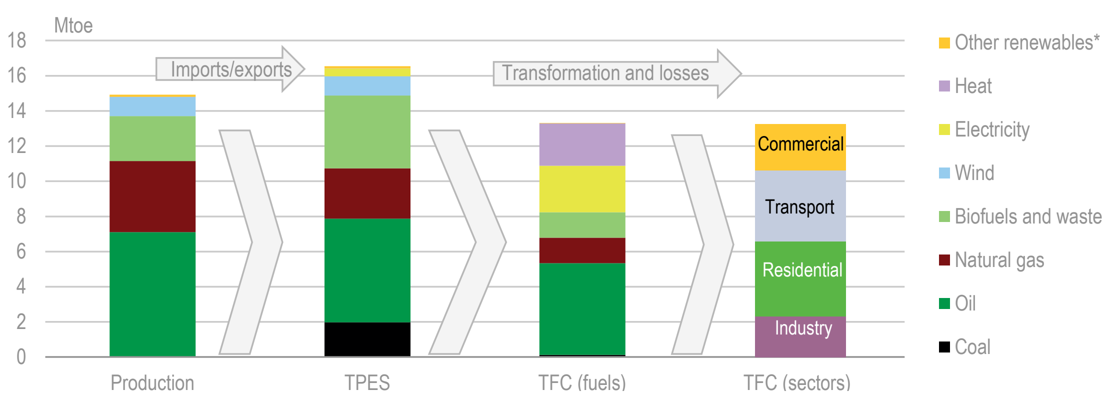
This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Denmark is a relatively rich country; it ranks ninth among OECD countries in terms of GDP per capita, at USD 49 972 (United States Dollar) in 2016, according to OECD statistics. Unemployment, at 6.2% in 2016, is slightly lower than the OECD average of 6.3%. The GDP composition by sector is the following: services 75.5%; industry 23.4%; agriculture 1.1%. The agricultural sector, which employs about 2.5% of the labour force, accounts for over 6% of Danish exports.[1] Exports of energy technology and services (DKK 83.8 billion in 2016) also make a significant contribution to Denmark's balance of trade. The contribution of oil and gas exports to the balance of trade has declined in recent years.

Supply and demand

Denmark's total primary energy supply (TPES) was slightly larger than its domestic energy production in 2016. While all coal for domestic consumption was imported, Denmark was a net exporter of gas. The volumes of oil imported and exported are nearly equal, with imports slightly larger than exports. Oil is the largest energy source in Denmark's TPES[2] and is mostly used in the transport sector, whereas the majority of coal and nearly one-third of all natural gas are used to generate heat and electricity. The district heating sector is large and heat is the third-largest energy source in total final consumption (TFC),[3] after oil and electricity. The transport and residential sectors have historically been the highest energy consuming sectors; in 2015, they accounted for nearly one-third of TFC each. The commercial and industry sectors accounted for the last third.

Figure 1.2 Overview of energy production, TPES and TFC, 2015/16



**Other renewables* includes hydro, geothermal and solar.

Notes: Consumption data (TFC) are for 2015. Supply data for 2016 are provisional.

Source: IEA (2017), *World Energy Balances* 2017, www.iea.org/statistics/.

[1] https://tradingeconomics.com/denmark/exports-by-category, accessed on 29 June 2017.

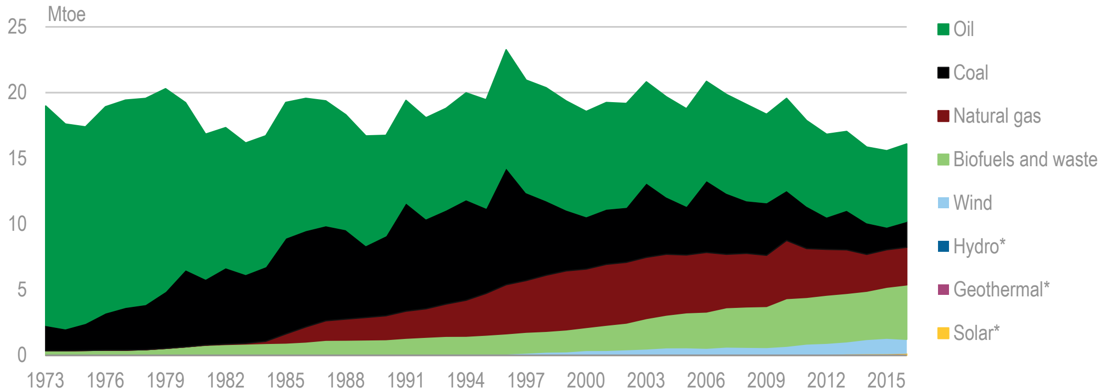
[2] TPES is made up of production + imports – exports - international marine and aviation bunkers ± stock changes. This equals the total supply of energy that is consumed domestically, either in transformation (e.g. power generation and refining) or in final use.

[3] TFC is the final consumption of fuels (e.g. electricity, heat, gas and oil products) by end-users, excluding the transformation sector (e.g. power generation and refining).

Primary energy supply

Denmark's total primary energy supply (TPES) in 2016 was 16.5 Mtoe, an 18% decline from 2006 (see Figure 1.3).

Figure 1.3 TPES by source, 1973-2016

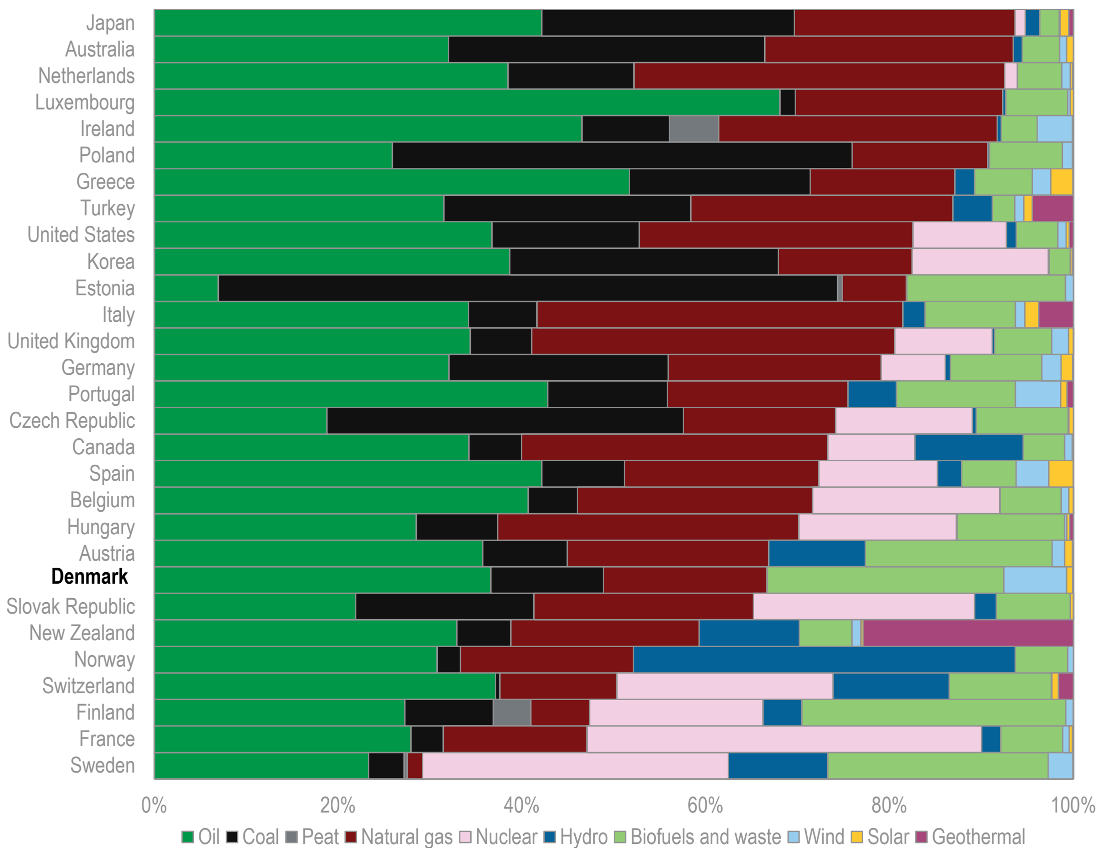


*Negligible.

Note: Data for 2016 are provisional.

Source: IEA (2017), *World Energy Balances* 2017, www.iea.org/statistics/.

Figure 1.4 Breakdown of TPES in IEA member countries, 2016



*Estonia's coal is represented by oil shale.

Note: Data are provisional.

Source: IEA (2017), *World Energy Balances* 2017, www.iea.org/statistics/.

Annual fluctuations in TPES are largely a result of variations in coal supply for power generation. Denmark forms part of the Nordic electricity market, where a significant share of electricity is produced by hydropower, and variations in hydro availability in Norway and Sweden have traditionally been balanced by coal-fired power plants in Denmark. This dynamic is changing, however, as a result of increasing generation from wind and other renewables.

Fossil fuels accounted for around 65% of TPES, decreasing from 87% in 2006. The share of fossil fuels in TPES is the eighth-lowest among IEA countries. Oil is the largest fossil fuel, at 35.6% of TPES in 2016. Natural gas accounted for 17.4% of TPES and coal for 11.9%. All fossil fuels have declined over the past decade, especially coal, which fell by more than half, as renewable energy sources replaced coal in heat and electricity generation.

The share of renewables in TPES grew from 16.3% in 2006 to 32.6% in 2016. Growth in wind and biofuels and waste in power and heat generation is notable. Wind energy in TPES doubled and biofuels and waste increased by 50% over the decade.

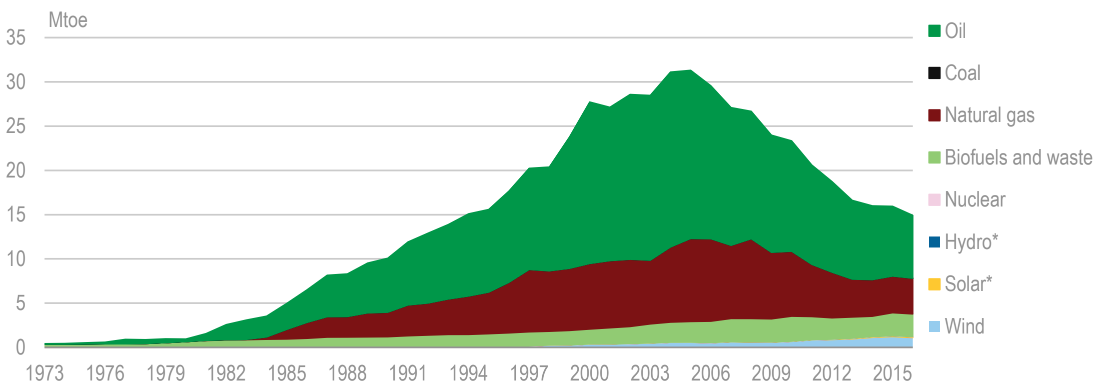
Energy production and self-sufficiency

In 2016, Denmark's total energy production was 14.9 Mtoe. Oil accounted for almost half of it (47.6%) and the rest was made up of natural gas (27.1%), biofuels and waste (17.1%), wind (7.4%), and solar (0.7%).

Denmark's total production peaked at 31.3 Mtoe in 2005, after which it decreased by 52% to 2016, owing to a decline in oil and gas production. Oil production fell by 63% from 2005 to 2016 and gas production dropped by 57%. During the same period, the country's renewable energy production increased by 29%. As a result, the share of renewables in production increased from 9.3% in 2005 to 25.3% in 2016.

Total energy production was slightly smaller than TPES, but levels of import dependencies largely differ by energy source (see Figure 1.5). For example, Denmark has 100% coal import dependence as it has no domestic coal production, but coal accounts for 11.9% of TPES in 2016. As for oil, export and import volumes were nearly equal in 2016. In contrast, Denmark has historically been a natural gas exporter with almost half its natural gas production exported in 2016.

Figure 1.5 Energy production by source, 1973-2016

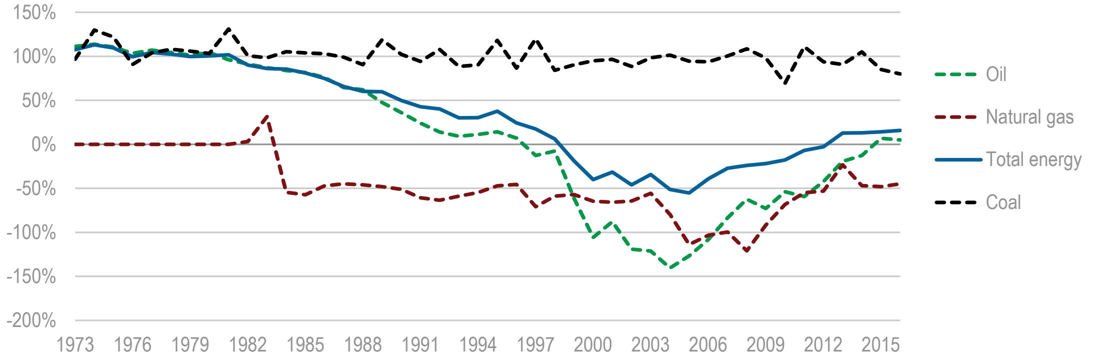


*Negligible.

Note: Data for 2016 are provisional.

Source: IEA (2017), *World Energy Balances* 2017, www.iea.org/statistics/.

Figure 1.6 Import dependence by fuel (net imports as share of TPES), 1990-2016



Note: Data for 2016 are provisional.

Source: IEA (2017), *World Energy Balances* 2017, www.iea.org/statistics/.

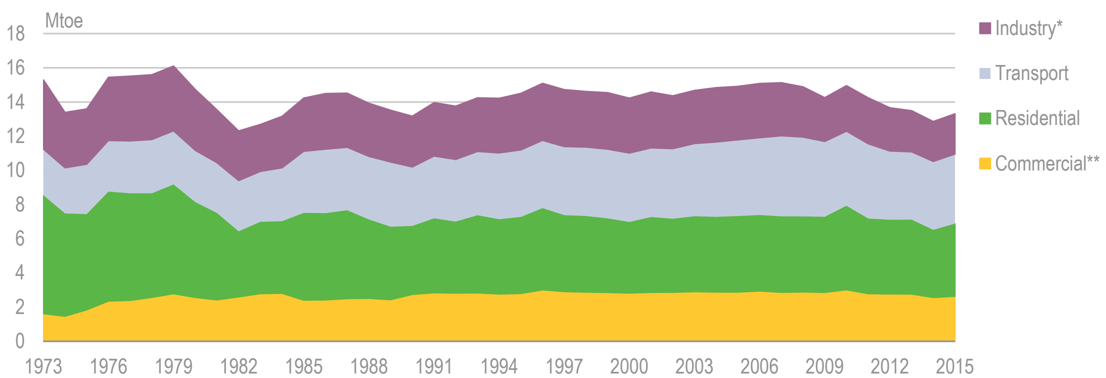
Demand

In 2015, Denmark's TFC was 13.3 Mtoe, a decrease by 11% from 2005. After being relatively stable at around 14-15 Mtoe over two decades, Denmark's TFC decreased continuously in the period 2010-14. In 2015, it increased slightly, mainly because of increased energy consumption in the residential sector.

The residential sector is the largest energy-consuming sector, accounting for 32.0% of the total in 2015, followed by the transport sector at 30.5% (see Figure 1.7). These two sectors are also historically the largest energy-consumers. In 2015, the share of the commercial sector (including agriculture, forestry and fishing) in TFC was 19.8% and that of industry (including consumption for non-energy purposes) 17.7%. From 2005 to 2015, TFC decreased in all sectors, in relative terms most in industry (25%).

Oil is the largest energy source in Denmark's final energy consumption, at 39.1 % of TFC in 2015 (see Figure 1.8). Most oil is consumed in the transport sector, but it also has a large share in industry and the commercial sector. Electricity is the second-largest source, at 19.8% of TFC. Electricity accounts for a considerable share in all sectors except in transport, and is especially important in the commercial sector. Electricity consumption (and the overall energy demand) is expected to grow with the construction of large data centres in Denmark.

Figure 1.7 TFC by sector, 1973-2015

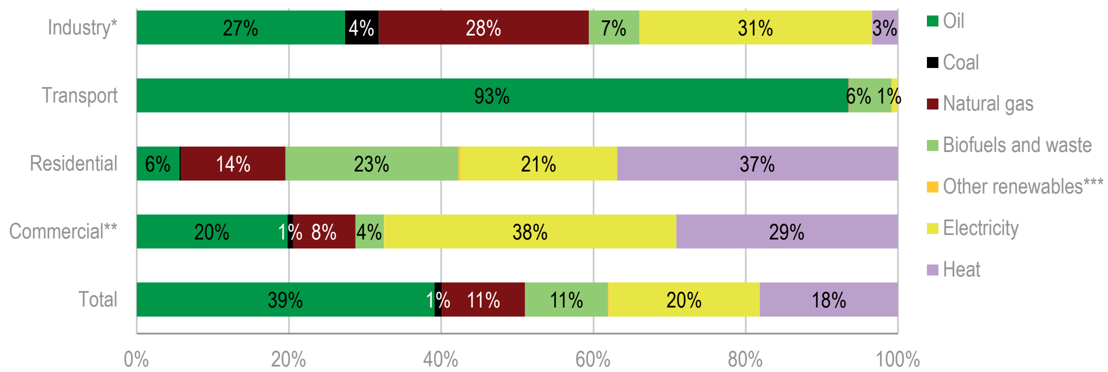


**Industry* includes non-energy use.

***Commercial* includes commercial and public services, agriculture, fishing and forestry.

Source: IEA (2017), *World Energy Balances* 2017, www.iea.org/statistics/.

Figure 1.8 Fuel share of TFC by sector, 2015



**Industry* includes non-energy use.

***Commercial* includes commercial and public services, agriculture, fishing and forestry.

****Other renewables* includes solar and geothermal.

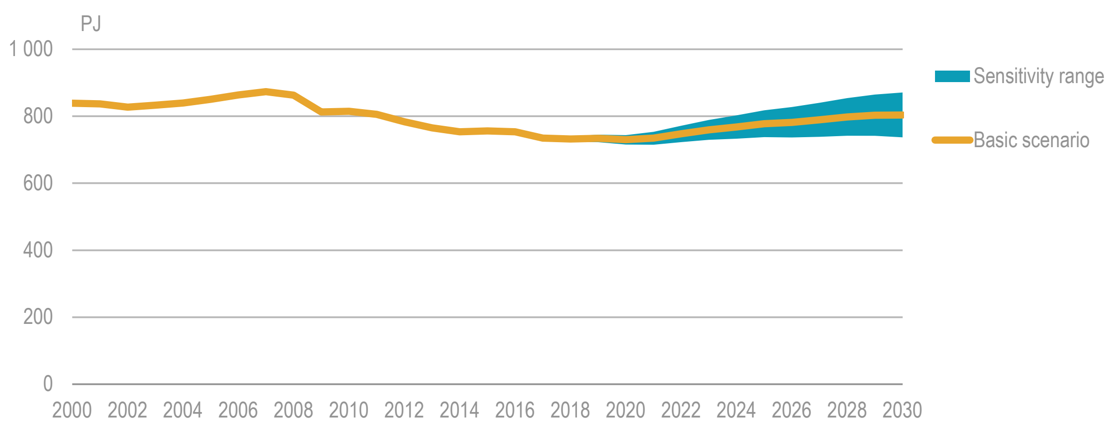
Source: IEA (2017), *World Energy Balances* 2017, www.iea.org/statistics/.

"Frozen Policies" projections

The Danish Energy Agency regularly makes baseline projections to assess how energy consumption, energy production and greenhouse gas (GHG) emissions will develop in the future. The *Energy and Climate Outlook* published in March 2017 provides a "Frozen Policy" Scenario up to 2030. It only takes into account the adopted policies and measures without including any new initiatives under consideration; therefore it should not be viewed as a prognosis, but rather as a foundation for political decision making. In addition, the *Outlook* provides a sensitivity range to reflect the uncertainties in the basic scenario, and includes an "alternative scenario", illustrating the impact of DONG Energy's announcement to stop the use of coal from 2023. The scenarios and sensitivity analyses show the following trends:

- continued decline in energy consumption up to 2020 followed by an increase in demand from 2020 to 2030 (Figure 1.9)
- stagnation in the growth of renewable energy use after 2020
- increased consumption of fossil fuels
- increase in GHG emissions between 2020 and 2030.

Figure 1.9 Gross energy consumption in the Frozen Policy Scenario (PJ)



Source: DEA (2017), *Denmark's Energy and Climate Outlook 2017*.

This *Outlook* demonstrates the need for strong new policies after 2020 when most of the existing measures expire, in order to meet Denmark's energy and climate objectives.

Institutions

The Danish **Ministry of Energy, Utilities and Climate**[4] is responsible for national and international policies to mitigate climate change, as well as for energy, national geological surveys, and for meteorology. The ministry consists of the Department itself, the Geological Survey of Denmark and Greenland, the Agency for Data Supply and Efficiency, the Danish Meteorological Institute, the Danish Geodata Agency, the Danish Energy Agency and the associated independent bodies: the Danish Energy Regulatory Authority, Energinet.dk, and the Danish Council on Climate Change.

The **Danish Energy Agency (DEA),**[5] established in 1976, is an agency under the Ministry of Energy, Utilities and Climate. It is responsible for the implementation of policies and measures related to the production, transmission and utilisation of energy, and their impact on climate change. It acts as a one-stop shop regarding offshore energy projects, allocates the necessary permits and co-ordinates consultation processes with other authorities.

Energinet.dk,[6] the transmission system operator, is an independent public enterprise owned by the Danish State represented by the Minister of Energy, Utilities and Climate. It owns the natural gas transmission system and the 400 kilovolt (kV) electricity transmission system. It is the co-owner of the electricity interconnections to Norway, Sweden and Germany. It is responsible for maintaining security of supply and ensuring the smooth operation of the electricity and gas markets.

The **Danish Energy Regulatory Authority (DERA)**[7] oversees the electricity, natural gas and district heating markets. DERA is a fully independent regulatory body governed by a board of seven people (plus two alternates), all of whom are appointed by the Minister of Energy, Utilities and Climate. Its decisions can be appealed to the Danish Energy Board of Appeal. The responsibilities of DERA include but are not limited to: regulation of the transmission system operator (TSO) and the wholesale market; regulation of the distribution system operators (DSOs) and the retail market, including cost benchmarks; regulation of the district heating sector; supervision of the energy efficiency obligation; supervision of network code implementation; co-operation with the Nordic regulators on regulation harmonisation; and commenting on relevant draft EU legislation.

The **Danish Council on Climate Change**[8] was established as a result of the 2014 Climate Change Act. The council is an independent body of experts that advises on the transition to a low-carbon society.

Regional and municipal authorities have an important role in the implementation of national energy and climate change policies through regional and municipal plans for

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[4] http://old.efkm.dk/en.
[5] https://ens.dk/en.
[6] http://energinet.dk/EN/Sider/default.aspx.
[7] http://energitilsynet.dk/tool-menu/english/.
[8] www.klimaradet.dk/en/frontpage.

urban and industrial development. Municipalities are responsible for planning onshore energy projects (wind power, biomass, biogas and solar PV) and district heating. Many municipalities also own local district heating companies.

All political initiatives with significant economic impact are discussed and eventually decided by the Danish government's **Economic Committee**, where relevant ministries participate. When developing new climate-related policies and initiatives, the Ministry of Energy, Utilities and Climate works closely with other relevant ministries, typically in working groups (for example with the **Ministry of Environment and Food,** the **Ministry of Transport, Building and Housing, the Ministry of Finance and the Ministry of Taxation**).

The **Energy Commission** is an independent advisory body with participation from academia and business. The government set it up in March 2016 as part of preparing a new Energy Agreement for the period beyond 2020. In April 2017, fulfilling its mandate, the Commission published a report with recommendations for future energy policies.

Key policies

Overview

The key characteristics of the Danish energy policy include:

- **Broad and sustained political support for a low-carbon transition** of the Danish energy sector. Since the oil crisis in 1973, energy efficiency and renewable energy have been among Denmark's policy priorities.

- **A holistic approach** to energy planning. Denmark pays great attention to interactions and synergies between different sectors and various policies and regulatory instruments.

- **Stakeholder engagement and informed decision making.** Denmark has a long tradition of building consensus between political parties, which includes dialogue with different stakeholders. The policy-making process relies on socio-economic analysis and projections. Another Danish characteristic is the important role played by local and regional authorities, by local co-operatives and associations, in many aspects of the low-carbon transition, e.g. in urban planning.

- **Strong international co-operation.** Danish electricity and gas markets are being increasingly integrated with the broader Nordic and European markets. Denmark actively contributes to the development of the EU energy policy and assists several developing countries in sustainable energy transition through bilateral engagements.

The Energy Agreement of 2012

The Danish energy policy is laid out in the so-called Energy Agreements, which are reached by political consensus and revised around every five years. The latest one was approved by the parliament in 2012 and amended in the consequent years. It covers the period until 2020 and includes many initiatives to support and reinforce the Danish position in the climate and energy area, and to support the EU targets. The total financing requirements were estimated at DKK 3.5 billion by 2020, to be financed mainly by the Public Service Obligation (PSO) levy.[9] The Energy Agreement focuses on many areas; the key ones are summarised below.

Energy efficiency: the Agreement contains initiatives to encourage more efficient technologies that target industry and buildings in particular, including the development of a comprehensive strategy for energy retrofitting of all the country's buildings.

Wind power and new energy technologies:

- Construction of 1 000 megawatts (MW) of offshore wind turbines and 500 MW in "nearshore" wind (close to the coast). In 2014 it was reduced to 400 MW.
- Increase in net onshore wind capacity by 500 MW despite decommissioning of old turbines.

These objectives had been almost achieved by 2015 when offshore wind capacity reached over 1 270 MW and onshore wind over 3 800 MW.

Replacing fossil fuels with bioenergy:

- Conversion from coal to biomass at combined heat and power (CHP) plants and heat-only boilers.
- Increased use of biogas in CHP plants, natural gas grid, industrial processes and transport.

As a result of the adopted measures, the use of biomass has grown significantly since 2012. Biofuels and waste accounted for about one-fifth of TPES and 17% of electricity generation in 2015, and biogas represented 4% of total biofuels and waste. Biogas projects have been developed throughout the country, and biogas has been upgraded to be used in the gas networks.

Renewable energy in industry, buildings and transport:

- Subsidies to promote the efficient use of renewable energy and CHP in enterprises.
- A halt to the installation of oil-fired and gas-fired boilers in new buildings from 2013 and to the installation of oil-fired boilers in existing buildings from 2016 in areas with district heating or natural gas.
- Support to the conversion of oil-fired and gas-fired boilers in existing buildings to renewable alternatives (solar, heat pumps, etc.).
- Establishing more recharging stations for electric cars and promoting the infrastructure for hydrogen cars.
- A strategy to promote energy-efficient vehicles.

Most of these measures have been implemented (see Chapters 7 and 8 on energy efficiency and renewable energy), although the efforts to promote electric and hydrogen vehicles have been mainly limited to tax incentives (Chapter 6 on energy and climate change).

[9] The PSO is being phased out now (see section on taxation).

Smart grids:
The Energy Agreement stipulated the development of a strategy for smart grids and other measures related to grid issues.

When the 2012 Energy Agreement was adopted, its implementation was expected to lead to the following results, among others:

- Over 35% of final energy consumption to come from renewable energy.
- Around 50% of electricity consumption to be supplied by wind power.
- A 7.6% reduction in gross energy consumption below the level in 2010.
- A 34% reduction in greenhouse gas emissions below the level in 1990.

Most of the expected outcomes of the Energy Agreement have already been achieved or are expected to be achieved by 2020. According to DEA statistics, renewable energy covered 28.6% of total gross energy consumption in 2015 (or 32.4% of TPES in 2016 according to the IEA methodology). According to *Denmark's Energy and Climate Outlook 2017,* the share of renewables in final energy consumption will reach 40% in 2020 (DEA, 2017). Wind power already accounted for 42% of all electricity generated in 2016, and is expected to cover 48% in 2020. TPES declined by 17% between 2010 and 2015, and TFC by 7.1% and is expected to decline in total by 10.3% from 2010 to 2020. GHG emissions dropped by 27% over the period 1990-2015. They are expected to drop by 37% from 1990 to 2020.

The New Energy Agreement for the years 2020-30

In 2017, the government is preparing a new Energy Agreement for the years 2020-30 in consultation with numerous stakeholders. As part of this process, in March 2016 the government set up a national Energy Commission, an independent advisory body with the participation of academia and businesses. In April 2017, the Commission published a report with recommendations which are summarised in Box 1.1. The government uses this report as a basis for preparing a proposal for a new Energy Agreement, which is expected to be submitted to the Parliament in late 2017.

The Commission highlights the need for an ambitious energy and climate policy after 2020, which would take the 2050 perspective into account. To achieve Denmark's goal to become a low-emission society by 2050, the Energy Commission recommends a paradigm shift in energy policy by putting the key focus on:

- International collaboration: seeing energy supply in the context of developments in neighbouring countries and in the European Union.
- Increased electrification of the heating, industry and transport sectors in order to integrate a larger share of renewable energy into the energy system.
- Efficient market-based solutions: further development of the electricity and gas markets, and the use of market-based instruments to stimulate renewable energy and energy efficiency efforts. One key recommendation is to gradually phase out the subsidies for renewable energy deployment (see Box 1.1).

Box 1.1 Energy Commission's recommendations

Efficient international energy markets must ensure security of supply

- Security of supply must be safeguarded through enhanced co-operation across national borders and must be based on the energy-only model.
- Electricity markets must be developed in order to ensure competition on a flexibility market.
- Regulation of distribution and transmission companies must be revised to improve efficiency and reduce tariffs.
- The EU Emissions Trading Scheme must be strengthened.

Renewable energy must be deployed on market terms

- Renewable energy subsidies must be phased out as the technologies become competitive on market terms.
- In the transitional period, subsidies must be based on technology-neutral tenders.

An integrated and flexible energy system must ensure an efficient and stable energy supply

- Integration of the Danish energy system must be promoted through increased electrification.
- Flexible consumption should be promoted.
- Initiatives to prepare the integration of electric vehicles into the energy system.
- Digitalisation must be exploited to support an efficient energy system.
- The district heating system must exploit renewable energy and surplus heat.
- The gas system continues to play a role in the green transition.

Energy efficiency improvements must continue to be an important part of the solution

- Energy efficiency improvements should be given priority when these are more cost-effective than renewable energy deployment.
- Denmark must work to achieve common ambitious EU frameworks, obligations and standards.
- Energy-saving initiatives must be reorganised to ensure more market-based and technology-neutral efforts.
- Energy efficiency improvements must be implemented in conjunction with other changes.

Denmark's position as an energy technology front-runner must be strengthened

- A national strategy must set the course and ensure co-ordinated efforts.
- Energy research funding must be increased and the continuity of efforts must be safeguarded.
- Priority must be given to more unique demonstration projects and test platforms.

Efforts outside the ETS must be focused on the transition of the energy system

- Transition of the energy system must be a priority focus.
- Cost-effective initiatives outside the ETS sector must be launched at an early stage.
- The initiatives must be reassessed on an ongoing basis.

Source: Energy Commission (2017), *Energikommissionens anbefalinger til fremtidens energipolitik* (Energy Commission's Recommendations for the Future Energy Policy).

Strategies

The government has adopted a number of strategies related directly or indirectly to the energy sector. Contrary to the Energy Agreements, such strategies are not the result of a broad political consensus but rather represent the government's vision of how the key directions of Danish policy can be implemented. Such strategic documents include, in particular, the strategies for smart grids (Chapter 5 on electricity), for energy retrofitting of buildings and for promoting energy-efficient vehicles (Chapter 7 on energy efficiency). A key overarching energy sector strategy is "Utilities for the Future" discussed below.

"Utilities for the Future"

The strategy "Utilities for the Future", adopted in 2016, sets the framework for the future regulation of the utilities sector based on five principles:

- **Competitive tendering of non-monopoly activities**. Any tasks that are not considered natural monopolies will be exposed to competition, while ensuring clear separation between monopolistic and competitive areas.
- **Incentive-based economic regulation of natural monopolies**. Consistent, incentive-based economic regulation is expected to create the best possible regulatory framework for more efficient utility companies and low prices.
- **Sound corporate governance** to encourage effective and transparent management of the utility companies.
- **Robust regulation of security of supply**. The strategy highlights the need to introduce additional measures that ensure the security of energy supply, for example: *i)* specific objectives and requirements for security of supply and appropriate sanctions in the case of failure (for example revenue caps); and *ii)* prohibition to transfer the control of critical infrastructure to owners who do not have the technical knowledge and financial capability to maintain security of supply.
- **Effective and transparent financial supervision**. This is expected to be achieved, in particular, through increased use of framework regulation and strengthened monitoring.

This strategy includes a number of specific initiatives which are expected to yield efficiency improvements worth DKK 5.9 billion (EUR 0.79 billion [Euro]) annually by 2025, while maintaining a high level of security of supply.

The Digital Strategy 2016-20

Denmark has a Digital Strategy 2016-20 "A Stronger and More Secure Digital Denmark", adopted by the central, regional and local governments. It outlines the country's efforts in public-sector digitalisation and their interaction with businesses and industry. One of the Strategy's focus areas is efficient utilities. The document highlights the need for open and high-quality data, including on production and consumption of electricity, gas and heating, as well as on underground infrastructure such as electric cables, district heating, sewage or natural gas pipes. The Strategy outlines a number of initiatives to facilitate access to reliable utilities data.

Meanwhile, since 2013, Energinet.dk, the TSO, operates a centralised national DataHub, which collects information on electricity consumption, standardises business processes, and gives web-based access to its own data for all 3.3 million Danish consumers. A number of digital pilot projects are also ongoing in smart cities, local grids and at commercial sites.

Low-carbon transition

The government has ambitious national targets: meeting 50% of Denmark's energy demand by renewable energy in 2030 and becoming independent of fossil fuels by 2050.

In addition, Denmark has a number of commitments and obligations under the United Nations Framework Convention on Climate Change (UNFCCC) and the EU regulations to make the energy sector more sustainable:

- Reduce GHG emissions from the sectors not covered by the EU Emissions Trading Scheme (ETS) by 20% by 2020 below their level in 2005. It is projected that Denmark will comply with the overall target; the annual intermediate target for year 2020 is expected to be underachieved, but this will be offset by overachievements in the previous years.

- Increase the share of renewable energy in gross final energy consumption to 30% by 2020 from 16% in 2005. The target is expected to be overachieved: as the share of renewable energy reaches 40% in 2020 with existing measures.

- Reach a share of renewable energy in land-based transport of at least 10% by 2020. The baseline projections suggest that, with existing measures, Denmark will reach only 9% by 2020. The government has also set a requirement of 0.9% advanced biofuels for land transport from 2020, which is more ambitious than the 0.5% obligation set by the EU regulation.

Apart from the new Energy Agreement 2020-30 discussed above, Denmark is also preparing a new Climate Plan and a strategy for reducing emissions in the non-ETS sector (see Chapter 6 on energy and climate change). As part of these preparations, there is intensive public debate on the optimal pathways towards a low-carbon future. The key discussion topics include: the role of biomass; electrification of heating, transport and other sectors and closer inter-sector integration; and the role of taxation in directing the energy sector development.

In 2015, the Danish Energy Agency simulated several scenarios and sensitivity analyses, which demonstrate that it is technically possible to design different energy systems independent of fossil fuels, largely bioenergy-based or largely wind-based. All the options have advantages and disadvantages and the choice of the future energy system would have different implications on the cost of supply, on GHG emissions, on energy security and on fuel supply security (related to the need to import biomass).

The recent IEA study, *Nordic Energy Technology Perspectives* (Norden and IEA, 2016), concludes that a transition to a carbon-neutral system in the Nordic region will likely cost less if it is based on a more distributed electricity supply with a high share of wind, compared to maintaining a system reliant on centralised nuclear and thermal generation. However, Denmark's current fiscal and regulatory framework stimulates the use of biomass-fired thermal generation (see below section on taxation), while many stakeholders raise concerns related to sustainability of biomass supply and a threat to lock the energy system in biomass assets.

Cross-sector planning and closer integration between energy supply and demand sectors is a very important element of the public debate about the future energy policies. There is a growing understanding in Denmark that, through closer linkages between electricity, heat, transport, buildings, industry and other sectors, the whole system can be operated more efficiently and at lower costs. In this context, electrification is seen as a key means to achieve an integrated, low-carbon energy system. In order to support this development, digitalisation is increasingly being used in the energy sector to expand automation and utilise data intelligently for new business models.

Energy security

Security of supply is a priority of the Danish energy policy. The strategy "Utilities for the Future", which covers all utilities including electricity, gas and district heating, places the key focus on energy security. The government plans to launch a number of initiatives and analyses to ensure a continued high level of security of supply. One of the planned measures is more active monitoring and supervision of the distribution companies, including their financial capacity.

In the **oil sector**, the energy security measures include the efforts to maintain domestic crude oil production, diversification of crude oil supplies to the two Danish refineries in Fredericia and Kalundborg, diversification of imports of refined products, and emergency stocks. The Danish Energy Agency has an emergency unit and a data unit, which deal with emergency preparedness issues. The Oil Emergency Plan was updated in 2014.

As a net oil exporter, Denmark has no obligation to hold oil emergency stocks in relation to the IEA. However, in relation to the European Union, Denmark has an obligation corresponding to 61 days of average daily inland consumption. Denmark holds emergency stocks 20% higher than the requirement.

In the **natural gas sector**, the responsibility for supply security lies with the gas system operator, Energinet.dk. Denmark's approach to the security of gas supply is based on EU regulations and includes three crisis levels: Early Warning, Alert, and Emergency. Energinet.dk can use several tools in the event of a supply disruption in order to maintain the security of supply for consumers. The measures are tailored to enable the operator to cover the demand of protected customers (households, district heating, and small and medium-sized enterprises) for a period of up to 60 days during a normal winter and for three days in a particularly cold winter.

While Danish gas production has been sufficient for meeting internal demand, the security of gas supply may become temporarily under pressure during the reconstruction of the Tyra field in 2019-22, especially in cold winters. The expansion of the transmission system in Germany, which increased the import capacity from Germany to Denmark to 10.8 million cubic metres per day (mcm/day), provides additional flexibility to the system. Chapters 2 and 3 provide more details on oil and gas security.

In the **electricity sector**, Energinet.dk and distribution network companies ensure supply security. Both transmission and distribution networks operate with a low level of outages. With the growing share of variable renewable energy generation, the flexibility and overall resource adequacy in the Danish system is achieved largely by the significant level of interconnections with Norway, Sweden and Germany. Additional interconnectors are planned or under construction, including to the Netherlands, the United Kingdom, and additional capacity to Germany. This level of interconnector capacity offers Denmark significant flexibility. Chapter 5 on electricity provides more details on electricity supply security.

Taxation

Taxation is a matter of fiscal policy, which is the responsibility of the Ministry of Taxation.[10] Energy taxes are an important source of budget revenues. At the same time they are a powerful instrument that influences the behaviour of consumers and suppliers in the energy sector. Energy taxes were introduced in the 1970s as a pricing mechanism to reduce demand for fossil fuels and promote energy efficiency.

As of 2017, the following taxes are used in different applications: energy tax, CO_2 tax, NO_x tax, SO_2 tax and a public service obligation (PSO) levy, as demonstrated in Table 1.1. The CO_2 tax is discussed in more detail in Chapter 6 on energy and climate change.

The current electricity tax has three different levels: *i)* very high tax for households, public institutions and small businesses, *ii)* a lower level for electricity used for heating, and *iii)* the lowest level for industry. Electricity prices for households in Denmark are among the highest in the IEA countries (see Chapter 5 on electricity).

Table 1.1 Effective tax rates for different energy applications, 2016

	Unit	Energy tax rate	CO_2 tax rate	NO_x tax rate(12)	SO_2 tax rate	PSO (11)	Total (12)
Road transport							
Fossil gasoline	Kr./GJ	129.1	12.5	1.3 (0.2)	0	0	142.9
Biogasoline[1]	Kr./GJ	129.1	0	1.3 (0.2)	0	0	130.4
Fossil diesel	Kr./GJ	75.2	12.7	1.3 (0.3)	0	0	89.2
Biodiesel[1]	Kr./GJ	75.2	0.0	1.3 (0.3)	0	0	76.5
Electricity[2]	Øre/kWh	0.4	0.0[3]	0	0	25.5[4]	25.9
Electricity net	Kr./GJ	1.1	0.0	0	0	70.8	71.9
Electricity gross[5]	Kr./GJ	0,5	0,0	0	0	29,3	130,8
Space heating							
Heating oil	Kr./GJ	54.9	12.7	1.3 (0,3)	0	0	68.9
Natural gas	Kr./GJ	54.9	9.7	1,0 (0,2)	0	0,4	65.6

[10] www.skm.dk/english

Coal	Kr./GJ	54.9	16.2	2.6 (0,5)	2.3[6]	0	
Straw, wood, etc.	Kr./GJ	0	0	2.4 (0.5)	1.8[6]	0	
Electricity for heating	Øre/kWh	38.3	0[3]	0	0	25.5[4]	63,8
Conversion, net	Kr./GJ	106.4	0	0	0	70.8	177.2
Conversion, gross[4]	Kr./GJ	43.9	0	0	0	29.3	73.2
Electricity, not for heating[2]	Øre/kWh	88.5	03	0	0	25.5	114.0
Conversion, net	Kr./GJ	245.8	0	0	0	70.8	316.7
Conversion, gross[5]	Kr./GJ	101.5	0	0	0	29.3	130.8
Industrial processes							
Fuel oil	Kr./GJ	4.5[8]	12.7[9]	1.3 (0.3)	0	0	18.5
Natural gas	Kr./GJ	4.5[8]	9.7[9]	1.0 (0.2)	0	0.4	15.6
Coal	Kr./GJ	45[8]	16.1[9]	2.6 (0.5)	2.2[6]	0	
Straw, wood, etc.	Kr./GJ	0	0	2.4 (0.5)	1.9[6]	0	
Electricity[2]	Øre/kWh	0.4	0[3]	0	0	25.5(4.1)	25.9
Conversion, net	Kr./GJ	1.1	0	0	0	70.8	71.9
Conversion, gross[5]	Kr./GJ	0.5	0	0	0	29.3	29.7
Fuel for power generation							
Within the ETS sector	Kr./GJ	0	0	0-2.6 (0.5)	0-5	0	1[10]
Outside the ETS sector	Kr./GJ	0	9.7-16.1	0-2.6 (0.5)	0-5	0	10[10]

GJ: gigajoule; Kr: krone; NO_x: nitrogen oxide; SO_2: sulphur dioxide.

Notes:

1. For mixing with fossil fuels.

2. El is indirectly charged with NO_x and SO_2 taxes.

3. No CO_2 tax on consumption of electricity but the electricity is generated within the ETS sector. The price of the quotas is thereby reflected in the price of electricity.

4. The tariff is for Q4 2015. The tariff was set quarterly.

5. Given an energy conversion efficiency of 41.3% (100 GJ of fuel input in power generation is converted to 41.3 GJ electricity).

6. Varies.

7. For consumption beyond 4 000 kWh in homes registered as electrically heated and electricity used in businesses for space and water heating and cooling.

8. The tax rate is zero for mineralogical and metallurgical processes.

9. Does not apply to fuels used for industrial processes or power production within ETS sector. For this uses the rate is zero.

10. On average.

11. PSO (public service obligation) is included in the table in line with the other energy taxes. However, the PSO will be phased out gradually over the period 2017-22.

12. The figures in brackets indicate the tax rates that apply from 1st July 2016. The column "Total" is calculated on the basis of tax rates before that date.

Source: Afgifts- og tilskudsanalysen på energiområdet Delanalyse 1 Udviklingen i afgifts- og tilskudsgrundlag www.skm.dk/media/1351877/afgifts-og-tilskudsanalysen-delanalyse-1_13052016.pdf.

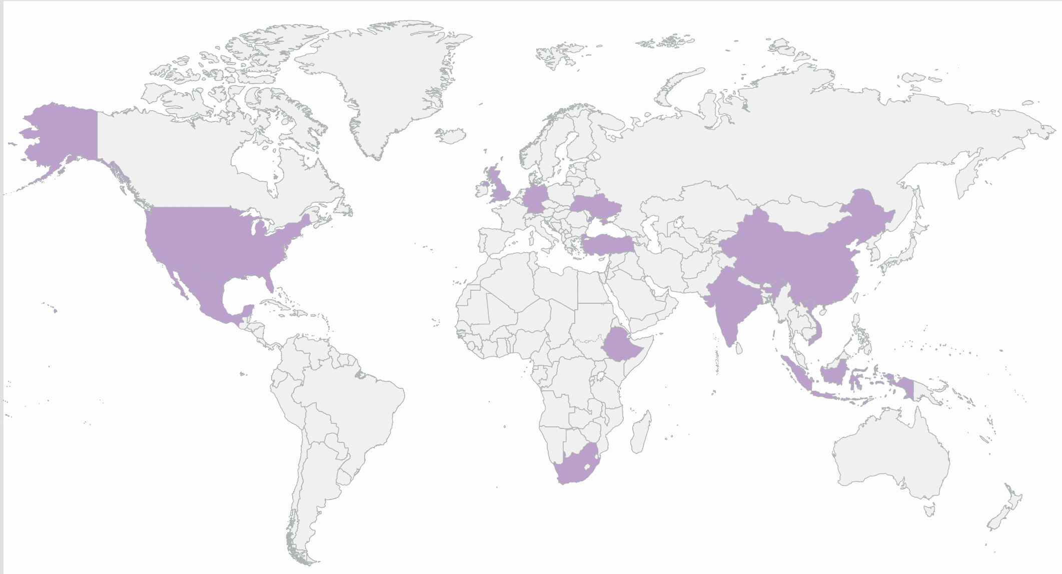
Box 1.2 Denmark's international collaboration

Denmark is a small and energy-efficient economy, with a relatively low level of GHG emissions. Therefore, the country's efforts to reduce its GHG emissions have only an insignificant direct impact on global emissions. However, Denmark combats climate change not only on its territory but also by providing examples to other countries. Denmark's case demonstrates that it is possible to achieve both economic growth and emissions reductions at the same time.

Denmark has entered into bilateral co-operation with 12 countries to help them improve their energy systems, expand the deployment of renewable energy, enhance energy efficiency and reduce GHG emissions. Through its bilateral engagements, Denmark has put in place a platform to promote renewable and sustainable energy in countries, which represents one-third of global CO_2 emissions and two billion energy consumers.

Climate finance that Denmark provides to developing countries reached EUR 222 million in 2014 (EU, 2016). According to the National Energy Efficiency Action Plan 2017, Denmark expects to spend DKK 115 million over a three-year period to help selected emerging economies in a low-carbon transition and to assist Viet Nam, the People's Republic of China, and Mexico with energy efficiency improvements. In addition, the Danish Energy Agency has several smaller programmes in Indonesia and Ukraine, which also support energy efficiency.

Figure 1.10 Denmark's bilateral co-operation on energy



Note: The map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory.

Sources: Information provided by the Ministry of Energy, Utilities and Climate; Government of Denmark (2017), *National Energy Efficiency Action Plan*, submitted to the European Union in May 2017.

The public service obligation (PSO) levy, which is added to electricity bills, is used to provide financial support for renewable energy projects. In 2016, a broad political coalition in the Danish Parliament reached an agreement to phase out the PSO and instead finance support for renewables through the national budget. The PSO tariff will be phased out gradually over the period 2017-21. As a result, the consumption of electricity is projected to increase by around 3.4 terawatt-hours (TWh) in 2020 owing to the reduction in the electricity bills.

Taxation is also used to influence consumer choices in the transport sector. For example, taxes on gasoline are higher than those on diesel (see Figure 2.8). The level of the registration tax for new vehicles depends on their fuel efficiency. The classification of gasoline and diesel cars was last updated in 2007. Electric vehicles in Denmark benefit from a lower car registration tax, but this will end in two years, or when 5 000 of such cars are registered, whichever comes first. Thereafter, the registration tax on electric vehicles will gradually increase yearly until, after five years, it is at the same level as low-emission cars in the same value category.

Assessment

The Danish tradition of broad energy agreements has provided predictability and continuity in energy policy. A new Energy Agreement for the period 2020-30 based on broad political support can offer a good foundation for a progressive energy policy while at the same time continuing to provide stability to the energy sector and its stakeholders.

To meet its ambitious energy and climate targets, Denmark makes commendable efforts to develop policies and measures based on sound socio-economic analysis and forecasts. The government is also to be praised for the attempts to address energy issues in a holistic manner, with great attention paid to interactions and synergies between: *i)* different sectors (electricity generation, heating, transport, buildings, etc.) and *ii)* various policies and regulatory instruments, including taxation schemes.

The new Energy Agreement is being prepared in open and transparent consultation with different stakeholders, which is a very constructive approach. The well-argued recommendations published in April 2017 by the independent Energy Commission provide a sound basis for developing the new agreement. The IEA supports most of the Commission's conclusions and recommendations, including the importance of a regional approach, market-based solutions, energy system integration across sectors, increased flexibility, improved energy efficiency and the need to launch cost-effective initiatives in the non-ETS sector at an early stage.

Low-carbon transition

Denmark's ambitious energy and climate policy has delivered a steady increase in renewable energy, a decrease in consumption of energy, particularly fossil fuels, and a reduction in GHG emissions.

Several of the different energy and climate targets set by the Danish government and Parliament, as well as by the European Union, are interlinked. Promoting measures to reach one target can help to reach another one (*e.g.* promoting renewables that replace fossil fuels also reduces emissions). Therefore, it is extremely important to look at energy and climate issues as a whole when evaluating and prioritising policy measures. In particular, policy makers should prioritise measures that are the most cost-efficient and suitable for meeting multiple targets and socio-economic objectives. In contrast, choosing separate measures for each of the different targets could lead to a sub-optimal outcome. The preparation of the Energy Agreement should thus be closely co-ordinated with the preparation of the Climate Plan and with the strategy for reducing emissions for the non-ETS sector in 2030 and beyond. The assignment of the responsibilities for energy and climate to the same ministry in 2007 facilitates close collaboration and horizontal policy development.

Denmark has energy and climate targets and goals for different time spans: short-term (2020), medium-term (2030) and long-term (2050). When planning measures for the short and medium term, it is essential to take into account also the long-term perspective to avoid a costly lock-in of assets that are not aligned with the longer energy and climate objectives. For example, replacing coal-fired generation by biomass seems a viable solution in the short term; however, an integrated, electrified system based on wind represents many more advantages in the longer term. Therefore, today's framework should facilitate solutions that would be sustainable in the long run.

Electrification and sector coupling are key elements of a low-carbon transition. Further expansion of renewable electricity, particularly wind, could displace fossil fuels in all sectors, including industry, buildings and transport. In addition, electrification can reduce total energy consumption because technologies powered by electricity, such as heat pumps and electric cars, are often significantly more efficient than fuel-based ones. Increased electrification in the Danish heating and transport sectors is expected in the near future. Furthermore, Denmark expects to attract new customer groups, such as data centres, that would also increase overall electricity demand. This development causes new challenges but also creates opportunities for the energy sector and the integration of the heat system, the electricity system and the transport sector.

The Danish government and other stakeholders rightly focus their attention on digitalisation of energy equipment, processes, data and communications. These can effectively contribute to the low-carbon transition by offering opportunities for enhanced efficiencies and performance.

Taxation

Energy taxation, besides being a fiscal instrument to generate revenue, can be a measure that encourages energy efficiency and steers towards low-emission solutions. Energy taxation has developed and has been modified over a long period. The current tax policy, however, no longer steers customers' and energy suppliers' choices and behaviour in a socio-economically optimal direction. In fact, energy taxation, renewable energy subsidy schemes and other requirements and restrictions (for example in district heating) steer in opposite directions in some cases. Many of the renewable energy subsidy schemes will expire in the near future and new support schemes are being discussed. Energy taxation should also be revised and adjusted accordingly, so that it efficiently supports the government's energy and climate policies. The following four areas require particular attention:

- Heavily taxed electricity creates distortions in the economy. Denmark has a very high electricity tax, which made sense in the past when most electricity was produced from fossil fuels. Now that Danish electricity is becoming increasingly cleaner, electricity from wind and solar is taxed at the same level as electricity from fossil fuels. The country needs to rethink its approach to energy taxation while maintaining the budget revenue. While the high tax on electricity for households encourages energy savings, it also has negative impacts. First, it can be a barrier to the increased use of heat pumps, efficient electric boilers and electric vehicles, thus limiting the potentially cost-efficient sector coupling. Second, it creates significant incentives for self-generation (by individual rooftop PV systems), including in cases where this is highly inefficient from a socio-economic perspective.

- The large difference between taxation of energy for different purposes, e.g. the three electricity tax levels, creates unequal incentives for energy savings, and the high taxation of electricity for heating purposes discourages the efficient utilisation of waste heat. Reduction of the gap between the energy tax rates for industrial processes, heating purposes and other uses would facilitate more equal energy saving incentives. Lower taxation of electricity for heating purposes would facilitate the use of waste heat.

- The double taxation of electricity stored in batteries (when purchased and when resold) can be a barrier to a wider use of batteries by district heating companies and end-users. This reduces opportunities for demand-side flexibility in the power system.

- The registration tax on cars also deserves special attention. The government should consider updating the classification of the registration tax for petrol and diesel cars, in line with the availability of cleaner vehicles. It could also consider extending the reduced registration tax for electric vehicles, along with other measures (see Chapter 6 on energy and climate change), keeping in mind Denmark’s ambition to increase electrification and sector coupling.

Energy security

Security of supply is a priority of the Danish energy policy. Thanks to competent planning, timely investments and efficient maintenance, the supply of electricity, heating, gas and oil products has been quite stable and without major interruptions in recent years. The electricity sector, in particular, has achieved a remarkable level or flexibility and resource adequacy with the growing shares of variable renewable energy. The government, the system operator, the utilities and the regulator should maintain their commendable efforts to ensure secure energy supply. Particular attention should be given to gas supply security during the temporary closure of the Tyra field.

Energy sector regulation

The responsibilities of the Danish Energy Regulatory Authority (DERA) include not only regulating the electricity, gas and district heating sectors, but also supervising the energy efficiency obligation and co-operating with the Nordic and EU regulators. However, DERA has limited possibilities to develop and improve the legal and regulatory framework in the sectors that it regulates. Given the increasing role of the electricity sector in the low-carbon transition, DERA may require additional competent staff with specific expertise. DERA’s staffing was recently increased, which is a positive decision. It is important to ensure that DERA continues to have sufficient funding and human resources in the future.

Recommendations

The government of Denmark should:

- ☐ Consider energy and climate issues as a whole when deciding upon policy measures for reaching its different energy and climate targets as well as the targets adopted internationally and in the European Union. Prioritise measures that are the most cost-effective and suitable for meeting multiple targets and socio-economic objectives.
- ☐ Ensure that policy measures for reaching medium-term energy and climate targets (to 2030) are dimensioned and directed so that they are consistent with possible paths towards long-term objectives (to 2050).
- ☐ Assess current energy taxation principles, structure and levels in light of the energy and climate policy objectives, and adjust them to ensure that taxation is not a barrier and does not undermine current or intended policy.
- ☐ Ensure that the Danish Energy Regulatory Authority has sufficient resources to continue to perform in a competent manner as its duties expand.

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2. Oil

Key data

(2016 provisional)

Crude oil production: 6.92 Mt, -59% since 2006

Net exports of crude oil: 0.45 Mt (3.84 imported, 4.28 Mt exported)

Oil products production: 8.95 Mt, +15% since 2006

Net imports of oil products: 0.76 Mt (9.28 Mt imported, 8.53 Mt exported)

Share of oil: 35.6% of TPES (2016) and 39.1% of TFC (2015)

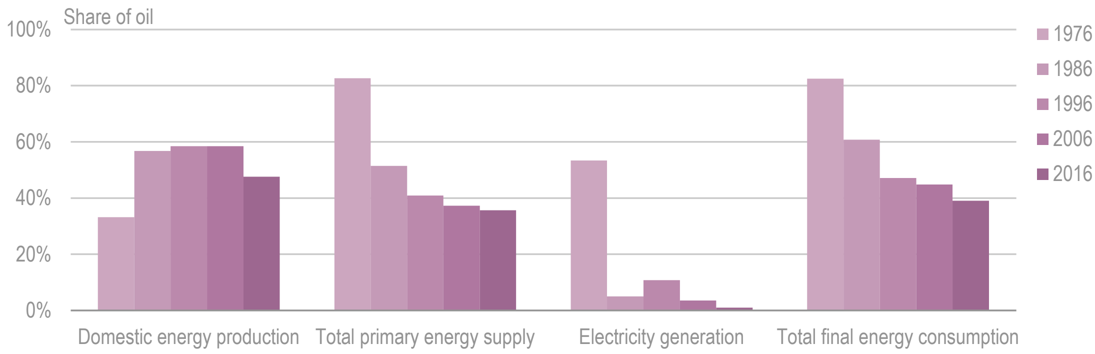
Supply by sector (2015): 5.82 Mtoe (transport 64.4%, industry 10.9%, other energy 10.1%, commercial 8.8%, residential 4.0%, power and heat generation 1.7%)

Overview

Oil is the most important fuel in Denmark's energy system, accounting for nearly half the domestic energy production and more than one-third of total primary energy supply (TPES). However, the dominance of oil has continuously decreased. The decline of oil production was followed by a drop in crude oil exports. Domestic consumption also decreased thanks to improved energy efficiency and the rising use of renewable energy which partly replaced oil.

Despite a significant decrease in crude oil exports over the past decade, Denmark is still a net exporter of crude oil, exporting mainly to Sweden. In contrast, Denmark is a net importer of oil products, mainly from the Russian Federation (hereafter, "Russia").

Figure 2.1 Oil's share in different energy supplies in Denmark, 1976-2016



Notes: Data are provisional for 2016. Consumption data are for 2015.

Source: IEA (2017a), *World Energy Balances* 2017, www.iea.org/statistics/.

Supply and demand

Production, imports and exports

Denmark's crude oil production decreased by 64%, from a peak of 19.3 million tonnes (Mt) in 2004 to 6.9 Mt in 2016. Correspondingly, its position as a net exporter of crude oil has weakened as net exports fell from 11.2 Mt in the peak year of 2004 to 0.4 Mt in 2016, the lowest level in two decades. Sweden is the largest net importer of Danish crude oil with 2.8 Mt, followed by the Netherlands (0.5 Mt) and the United Kingdom (0.4 Mt).

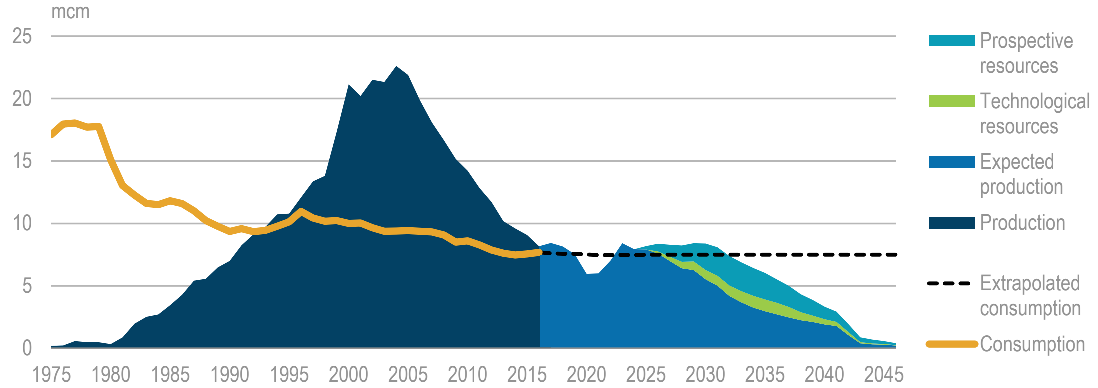
At the beginning of 2016, Denmark's oil reserves totalled around 490 million barrels (mb) according to the Danish Energy Agency (DEA). The DEA also put contingent oil resources at around 515 mb out of which around 430 mb are pending development, around 15 mb are unclarified and around 70 mb are not viable for development (DEA, 2016). Seventeen fields are producing in Denmark, but most oil comes from three fields: Halfdan (36.9% of the total in 2015), Dan (17.5%) and South Arne (11.3%) (DEA, 2017a).

According to Denmark's oil and gas strategy of July 2017, the country has a geological oil and gas potential of around three billion barrels (bb) of oil-equivalent. For comparison, Denmark's accumulated production so far totals around 3.8 bb of oil-equivalent. The strategy foresees that around half this potential could be produced with current technology. Domestic oil and gas demand is expected to decline until 2050 and the potential resource will help Denmark maintain security of supply in the coming decades (DEA, 2017b).

Produced and imported crude oil is refined in two refineries, in Fredericia and in Kalundborg. In addition to domestically refined oil, Denmark has historically been a net importer of oil products with the exception of 1995-96 and 2012. While levels of net imports decreased over the past decade and exports grew faster than imports, the overall trade flow of oil products significantly increased. Between 2005 and 2015, imports increased by 60%, and exports more than doubled. In 2015, oil products from Russia accounted for 46% of total imports, followed by Sweden (11%) and Norway (8%).

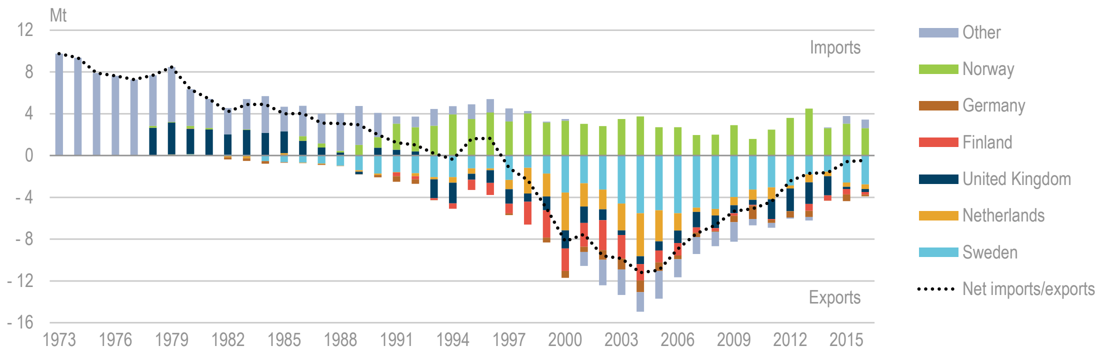
Oil consumption is expected to exceed production in years 2019 and 2020, while the expected production is once again forecast to exceed consumption from 2021 to 2026 (see Figure 2.2). A reduction in oil production is expected until 2021 mainly owing to a postponement of the commissioning of the Hejre field and the reconstruction of the Tyra field installations. If the technological and prospective resources are included, the government expects Denmark to remain a net exporter at least until 2032, except in years 2019 and 2020.

Figure 2.2 Oil production forecast



Source: DEA (2016), *Resources and forecasts*, Copenhagen, https://ens.dk/sites/ens.dk/files/OlieGas/ress_progn_2015_uk_05092016.pdf.

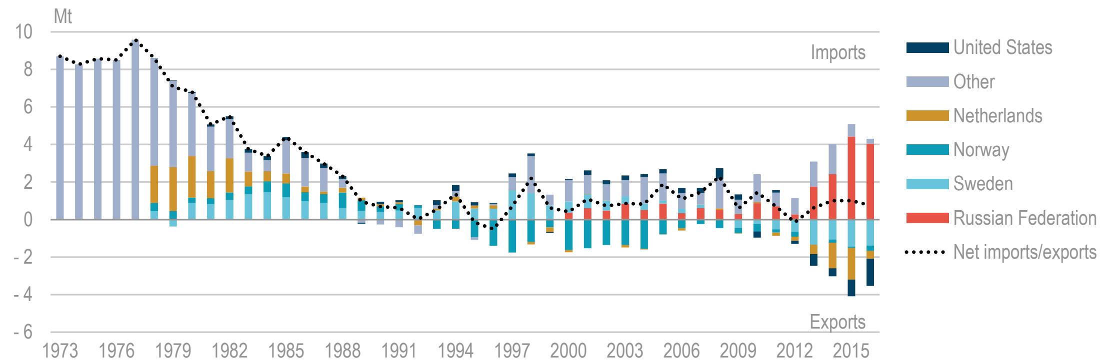
Figure 2.3 Crude oil imports and exports by country, 1973-2016



Note: Crude oil includes natural gas liquids and feedstock.

Source: IEA (2017b), *Oil Information 2017*, www.iea.org/statistics/.

Figure 2.4 Oil products imports and exports by country, 1979-2016



Note: Data are provisional for 2016.

Source: IEA (2017b), *Oil Information 2017*, www.iea.org/statistics/.

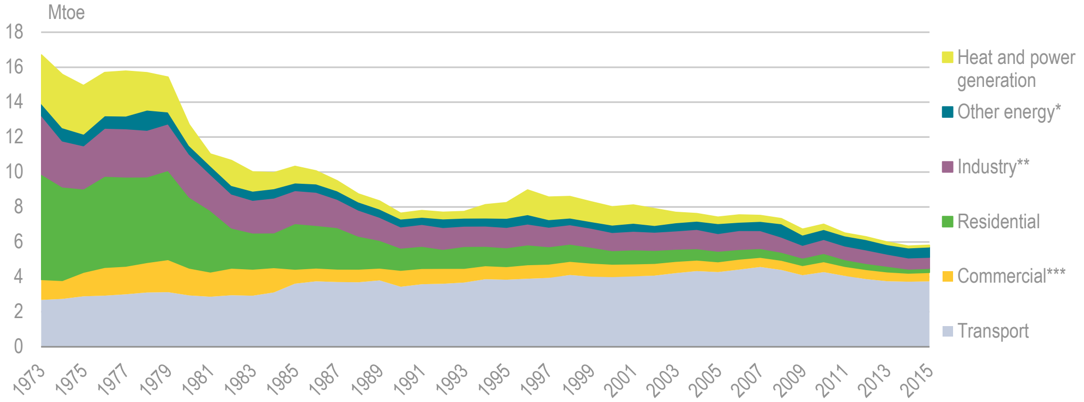
Consumption

Oil consumption in Denmark has been declining since the 1970s. In 2015, TPES of oil was 5.8 million tonnes of oil-equivalent (Mtoe), a 22% decrease compared with 2005. Total final consumption was 5.2 Mtoe. The transport sector consumed more oil than all other sectors combined, 64.4% of the TPES of oil. Road transport is the largest oil user within the transport sector and represents half the total oil consumption. Oil use for transport has declined at a slower rate than other sectors over the past decade, and as a result, the share of the transport sector increased from 57.6% in 2005 to 64.4 % in 2015.

Industry was the second-largest oil consumer, at 10.9% of the total, and was followed by consumption in the energy transformation (other than power and heat) sector (10.1%), the commercial (8.8%) and residential (4.0%) sectors, and power and heat generation (1.7%). Power and heat generation has seen the biggest decrease in oil consumption over the past decade.

Diesel is the most used oil product, accounting for 56% of total consumption, followed by motor gasoline (20%), and kerosene (14%). Over a ten-year period from 2005 to 2015, consumption of all oil products was reduced.

Figure 2.5 Oil consumption by sector, 1973-2015



* *Other energy* includes petroleum refineries and energy own-use.

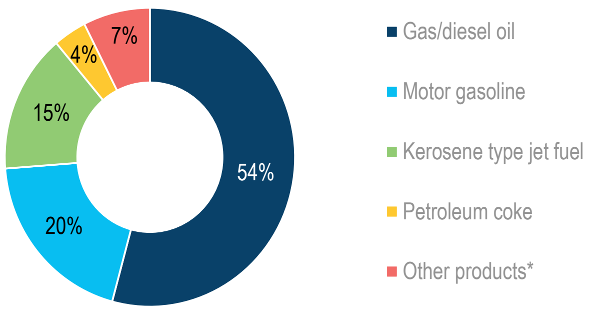
** *Industry* included non-energy use.

*** *Commercial* includes commercial and public services, agriculture, forestry and fishing.

Note: Total primary energy supply of oil by consuming sector.

Source: IEA (2017a), *World Energy Balances* 2017, www.iea.org/statistics/.

Figure 2.6 Oil supply by product, 2015



**Other products* include liquefied petroleum gas, bitumen, lubricants, naphtha and other undefined oil products.

Source: IEA (2017b), *Oil Information 2017*, www.iea.org/statistics/.

Infrastructure

Refineries

Denmark has two refineries, located in Kalundborg and Fredericia, with a total crude distillation capacity of 197 thousand barrels per day (kbd) or 8.5 Mt/year. The refineries produce a range of products that serve both the Danish domestic market and the markets of its neighbouring countries.

The Kalundborg refinery, owned by Statoil, has a capacity of around 127 kbd and is capable of processing various crude oils and condensates, primarily sourced from the North Sea. Crude oil deliveries arrive by ship, while condensate is delivered primarily from the Sleipner area via Statoil's gas processing plant at Kårstø, Norway. The primary markets for the finished products are the countries in the Baltic region.

The Fredericia refinery has a capacity of 70 kbd. It processes Danish North Sea oil, which is sent to the refinery via pipeline from offshore operations. Its products supply the Danish domestic market as well as those of neighbouring countries. In September 2016, Shell sold the remainder of its downstream operations in Denmark (including the Fredericia refinery) to Dansk Olieselskab. The deal is set to be finalised in 2017.

Total Danish refinery output was around 189 kbd in 2015, sufficient to meet domestic demand for all major products except for jet fuel and kerosene. However, for logistical reasons, Denmark also imports a significant amount of refined products. In 2015, it imported around 188 kbd of total products, primarily from Russia.

Ports and pipelines

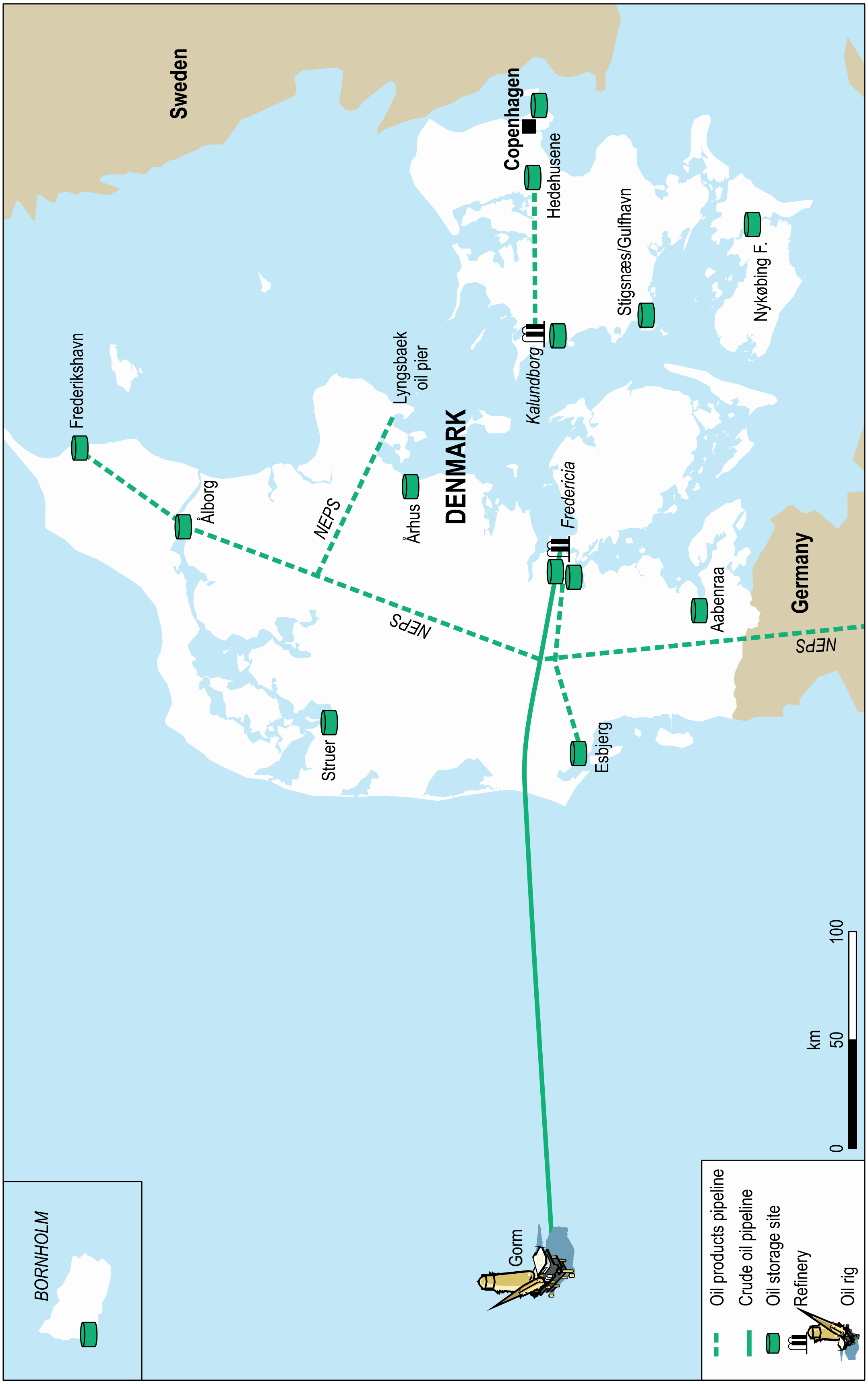
Denmark has 16 oil terminals, with a total loading capacity of 0.5 million cubic metres per day (mcm/d) and a total discharging capacity of 1.2 mcm/d. The two oil refineries (Fredericia and Kalundborg) receive crude oil via terminals with a combined importing capacity of 240 thousand barrels per day (kb/d).

In addition to the two terminals at the refineries, there are three other main terminals for loading and discharging refined products via tanker at the ports of Aabenraa, Copenhagen and Stigsnaes. The remaining eleven oil terminals operate simply as oil product import facilities.

Denmark has only one crude oil pipeline connecting most of its offshore production to the refinery and the crude export terminal at Fredericia. Owned and operated by DONG Oil Pipe AS, the pipeline is 330 km-long (including 110 km on land) with a maximum flow capacity of 360 kb/d.

The Northern European Pipeline System (NEPS) extends from Heide in Germany to North Jutland and is owned and operated by the Danish military forces as it is a part of the NATO Pipeline System (NPS). Additionally, the country's stockholding agency, FDO, owns and operates three product pipelines in Jutland and Zealand. Two of them are 85 km-long with a combined flow capacity of 430 cm/hour (equivalent to 65 kb/d) and connect the Kalundborg refinery with the Hedehusene product terminal, supplying a large volume of gasoline and gasoil to Copenhagen. Those pipelines are normally used in one direction but can be reversed in only a few days if necessary. In 2014, the combined annual utilisation rate of those two pipelines was 37%.

Figure 2.7 Map of oil infrastructure, 2017



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

The other FDO pipeline, FDO Jutland South, connects the Fredericia terminal with some of the underground FDO storage sites in Jutland and the harbour in Fredericia. There is also a jet fuel pipeline connecting the Copenhagen terminal with the Copenhagen airport.

Storage

As of 2015, Denmark possesses a total of 7.6 mcm (approximately 47.7 mb) of combined stocks held for industry operations and to cover compulsory stockholding obligations. This equates to approximately 302 days of Danish domestic oil consumption.

Close to half the country's total combined (crude and product) storage capacity is located at the two main refineries. Their crude oil storage accounted for 13% of the country's total combined storage capacity. Capacity at the Fredericia refinery is slightly over 8 mb (or 1.3 mcm) for refined products, while capacity at the Kalundborg refinery is approximately 7.4 mb (or 1.1 mcm) for the same products.

Apart from the above-ground facilities at the two refineries, the FDO operates an additional nine underground facilities with a combined storage capacity of some 3.5 mb (or 560 000 cm). This is down from 15 underground facilities at the end of 2009 (with a combined storage capacity of 5.3 mb), as six of the sites were shut down as a result of decreasing domestic oil demand. The FDO is not currently planning to shut down any additional storage sites.

Retail sector

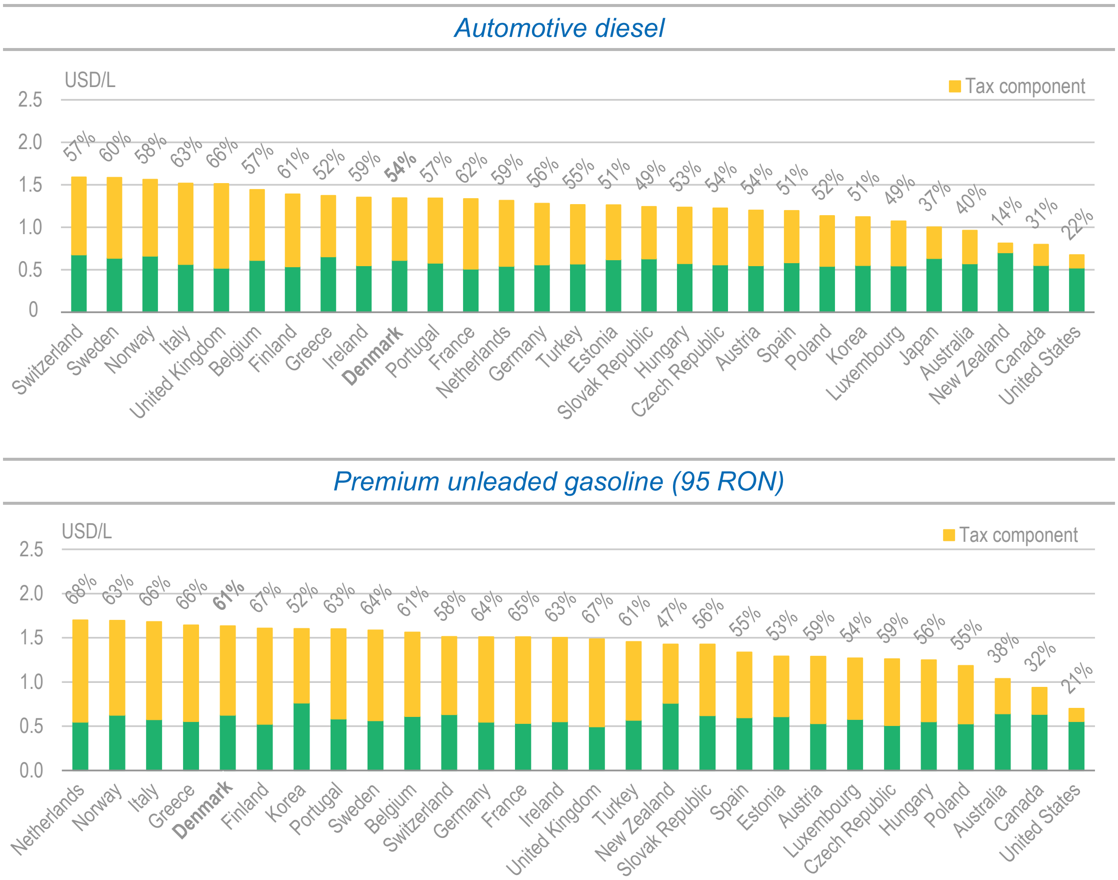
As of end-2016, Denmark had a total of 2 028 petrol stations (EOF, 2017). Companies with the largest stake in the retail sector are OK (with a total of 662 stations), Circle (296), Uno-X (254), Shell (153, plus an additional 44 Shell Express), F24 (133), INGO (130), Go'on (111), and Q8 (108). The remaining 135 are owned by a number of smaller companies. The number of unmanned stations has been growing in recent years, and these accounted for 75% of all stations in 2016.

Prices and taxes

Diesel and gasoline prices in Denmark are comparable to its North Sea neighbours and higher than in many IEA member countries. For diesel, the Danish price is tenth-highest among IEA member countries (second quarter of 2017), but it is slightly lower than its neighbours, namely Sweden, Norway and Finland, because of a relatively lower tax. Gasoline prices are fifth-highest among IEA member countries, above the prices in Finland and Sweden, but below those in Norway.

Prices of oil products are determined mainly by supply and demand factors of the world market, and are also influenced by the US dollar exchange rate as it is the currency generally used for oil trade. The role of government in determining oil product prices is rather restricted to taxation. Danish taxes on oil products include the hydrocarbon tax, the corporate income tax and royalty. Denmark has no floor or ceiling on oil prices for consumers and no consumption subsidies for oil products.

Figure 2.8 Fuel prices in IEA member countries, second quarter 2017



Note: No data available for gasoline in Japan.

Source: IEA (2017c), *Energy Prices and Taxes, Third Quarter 2017*, www.iea.org/statistics/.

Emergency response policy

Security of supply

Security of supply is promoted thanks to stable crude oil production from the North Sea and compulsory oil stocks in industry. In March 2017, the Danish government reached an agreement which secures the development of North Sea oil and gas production and the continuation of the Tyra fields. According to the agreement, the Tyra fields have to be fully reconstructed, which will contribute to Danish security of supply. Further, the Danish government imposes a compulsory stockholding obligation on all producers and importers of crude oil and refined products to ensure that stocks remain adequate.

Decision-making structure

The Minister for Energy, Utilities and Climate is responsible for security of oil supply. Within the ministry, the Danish Energy Agency (DEA) is responsible for matters related to energy production, supply and consumption. As an integrated part of the DEA, the Danish national emergency strategy organisation (NESO) consists of an emergency unit and a data unit, both of which are involved in issues related to emergency preparedness. The emergency unit is the core body responsible for co-ordination among all stakeholders, including the FDO (the central stockholding agency), obligated oil companies, and international organisations such as the IEA and the European Commission. The data unit is responsible for the calculation of the compulsory stock obligation and data submissions.

In the event of an oil supply disruption, NESO could be expanded to include other DEA staff in order to implement emergency measures in co-operation with other energy sector operations. The Danish Oil Advisory Board would also convene meetings to hold discussions with various stakeholders (including upstream and downstream oil industry representatives) on how best to assess the crisis, how best to respond, and what kind of emergency measures should be implemented. The Board consists of representatives from the DEA, the Ministry of Foreign Affairs, the Danish Competition Authority, major downstream and upstream oil companies, electricity generators, and the FDO. The Board can be open to other stakeholders if necessary.

The DEA has prepared an Oil Emergency Plan (updated in 2014), a small handbook for the internal handling of oil crises by the involved Danish parties.

Emergency stocks

Stockholding policy

The use of emergency oil stocks is central to Denmark's emergency response policy. An updated catalogue for demand restraint measures and adjunct decision policy is being developed to supplement the emergency stocks during an oil crisis.

As a net exporter of oil, Denmark is exempt from the IEA stockholding obligation; however, it is subject to the EU obligation, which requires that all members hold stocks equivalent to at least 61 days of average daily inland consumption. Denmark has decided to hold an additional 20% in excess of this obligation.

Denmark imposes a compulsory stockholding obligation on all producers and importers of crude oil and refined products. The obligation is calculated on the basis of net domestic sales to end-users and non-obligated companies.

The central stockholding agency (FDO)

The FDO, the Danish central stockholding entity, was created in 1964 by the Danish oil industry for the purpose of holding emergency stocks on behalf of obligated companies. The FDO is managed and financed entirely by the oil industry and co-operates closely with the Danish Energy Agency on issues related to oil emergency preparedness. It is responsible for collecting and processing oil data submitted by oil companies that are subject to the compulsory stockholding obligation, ticket applications with other countries and registering national tickets. Approximately 70% of Danish compulsory stocks are held by FDO, while the remaining 30% is held in individual companies' commercial tanks.

Monitoring and compliance

The FDO is responsible for monitoring compulsory stocks. All obligated companies submit a monthly data report through a computer system called Oildata. The FDO conducts random checks and inspections. Once per year, each company is obliged to deliver a declaration from an independent auditor stating that the data submitted in Oildata during the last year is correct. In case of infringement, the FDO informs the DEA of non-compliance with the domestic obligation. Companies committing incorrect and/or non-timely reporting can be fined.

Draw-down procedures

The Minister for Energy, Utilities and Climate has the authority to decide over the release of compulsory stocks with or without consultation with the Danish Oil Advisory Board.

After a decision regarding the release of emergency stocks has been taken by the minister, the FDO will convene an Operations Committee meeting. The Committee, consisting of representatives from the DEA, the FDO Board and FDO management, will take a decision on how stocks will be released. Stocks would be made available to the market by tender process.

Demand restraint

The legal authority for the implementation of demand restraint measures Denmark is established by the Consolidated Act 88 of 26 February 1986 on Supply Measures. Under this Act, the minister may, in time of an internationally induced crisis, stipulate provisions about the use, distribution, price equalisation and location of stocks of commodities. The administration does not consider demand restraint as a viable initial emergency response measure and would only envisage using it as a supplementary measure to the use of compulsory stocks in the event of a severe and long-lasting oil supply disruption.

Assessment

Denmark has been an oil producer since 1972. Domestic oil production peaked at 19.3 Mt in 2004 and decreased to 6.9 Mt in 2016. In the same vein, the country's crude oil net exports peaked in 2004 at 11.2 Mt and decreased to 0.4 Mt in 2016. Over the same period, oil imports remained stable at 3.9 Mt. Denmark still is a (small) net exporter of oil, a rare species in the IEA family; Canada and Norway are the only other net exporters.

In 2013, the terms and conditions for hydrocarbon production in the North Sea were revised. Following this overhaul, the government prepared an overall oil and gas strategy in co-operation with the industry, the aim being to ensure that the North Sea oil and gas resources are exploited efficiently. According to a political agreement from March 2017, a temporary tax relief will be introduced in the period 2017-25 together with some further regulation on third-party access to existing infrastructure. Both initiatives focus on enhancing incentives to continue production in the Danish part of the North Sea, where recoveries typically are relatively small but also situated near existing infrastructure. In general, the government should benchmark the terms and conditions for production, including royalties, with other countries around the North Sea, to ensure that Denmark remains attractive for future exploration. The technology of carbon capture and storage (CCS) for enhanced oil recovery is not practised in Denmark, though there are good results in some other jurisdictions in the North Sea.

Domestic oil consumption has declined by more than one-fifth since 2005. Oil demand is expected to decline slightly further in the years to come. Oil is mainly used in transport, accounting for almost two-thirds of total consumption. As a result of lower taxes on diesel compared to gasoline, diesel consumption is increasing slightly, but not matching the decrease in gasoline consumption.

Denmark is foreseen to remain a net exporter of crude oil until 2026, except for the years 2019-20. Consumption is expected to exceed production during 2019 and 2020, while the expected production is forecast to exceed consumption again thereafter. The temporary reduction in oil production in 2019-2020 is mainly caused by a postponement of the commissioning of the Hejre field and the reconstruction of the Tyra field installations. If the technological and prospective resources are included, the government expects Denmark to remain a net exporter in the coming decades.

As a net oil exporter, Denmark has no IEA obligation to hold oil emergency stocks. However, in relation to the European Union, Denmark has an obligation corresponding to 61 days of average daily inland consumption. It holds emergency stocks 20% higher than that requirement, corresponding to 73 days of average daily inland consumption. The IEA welcomes this contribution to oil security.

Recommendations

The government of Denmark should:

- Encourage upstream investments by carefully benchmarking the Danish terms and conditions for exploration and production with those of other countries around the North Sea, and adjust them where appropriate.
- Investigate, together with industry, the potential of economic carbon capture and storage for enhanced oil recovery.

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3. Natural gas

Key data

(2016 provisional)

Natural gas production: 4.5 bcm, -57% since 2005

Net exports: 1.4 bcm (imports: 0.7 bcm, exports: 2.1 bcm), -73% since 2005

Share of natural gas: 17.4% of TPES and 7.3% of electricity generation

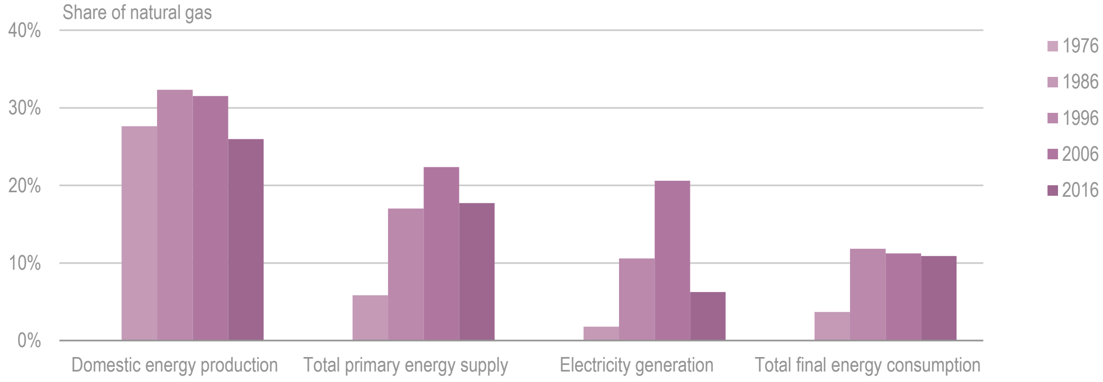
Consumption by sector (2015): 2.9 Mtoe (heat and power generation 28.7%, industry 22.7%, other energy 20.6%, residential 20.4%, commercial 7.5%, transport 0.1%)

Overview

Natural gas has traditionally been one of the most important energy sources for Denmark, along with oil and coal. However, its importance has diminished over the past decade with a rise of renewable energy sources. The share of natural gas in Denmark's total primary energy supply (TPES) fell from 22% in 2006 to 17.4% in 2016, mainly as wind power replaced gas in power generation.

Denmark is self-sufficient in natural gas and trades it with Germany, Sweden, the Netherlands and Norway. Power and heat generation remains the largest gas-consuming sector, but gas demand fell significantly as renewable energy use increased rapidly.

Figure 3.1 Natural gas shares in Denmark's energy system, 1976-2016



Notes: Data are provisional for 2016. Consumption data are for 2015.

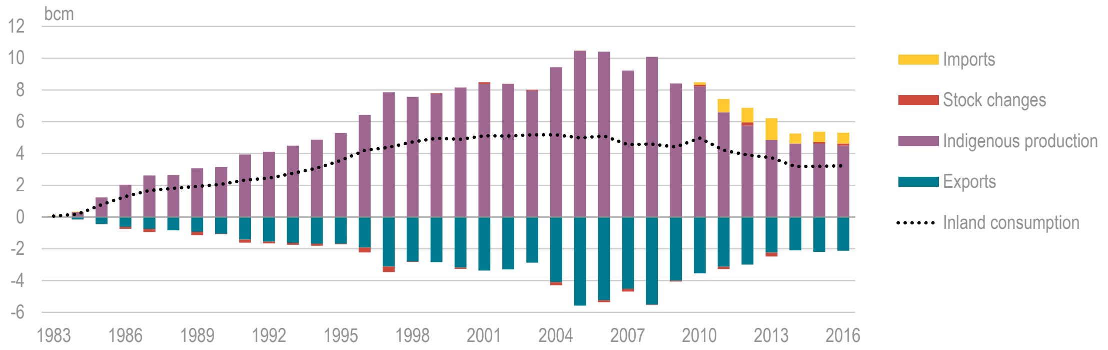
Source: IEA (2017a), *World Energy Balances* 2017, www.iea.org/statistics/.

Supply and demand

Production and resources

Natural gas production in Denmark began in 1983. Production increased gradually to peak at 10.4 billion cubic metres (bcm) in 2005, then declined to 4.5 bcm in 2016 (see Figure 3.2). There are 17 fields producing natural gas in Denmark, but most gas comes from two fields: Halfdan (30.9% of the total in 2015) and Tyra (27.0%). The third-highest production in 2015 came from the Harald field, at 8.6% of the total (DEA, 2017).

Figure 3.2 Natural gas supply by source, 1983-2016



Source: IEA (2017b), Natural Gas Information 2017, www.iea.org/statistics/.

In its most recent five-year *Outlook*, the Danish Energy Agency (DEA) forecasts gas production to decline from 3.7 bcm in 2016-17 to 1.1 bcm in 2020 (DEA, 2016) because of the reconstruction of the Tyra field and a postponement of the commissioning of the Hejre field.

According to Maersk Oil, Tyra's operator, the field needs to be reconstructed because of subsidence of the chalk reservoir which has led to the platforms sinking by around five metres in the last 30 years. The reconstruction is expected to lead to a shutdown of production at Tyra from December 2019 to March 2022 (Maersk Oil, 2017).

Tyra is Denmark's largest gas field and more than 90% of national gas production is processed through its facilities. Tyra is the processing and export centre for all gas produced by the Danish Underground Consortium (DUC) which includes Shell (36.8% share), Maersk Oil (31.2%), Nordsøfonden (20%) and Chevron (12%).

At the beginning of 2016, Denmark's remaining gas reserves totalled 16 bcm, according to the DEA. The DEA also put contingent gas resources at 64 bcm, out of which around 51 bcm are pending development, about 10 bcm are not viable for development and the status of the remaining, approximately 2 bcm, is unclarified (DEA, 2016).

Economically viable shale gas deposits have not been found in Denmark, and the issuance of new licences for shale gas exploration and production was suspended in June 2012 by the Minister for Energy, Climate and Building on environmental grounds.

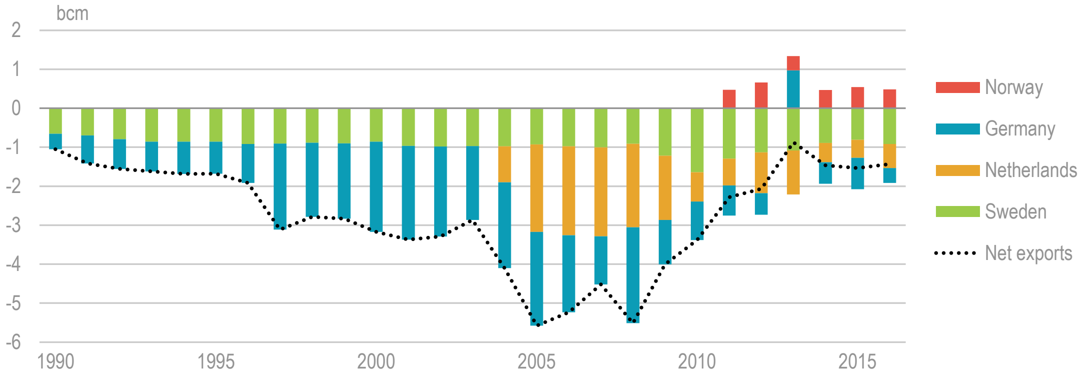
Exports

Denmark has been a net exporter of natural gas since the start of domestic production. As they are linked to production levels, exports peaked in 2005, before declining by 73%

over the following decade (see Figure 3.3). In 2016, net exports totalled 1.4 bcm and exports were destined to Sweden (48%), the Netherlands (32%), and Germany (20%).

Since 2010, Denmark has also been importing small volumes of gas, mainly from Norway, but also from Germany. Denmark's gas infrastructure is well connected with the neighbouring countries, and it also serves for gas transit in the region.

Figure 3.3 Natural gas imports and exports by country, 1990-2016



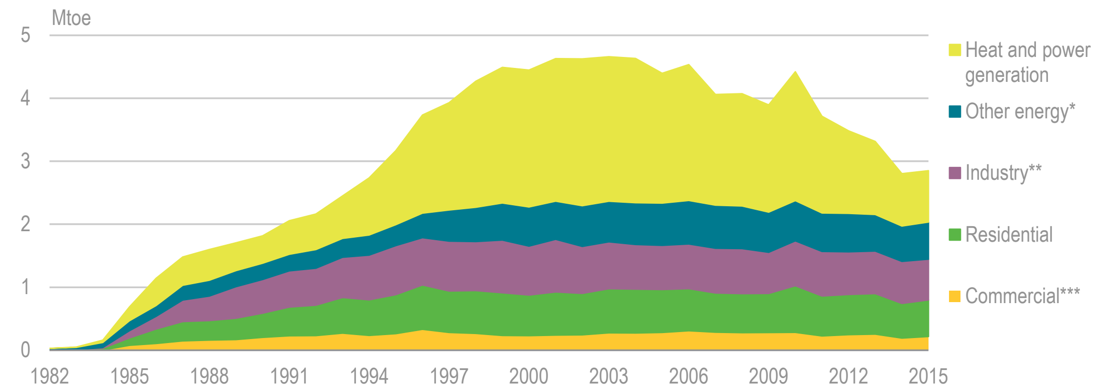
Source: IEA (2017b), *Natural Gas Information 2017*, www.iea.org/statistics/.

Demand

Natural gas demand was 2.9 Mtoe in 2015, a decline of 35% from 2005. Power generation was the largest gas consumer, at 28.7% of the total, followed by industry (22.7%), oil and gas extraction (20.6%), residential (20.4%) and the commercial sector (7.5%). Natural gas use in transport was negligible (0.1%).

The government expects natural gas consumption (excluding gas consumption at production facilities) to gradually decrease from 2.8 bcm in 2013 to some 2.4 bcm in 2025 because of greater energy efficiency and a switch to renewable energy at power and heat plants and in households.

Figure 3.4 Natural gas consumption by sector, 1982-2015



* *Other energy* includes oil and gas extraction.

** *Industry* includes non-energy use.

*** *Commercial* includes commercial and public services, agriculture/fishing and forestry.

Note: Total primary energy supply of natural gas by consuming sector.

Source: IEA (2017a), *World Energy Balances* 2017, www.iea.org/statistics/.

Legal and regulatory framework

Upstream

Concessions and approvals for preliminary investigations, exploration for and production of hydrocarbons are granted according to the Act on the Use of the Danish Subsoil (September 2011). Concessions in the western part of the North Sea, where most hydrocarbons are found, are granted in accordance with the rules in the EU Concessions Directive on Licensing Rounds, whereas concessions for hydrocarbon activities on the remaining Danish territory are given according to the open-door principle. To date, no commercial oil or gas discoveries have been made in the open-door area. The rules concerning access to the upstream gas pipeline network are found in the Executive Order on Upstream Pipeline Access.

Concessions are granted by the Minister of Energy, Utilities and Climate, and they are supervised and administered by the Danish Energy Agency (DEA). The Act also contains rules on the use of the subsoil for storage or for purposes other than the production of raw materials.

Since 1984, seven licensing rounds have been held. The sixth licensing round in 2005 resulted in 14 licences being issued in 2006. Sixteen licences in the seventh licensing round were awarded in April 2016. The DEA plans to carry out licensing rounds every second year from 2016 (or more likely 2017) onwards. Licences awarded are exclusive licences for both oil and natural gas exploration and production.

Downstream

The legal basis for the functioning of Denmark's natural gas system is provided by EU regulations and national laws implementing EU directives. Since 2008, as in the electricity sector, the European Union has increased harmonisation in the natural gas sector with the aim of creating a single market.

Creating a single EU natural gas market has focused on two areas: first, integrating national and regional gas markets and co-ordinating system operations via commonly agreed network codes and, second, constructing cross-border interconnections and co-ordinating network infrastructure planning via ten-year network development plans of the European Network of Transmission System Operators for Gas (ENTSO-G) and via regional plans. The relevant EU directives and regulations for natural gas are:

- Directive 2009/73/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in natural gas, and repealing Directive 2003/55/EC ("Gas Directive").

- Regulation (EC) No 715/2009 of the European Parliament and of the Council of 13 July 2009 on conditions for access to the natural gas transmission networks and repealing Regulation (EC) No 1775/2005 ("Gas Regulation").

- Regulation (EC) No 713/2009 of the European Parliament and of the Council of 13 July 2009 establishing an Agency for the Cooperation of Energy Regulators ("ACER Regulation").

- Regulation (EU) No 1227/2011 of the European Parliament and of the Council on wholesale energy market integrity and transparency ("REMIT Regulation").

The cornerstone of the 2009 Gas Directive is to effectively separate network activities from supply, generation or production activities, the so-called unbundling. The directive also strengthened the independence of national regulatory authorities from the government and promotes their co-operation at EU level through the Agency for the Cooperation of Energy Regulators (ACER). It also increased the independence of the transmission system operators (TSOs) and their co-operation at EU level, through ENTSO-G.

Denmark transposed the Gas Directive into national legislation by the Danish Natural Gas Supply Act which sets the roles and responsibilities for transmission, distribution, supply and storage of gas and the usage of biogas in the natural gas system. It also stipulates the role and responsibilities of the TSO and distribution system operators (DSOs) and defines certain consumer rights as well as the frames for regulating access to the upstream pipeline network.

The Danish Energy Regulatory Authority (DERA) oversees the natural gas market and is also responsible for settling disputes regarding access tariffs to the upstream pipeline system. DERA certified Energinet.dk in 2012 as the operator of the Danish gas transmission system. Energinet.dk is fully ownership-unbundled. It is owned by the Ministry of Energy, Utilities and Climate.

Infrastructure

Gas transmission system

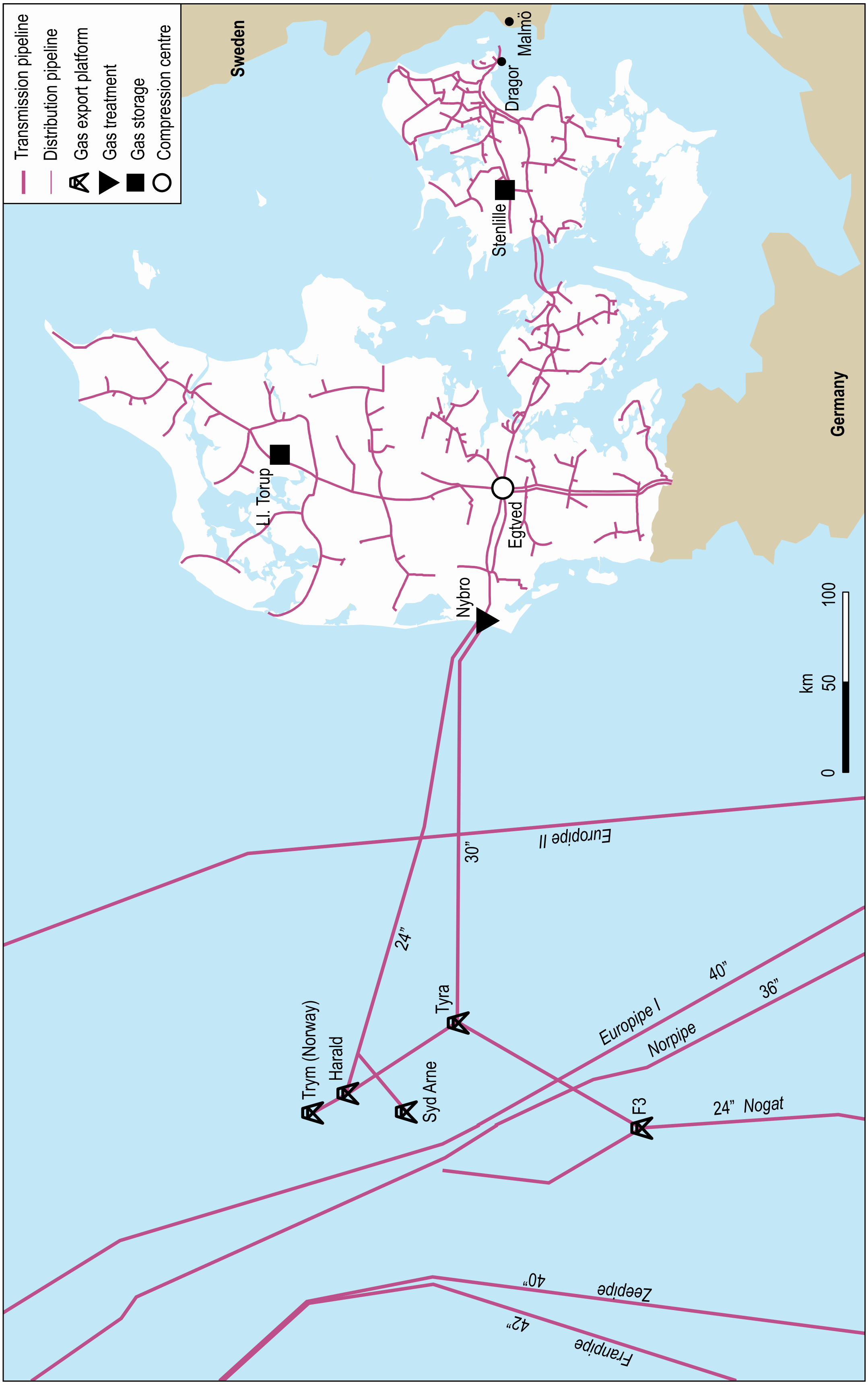
The backbone of the gas infrastructure is the transmission system which links gas production locations in the North Sea and the interconnectors with the neighbouring countries to the distribution grids connecting to consumers. The transmission grid in Denmark is owned and operated by Energinet.dk. In total, the pipelines in the transmission grid were 924 km-long in 2016 (DERA, 2016). The transmission grid is connected to the distribution grids via 43 metering and regulator stations which reduce the pressure for the pipeline systems of the distribution companies.

The transmission system also provides access to the two gas storage facilities: Stenlille on Zealand and Lille Torup in Northern Jutland. Both are owned and operated by Energinet.dk. They are used to compensate for seasonal fluctuations in consumption and for commercial reasons to reduce gas price differences. They are also used as a tool to maintain security of supply. In 2016, the storages had a total commercial injection capacity of 4.2 gigawatt-hours per hour (GWh/h) and a withdrawal capacity of 8.1 GWh/h, and a working gas volume of around 11.5 terawatt-hours (TWh).

The gas transmission system has the following interconnection capacities:

- Nybro entry from the offshore production: 16.5 GWh/h
- Ellund entry from Germany: 7.7 GWh/h
- Ellund exit to Germany: 10 GWh/h
- Dragør exit to Sweden: 3.6 GWh/h.

Figure 3.5 Map of natural gas infrastructure, 2017



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Natural gas in Denmark comes primarily from the Danish North Sea fields through two subsea pipelines of approximately 235 and 260 km. The gas comes ashore at the beach terminal in Nybro where it is treated before it is injected into the transmission network. Denmark does not have liquefied natural gas (LNG) facilities.

With regard to transit from the North Sea to the European market, the Danish system is in competition with the Dutch gas infrastructure, which is also linked to the fields in the Danish part of the North Sea. The gas is transported via the route with the lowest transport costs.

Gas distribution system

The distribution grid has a total line length of around 19 000 kilometres (km) and is connected to around 410 000 supply points, i.e. households and businesses (DERA, 2016). Around 15% of Danish households are connected to the natural gas grid. In addition, in Copenhagen, Frederiksberg and part of Aalborg, there is a network supplying consumers with town gas – a mixture of natural gas and air. The distribution grid is owned and operated by the four Danish distribution companies (see Table 3.1).

The distribution grid was originally designed only to receive natural gas from the transmission grid but, today, biogas upgraded to natural gas quality is also supplied to the distribution grid from biogas plants.

The Baltic Pipe project

The Baltic Pipe project between Denmark and Poland has been identified by the European Union as a project of common interest (PCI). The project consists of a tie-in to Norwegian Europipe 2 on the Danish continental shelf, an upstream pipeline to onshore, an extension of the Danish transmission network from west to east, and a pipeline through the Baltic Sea to Poland. An open-season process is conducted in 2017 to identify market demand. If the project is constructed, a new transport route for Norwegian gas to Continental Europe will enable Denmark to diversify gas supply and improve security of supply. The supply of gas to Poland is expected to range from 7 to 10 bcm per year.

Market structure

Table 3.1 Structure of the natural gas sector

Subsector	Company	Ownership
Transmission	Energinet.dk	State-owned
Distribution	Dansk Gas Distribution*	Energinet.dk (as an independent entity)
	Nature Energy	Municipalities
	HMN Naturgas	Municipalities
	Aalborg Gas	Municipality
Storage	Gas Storage Denmark	Energinet.dk (as an independent entity)
Retail	15-20 companies	Municipalities and private companies

*As a result of introducing DONG Energy on the Danish Stock Exchange in June 2016, DONG Energy Gas Distribution was sold to the Danish state. In practice, the TSO Energinet.dk took over DONG Gas Distribution in October 2016. The company has been renamed Dansk Gas Distribution and is a subsidiary of Energinet.dk.

Wholesale market

Following the gas market liberalisation in 2004, Energinet.dk and Nord Pool established a physical wholesale gas exchange, Nord Pool Gas, in 2008. The exchange, which is called Gaspoint Nordic since July 2013, provides trading in intraday, day-ahead, weekend and month-ahead contracts. Since July 2016, Gaspoint Nordic is owned by Powernext and forms part of the PEGAS gas trading platform, which offers products for several European countries.

The exchange volume has grown fast and, in the first three quarters of 2016, the volume traded at the exchange equalled 84% of domestic gas demand. Exchange traded volumes surpassed over-the-counter (OTC) volumes in 2015. The spot price on Gaspoint Nordic is highly correlated with the spot prices on the German gas hubs NCG and Gaspool, as well as with the Dutch gas hub TTF (Gaspoint Nordic, 2016).

To increase the competitiveness and liquidity especially on the within-day market in Denmark, Energinet.dk implemented the following changes in 2016:

- Balancing pricing on the basis of within-day market price alone (previously a split between day-ahead and within-day).
- Continuous trading on balancing actions within-day (to spread liquidity out during the day, instead of having only small trading windows).
- Suggesting the introduction of one or more market makers on the within-day market. Gaspoint Nordic has then been successful in obtaining agreements with two market players that are now active as market makers.

Retail market

Since 2004, the Danish gas market has been liberalised and customers can choose their supplier and natural gas product. In 2016, 18 natural gas suppliers were present in the market. A gas supplier must enter into a Gas Supply Agreement with one or more distribution companies to deliver gas to consumers. Two suppliers (NGF Gasforsyning and HMN Gassalg) belong to the same business group as a DSO. Until May 2016, a third supplier (DONG) was also affiliated with a DSO (DERA, 2016).

Suppliers sell and deliver gas to end consumers, some of them under so-called universal service obligations, i.e. under a legal obligation to supply small consumers in certain areas. The gas price for deliveries under the universal service obligation is decided through tenders of supply obligation licences, and the price is regulated by DERA (Energitilsynet). Tenders were organised by the Danish Energy Agency for three-year supply periods starting in 2013 and 2016.

Retail market competition remains a concern. In its analysis of autumn 2014, DERA concluded that consumers do not have a sufficient incentive to make an active choice of supplier or product. It also concluded that the price of a product under supply obligation is so low that it is difficult for independent suppliers to compete in the gas retail market. Specifically, low price levels could reduce incentives to be a retail gas supplier. Fewer suppliers would increase market concentration and could result in higher prices in the long run. Measured by using the Herfindahl-Hirschman Index (HHI), the Danish retail gas market is rather highly concentrated, with HHI (in gas sales volume) at 3 484 in 2015, though slightly lower than the 3 648 in 2014 (DERA, 2016).

Products under the price-regulated supply obligation are being phased out, however. At the end of the 2016-19 supply obligation licence period, customers who have received a supply obligation product and who have not actively chosen a new supplier are automatically transferred to a basic product. The price and conditions of the basic product must correspond to those of the previously delivered supply obligation product. Furthermore, the basic product must be available to customers during the period following the supply obligation licences, however, not more than three years.

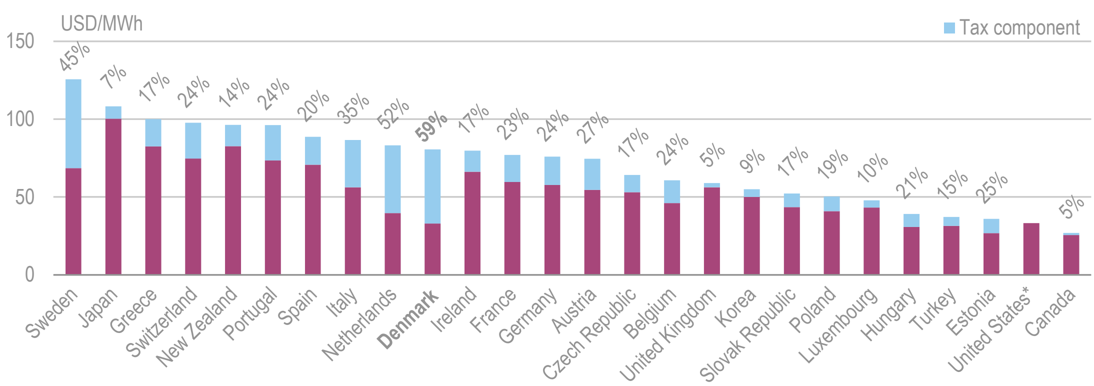
Consumers can switch supplier on the website Gasprisguiden (http://gasprisguiden.dk/) where they can also find information on prices and products. Around 10% of the consumers changed supplier in 2015. This includes customers who actively wanted to keep their present supplier after moving address/house. The figure is 4.4% if customers moving address/house are excluded.

In 2016, the government presented the strategy "Utilities for the Future" which covers energy supply, district heating and water, as well as the management of waste and wastewater. The purpose of the strategy is to modernise the utility sector and thereby realise an overall efficiency potential of DKK 5.9 billion yearly in 2025. Since 2005, gas distribution companies operate under a revenue cap, and the government sees an efficiency potential of DKK 112 million by 2025 for these companies.

Prices and tariffs

Among IEA countries, Denmark has the tenth-highest gas price for households despite one of the lowest pre-tax prices. The share of tax in Danish natural gas prices for households accounts for 59% of the total price, which is the highest level in the IEA comparison (see Figure 3.6). The Danish price has declined in recent years, and the gap to other European countries has been reduced (see Figure 3.7). According to DERA, in 2015, the share of energy in the retail price was 30% and distribution costs 13% (DERA, 2016).

Figure 3.6 Natural gas prices for households in IEA member countries, 2016

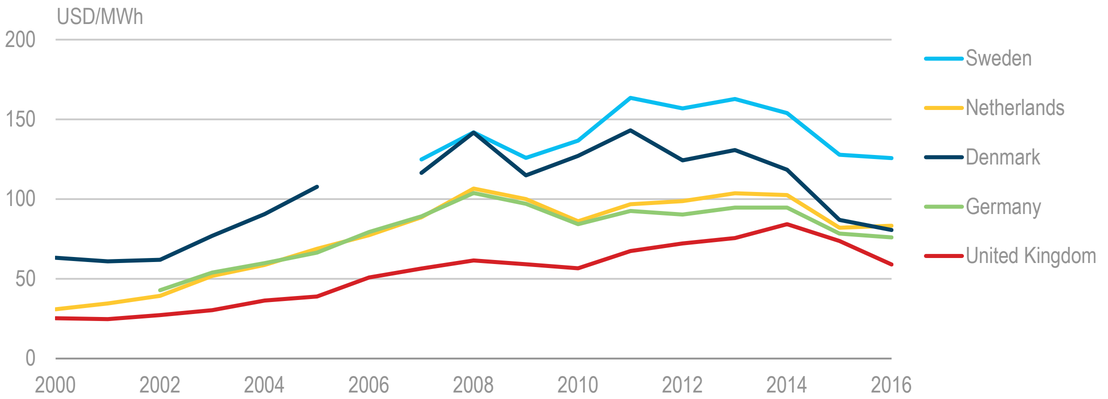


*No tax data available.

Note: Data are not available for Australia, Finland and Norway.

Source: IEA (2017c), *Energy Prices and Taxes, Third Quarter 2017*, www.iea.org/statistics/.

Figure 3.7 Natural gas prices for households in a sample of IEA member countries, 2000-16



Note: Data are not available for some Germany 2001, Denmark 2006 and Sweden 2000-6.
Source: IEA (2017c), *Energy Prices and Taxes, Third Quarter 2017*, www.iea.org/statistics/.

As of May 2016, more than 90% of gas customers are supplied at un-regulated prices. The supply obligation products and the basic products are supplied by two gas suppliers, and DERA monitors the prices of these products.

Security of supply

Denmark is expected to continue to be self-sufficient with natural gas from the North Sea for another decade. The transmission capacity from Northern Germany has increased to 450 000 cubic metres per hour (cm/h). Imports from Germany to Denmark (and Sweden) primarily take place in winter (heating season), when supply from the North Sea is not sufficient to cover the demand in Denmark and Sweden. Denmark is the only gas supplier to Sweden, serving their relatively small grid on the west coast. The temporary shutdown of Tyra because of reconstruction will increase import demand from late 2019 to early 2022, according to the Tyra project plan. The government foresees total Danish gas production to decline by around 2 bcm during this period.

Natural gas emergency response policies in Denmark are underpinned by the Risk Assessment, the Preventive Action Plan and the 2016 Emergency Plan for the Danish gas transmission system. In accordance with the EU Regulation 994/2010/EC, they include several crisis levels and a variety of actions to address them.

Protected consumers are households, district heating installations (provided that they are not able to switch to other fuels), and small and medium-sized enterprises. The TSO determines a threshold for protected consumers in order to comply with the EU regulation.

The Danish emergency plan covers protected consumers for up to 60 days during a normal winter (corresponding to the expected repair time needed after the breakdown of an offshore pipeline) and for three days during particularly cold periods (defined as a daily mean temperature of -13°C which results in gas consumption of around 19.1 mcm/d). Non-protected consumers will also be covered for up to three days (or 72 hours) in a supply emergency. In 2016, there were around 50 non-protected customers, corresponding to around 20% of annual gas demand.

To meet this security objective, all gas storage users must hold a minimum level of gas stocks for winter. Every year, Energinet.dk calculates the minimum stockholding requirement for each storage user, which declines towards the end of the winter. For winter 2016-17, the emergency gas stock totalled around 150 mcm.

The TSO has signed contracts with commercially interruptible consumers in Denmark and Sweden. These interruptions may be activated when declaring an alert or emergency level.

Potential serious gas disruptions are considered to derive from a rupture of the offshore pipelines, long-term interruptions in the gas storage facilities or long-term interruptions in the production of natural gas on the Tyra platform.

Assessment

Since the last review, the future of gas supply to the national system has been widely debated in Denmark. The reason has been the Tyra field, which was at risk of shutting down completely. In March 2017, the government and the operator concluded a final agreement to secure the full reconstruction of the Tyra field facilities (2019-2022) and the development of North Sea oil and gas production. The IEA welcomes and commends this development. Tyra will provide a stable source of gas and self-sufficiency to meet Danish consumption for the period after reconstruction, even with gas production declining by more than half since 2005. However, the government should address the reconstruction of Tyra in detail to avoid any risks to the security of supply and market price formation, for example in case of a cold spell.

The government sees natural gas as part of the energy mix in the coming decades, however with decreasing demand. From 2000 to 2015, natural gas consumption in households decreased by 10%, and in electricity and heat generation by 62%. At the same time, the policy of independence from fossil fuels is being implemented. Therefore, the vision on the role of gas in the Danish economy has to be clarified, and the government should do so when preparing the new Energy Agreement.

It is welcome that the government has addressed the development of the gas system in the strategy "Utilities for the Future". The gas system needs a guarantee of stability in the future, and the strategy sets new targets for the overall utility sector in Denmark. However, future prospects for the functioning of the gas infrastructure are still unclear. According to a scenario analysis by Energinet.dk, in 2050 the network could be solely used for transporting biogas and for the power-to-gas technology. According to DEA projections, by 2050 gas consumption will decline by half, and the consumption of renewable gas will replace natural gas. However, in the face of declining demand, it is clear that, without any adaptation, the infrastructure tariffs would have to be increased. The government should assess possible strategies for the future of gas infrastructure and ensure optimal use and maintenance of the existing infrastructure, in light of its evolving role.

The Danish gas system has been designed to receive gas from the North Sea and Germany. It also operates as a transit system to Sweden. The transmission system does not experience any congestion and the increase in the capacity from Germany to Denmark further improves its flexibility.

The IEA commends the development of the Baltic Pipe project as a way to help diversify gas sources. The project may also benefit the development of the Danish gas system, as it can help ensure a stable future for gas infrastructure and can diversify gas supplies and improve security of supply in Denmark. For the European Union, the project is an important part of the Energy Union strategy. The government will take into account whether it is economically feasible, and whether it has the status of a project of common interest (PCI). Implementing the project should also help comply with the EU Gas Target Model requirements, particularly the number of gas sources and other wholesale development indicators.

The gas distribution grid is around 19 000 km-long, connected to around 410 000 points and owned by four companies. In 2016, DONG Energy Gas Distribution was sold to Energinet.dk, the TSO. This transaction is a way to implement functional and ownership unbundling of the infrastructure and supply activity. Effective enforcement of unbundling is critical for retail market competition, as vertical integration can impede competition in several ways. For example, customers should be able to easily distinguish the supplier from the distributor. In practice, this is not always the case. The IEA welcomes DERA's work to carry out competition inquiries regularly and stresses the need to monitor closely the implementation of recommendations, as the retail market remains highly concentrated.

Wholesale market volumes have decisively moved to the centralised and transparent gas exchange Gaspoint Nordic where the volume traded now far exceeds the over-the-counter market volume. The prices on the Danish gas exchange increasingly correlate with prices at other north-west European gas hubs. The IEA acknowledges the recent positive developments in the Danish wholesale gas market.

The IEA appreciates all activities that aim to enhance security of supply to the most vulnerable customers. However, even after the liberalisation of the gas market in 2004, regulated prices still exist and customers are not encouraged to play an active role on the market (only around 4% changed supplier in 2015). Regulated prices may be detrimental to competition (the price of supply obligation products can be so low that it will be difficult for independent suppliers to compete) and in the retail gas market, competition remains indeed limited.

Recommendations

The government of Denmark should:

- ☐ Take measures to alleviate the risk associated with the reconstruction of the Tyra field in 2019-22 to limit the negative impacts on the security of supply and wholesale gas prices.
- ☐ Proceed with the realisation of projects of common interest that help diversify natural gas supply, enhance the security of supply, and may have positive effects on the Danish infrastructure utilisation.
- ☐ Assess possible strategies for the future use of the natural gas system in light of developments in energy policy, technology and climate objectives.
- ☐ Promote competition in the retail natural gas market, evaluate the impact of regulated prices on natural gas price formation and consider further ownership unbundling.

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4. Coal

Key data

(2016 provisional)

Coal production: Nil

Coal imports and exports (hard coal): 2.89 Mt imported, 0.02 Mt exported

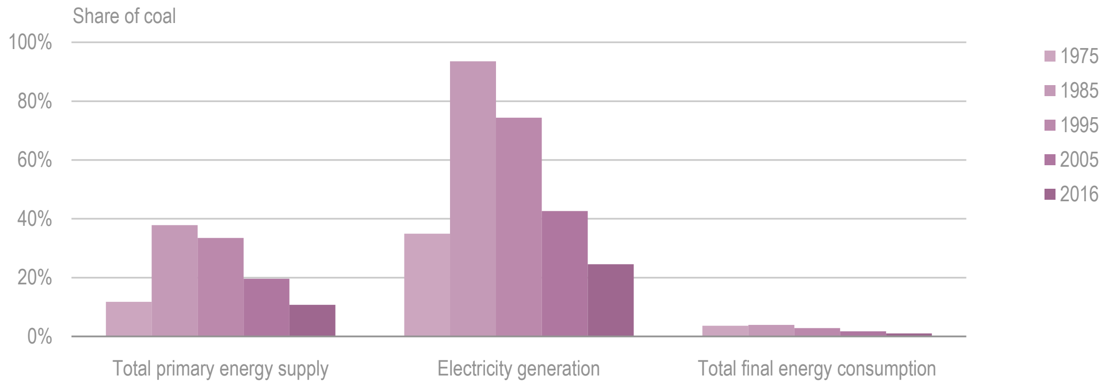
Share of coal: 11.9% of TPES and 28.8% of electricity generation

Consumption by sector (2015): 1.7 Mtoe (power and heat generation and other energy industry 92.8%, industry 5.8%, commercial 1.0%, residential 0.4%)

Overview

Coal was the main energy source for power generation from 1978 to 2013, but has since then lost its dominant position to wind power as a consequence of Denmark's successful policy to reduce dependence on fossil fuels. The share of coal in power generation fell from 54% in 2006 to 28.8% in 2016 and the share in total primary energy supply (TPES) correspondingly fell from 27% to 12%. Electricity generation accounts for over 90% of coal consumption, and the share of coal in total final consumption (TFC) is very low.

Figure 4.1 Coal's share in different energy supplies in Denmark, 1975-2015



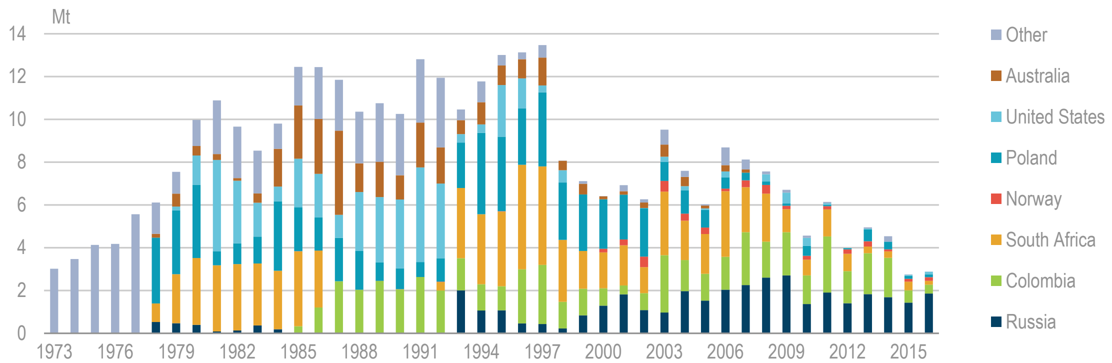
Notes: Data are provisional for 2016. Consumption data are for 2015.
Source: IEA (2017a), *World Energy Balances* 2017, www.iea.org/statistics/.

Supply and demand

Imports

Denmark has no domestic coal production and all coal is imported. In 2016, Denmark imported 2.9 million tonnes (Mt) of hard coal, which represented a decline by two-thirds since 2006. The Russian Federation was the largest source of coal, accounting for 64% of total imports, followed by Colombia (14%), South Africa (6%), Norway (6%), Poland (5%) and United States (4%).

Figure 4.2 Coal supply by source, 1973-2016



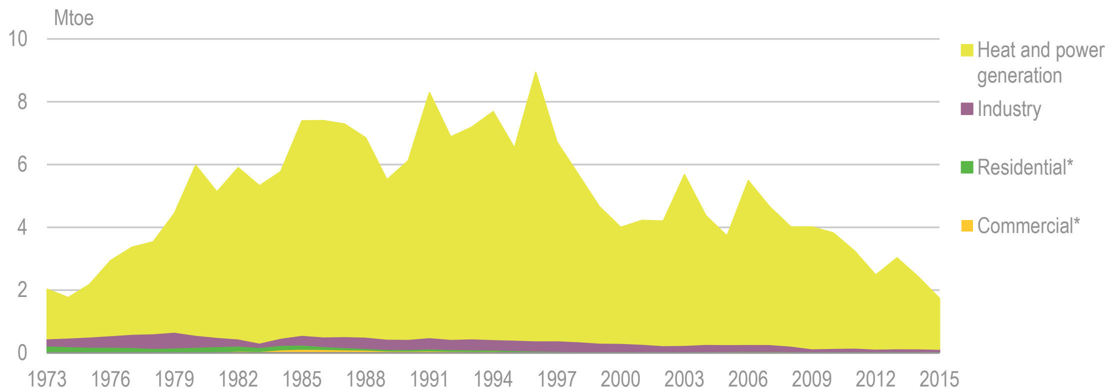
Notes: Data per country not available before 1978. Data are provisional for 2016.

Source: IEA (2017b), *Coal Information* 2017, www.iea.org/statistics/.

Consumption

Almost all coal is used for electricity generation, which has accounted for around 95% of total coal demand over the last two decades. However, in line with the Danish energy target to become independent from fossil fuels by 2050, Denmark's energy mix for power generation has rapidly shifted towards renewable sources. The share of coal in power generation fell from 42% in 2005 to 24.5% in 2015, and accordingly, coal demand and imports decreased considerably. However, the demand for coal varies annually depending on availability of low-cost electricity imports and domestic renewable sources for power generation.

Figure 4.3 Coal consumption by sector, 1973-2015



* Negligible.

Note: Total primary energy supply of coal by consuming sector.

Source: IEA (2017a), *World Energy Balances* 2017, www.iea.org/statistics/.

Coal is also used in industry (5.8% of total demand) and in the commercial sector (1.0%). Over the past ten years, coal use in Industry declined by 54% and in the commercial sector by 43%.

Future demand

DONG Energy, the largest energy company in Denmark and the owner of most coal power plants in the country, announced in February 2017 its decision to stop all use of coal from 2023. In recent years, DONG Energy has converted several coal-fired combined heat and power (CHP) plants into ones using sustainable biomass (wood chips and pellets) and this alone accounts for around half Denmark's greenhouse gas (GHG) emissions reductions since 2006 (DONG, 2017). The government has provided financial incentives for such conversions.

DONG Energy's decision will have a large impact on the future for coal in Denmark. In its *Energy and Climate Outlook 2017*, the Danish Energy Agency uses two scenarios for future demand for coal in Denmark after 2020, based on whether or not DONG Energy's coal-fired plants will continue with other owners. Coal consumption is set to fall by around 30% from 2015 to 2020 in both scenarios. From 2020 to 2030, coal consumption will either decline further to around 50% of the 2015 level (if the power plants stop using coal) or increase to around 20% above the 2015 level as a result of increasing electricity prices and more expensive biomass compared to coal (DEA, 2017).

Assessment

In 2016, coal provided 11.9% of TPES in Denmark. All coal is imported and almost entirely used for power and heat generation. Supply and demand are market-based.

For several years, government policy has been to replace coal use by renewable energy, and total coal use has more than halved over the past two decades. Coal was, until recently, Denmark's largest source for electricity, and still in 2016 generated 28.8% of total electricity generation. The government's efforts to promote wind power have been successful, and wind has now overtaken coal as the primary source of electricity. In recent years, several large coal-fired CHP plants have been converted to biomass ones, also thanks to subsidies, and this trend is set to continue, according to statements from DONG Energy. The government's recent baseline energy scenario, however, is not clear about the trend in coal use after 2020.

In the Nordic electricity market, coal has had an important role, especially in times of low hydropower availability in Norway and Sweden. Coal has helped maintain security of electricity supply, but despite this benefit, reducing its use is consistent with the government´s energy and climate policy. Coal use in Denmark falls under the European Union Emissions Trading Scheme (EU-ETS), and any possible political decision to impose a full phase-out of coal by a specific date should take into account cost efficiency and other considerations to avoid unnecessary stranded costs.

Recommendations

The government of Denmark should:

- Support non-fossil alternatives for coal use in a cost-effective manner.

References

DEA (Danish Energy Agency) (2017), *Denmark's Energy and Climate Outlook 2017*, Copenhagen.

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5. Electricity

Key data

(2016 provisional)

Total electricity generation: 30.1 TWh, -34.0% since 2006

Electricity generation mix: wind 42.5%, coal 28.8%, biofuels and waste 17.9%, natural gas 7.3%, solar 2.5%, oil 1.0%, hydro 0.1%

Installed capacity (2015): 14.0 GW

Peak load (2015): 5.6 GW

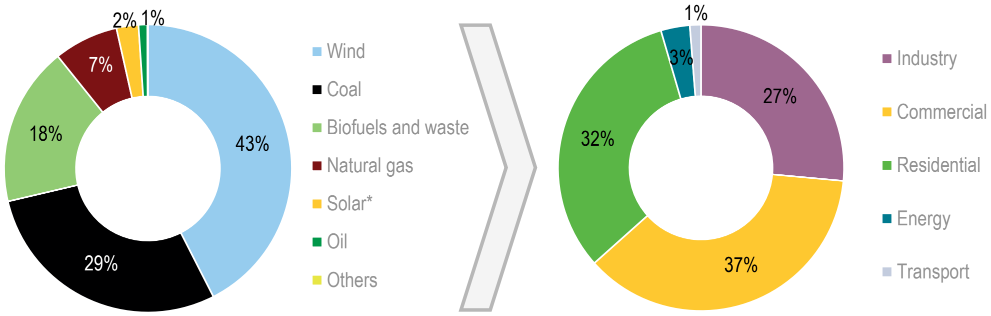
Electricity consumption (2015): 31.7 TWh, -7.3% since 2005; commercial 37.0%, residential 32.1%, industry 26.5%, other energy 3.3%, transport 1.3%

Overview

Denmark's electricity sector has undergone a number of significant changes over the past decade. While total electricity generation has decreased, the share of renewable energy has grown rapidly, accounting for nearly two-thirds of electricity generation in 2016. Wind power made up 42.5% of total electricity generation, the highest share among all IEA countries. Related to this, the share of fossil fuels in power generation has decreased significantly.

Domestic supply is fluctuating year-on-year, but the annual electricity consumption has been relatively stable over the last decade, with declining domestic supply compensated for by increased imports. The commercial sector was the largest electricity consumer, with over a third of total consumption, followed by the residential sector and industry.

Figure 5.1 Electricity generation by source and consumption by sector, 2015-16



*Solar is negligible.

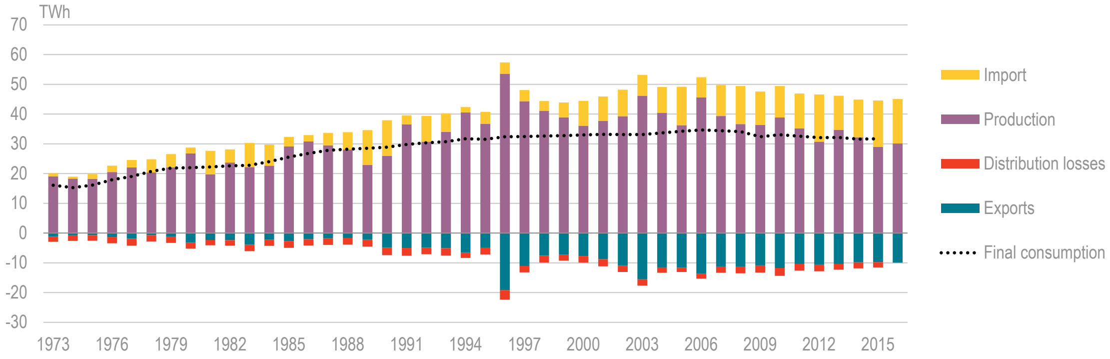
Notes: Consumption data are for 2015. Supply data are provisional for 2016.

Source: IEA (2017a), *World Energy Balances* 2017, www.iea.org/statistics/.

Supply and demand

Denmark balances its variable domestic production with high shares of trade with neighbouring countries. In 2015, the country was a net importer, importing electricity primarily from Sweden and Norway, and exporting primarily to Germany.

Figure 5.2 Electricity production, trade, and final consumption, 1973-2016



Notes: Data are provisional for 2016. Data on final consumption and distribution losses are not available for 2016.
Source: IEA (2017b), *Electricity Information 2017*, www.iea.org/statistics/.

Production

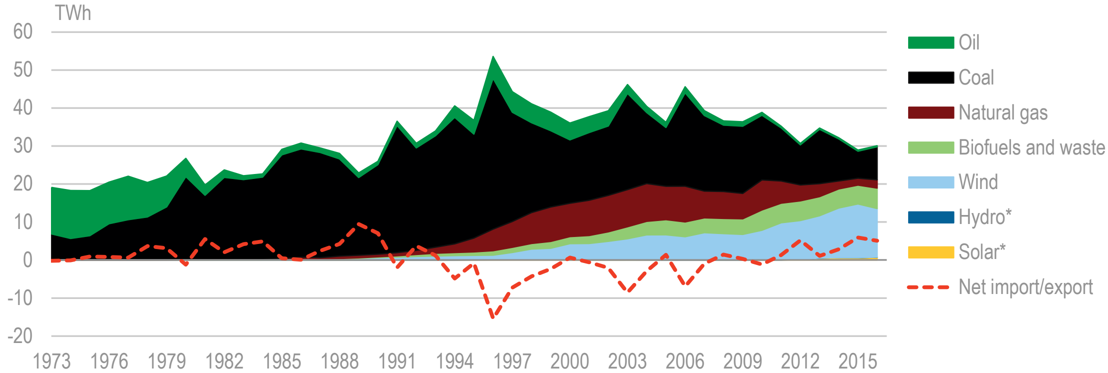
In 2016, Denmark's electricity generation was 30.1 terawatt-hours (TWh), down from 45.6 TWh in 2006. Electricity generated from renewable sources (wind, biofuels and waste, and solar) was 19.9 TWh, accounting for nearly two-thirds of total generation. The share of renewables was slightly lower than the record-high level of 19.7 TWh in 2016 because of limited wind power availability (see Figure 5.3). According to the Danish Wind Industry Association (Weston, 2017), 2016 was the least windy year in the past six years.

Despite large annual fluctuations, the growth of wind energy in electricity generation is noteworthy; it increased from 6.1 TWh in 2006 to 12.8 TWh in 2016, and further growth is expected. The installed wind turbine capacity is projected to increase to 7.8 GW in 2025 from 5.1 GW in 2015; as a result, wind power generation is expected to grow to 25 TWh in 2025 and cover around 60% of Denmark's electricity generation. This makes Denmark a world leader in terms of integrating variable renewable energy into its electricity system. The majority of generation is privately owned.

The growth of solar energy in electricity generation is also substantial, although its overall share remains low compared to wind. Contribution from solar energy grew from insignificant levels in 2005 to 0.7 TWh in 2015. In 2025, the installed photovoltaic (PV) capacity is expected to be around 2.1 GW compared to 783 MW at the end of 2015, and electricity generation from PV is expected to increase to around 1.9 TWh over the same period.

Among IEA countries, Denmark has the seventh-highest share of renewable sources in power generation, and by far the highest share of wind power (see Figure 5.4).

Figure 5.3 Electricity generation by source, 1973-2016

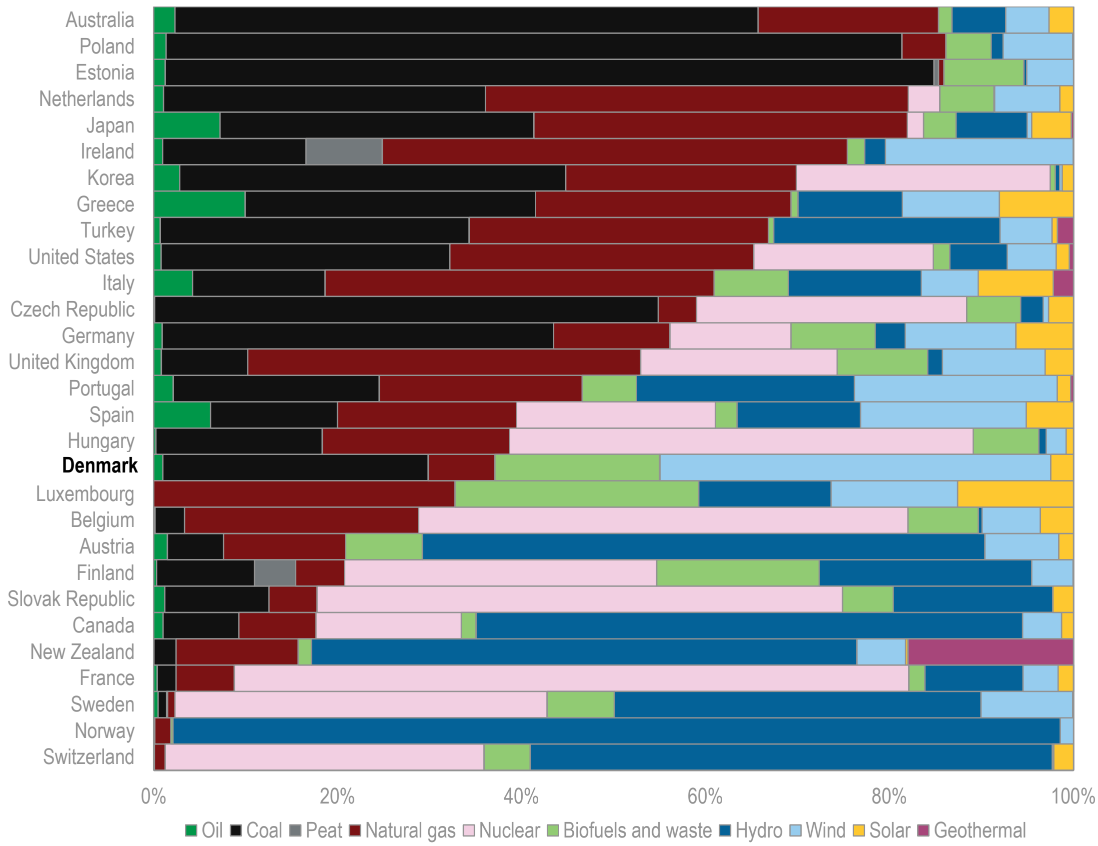


*Negligible.

Note: Data are provisional for 2016.

Source: IEA (2017a), *World Energy Balances* 2017, www.iea.org/statistics/.

Figure 5.4 Electricity generation by source in IEA member countries, 2016



* Estonia's coal represents oil shale.

Note: Data are provisional.

Source: IEA (2017a), *World Energy Balances* 2017, www.iea.org/statistics/.

With regard to fossil fuels, coal power has declined substantially in both relative and absolute terms over the last two decades, from over 90% of total generation in the early 1990s to 28.8% in 2016. Continued growth in renewable electricity will further reduce the demand for coal power, but coal is expect to still have a role, especially in dry years when hydro supply in Norway and Sweden is low and in less windy years when domestic wind power generation falls. Coal is used for peaking generation at times when domestic renewable sources with lower marginal costs and lower-cost imports are unavailable, leading to spikes in coal generation. Given Denmark's reliance on a varying quantity of electricity imports and renewable, year-by-year comparisons of the Danish electricity generation mix become less representative, especially for coal power.

The role of other fossil fuels in power generation has also significantly decreased. Natural gas and oil accounted for only 7.3% and 1.0%, respectively, in 2016, compared with 20.6% and 3.5% in 2006. Natural gas generation increased significantly in the 1990s as several combined cycle gas power plants (CCGP) were installed, but declined again in the last decade as a result of competition from renewable energy sources and low-cost imports. There is thus a significant quantity of under-utilised gas power capacity available in Denmark (see Table 5.1).

Total installed capacity has increased from 10.8 GW in 1995 to 14.0 GW in 2015 (Table 5.1). This growth has been driven primarily by investments in onshore and offshore wind, which more than doubled between 2000 and 2015 to reach nearly 5.1 GW.

Table 5.1 Installed electricity generating capacity, 1995-2015 (MW)

Energy source	1995	2000	2005	2010	2015
Coal and coal products*	451	9	6	6	4
Natural gas and gas works gas	782	1 533	1 503	1 491	1 716
Liquid fuels, including refinery gas	1 153	1 904	887	1 371	1 149
Other combustible fuels	96	129	183	208	241
Solid/liquid	6 760	4 743	5 286	4 616	2 507
Solid/gas	88	224	241	244	297
Liquid/gas	357	746	862	653	445
Solid/liquid/gas	527	627	926	1 031	1 782
Total combustible fuels	**10 214**	**9 915**	**9 894**	**9 620**	**8 141**
Hydro	10	10	11	9	7
Wind	599	2 390	3 128	3 802	5 075
Solar photovoltaics	0	1	3	7	782
Total capacity	**10 823**	**12 316**	**13 036**	**13 438**	**14 005**

*Most of coal power capacity is included in the categories Solid/liquid, Solid/gas, and Solid/liquid/gas.

Source: IEA (2017b), *Electricity Information 2017*, www.iea.org/statistics/.

Imports and exports

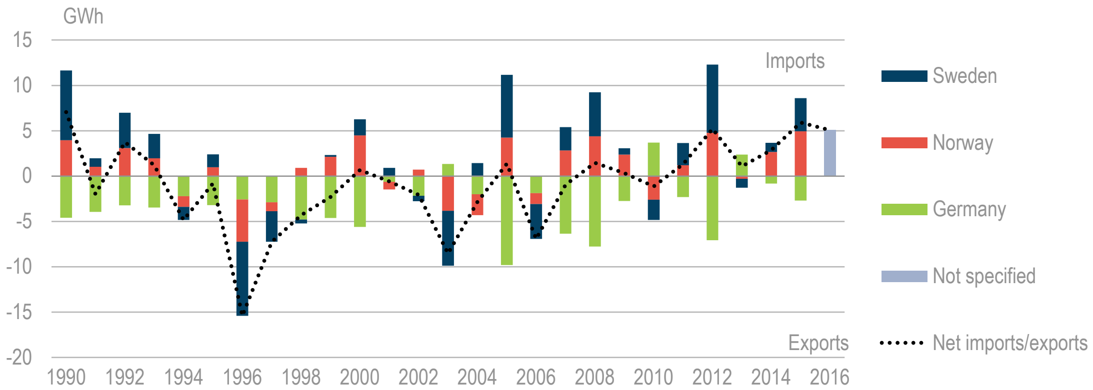
The Danish electricity system has interconnections with Norway, Sweden and Germany, and there is interchange of electricity across the borders every hour. The extent and direction of the interchange (import or export) is determined by the differences in electricity prices between the countries as well as by limitations to capacity on the international connections.

In 2015, Denmark's net import was 5.9 TWh, the highest since 1990, and the net import of electricity covered 17% of total supply (production plus net imports). Denmark was a net importer from Sweden (3.6 TWh) and Norway (5.0 TWh), and a net exporter to Germany (2.7 TWh). In 2012 and again in 2015, record-high electricity generation in both Sweden and Norway as a result of large amounts of available hydroelectric power led to large net imports to Denmark.

Denmark typically has a generation surplus in the winter months, while there is a generation deficit in the summer months. This is largely explained by the fact that combined heat and electricity generation in Denmark is determined by the demand for heat, and by the fact that there generally is more wind during the winter than during the summer. The amount of fluctuating generation from wind and sun has had an increasingly significant impact on the wholesale price level in countries such as Denmark and Germany, and thus also for the exchange of electricity with the surrounding countries.

Further strengthening and expansion of the international connections are expected. Examples of this are the connection to the Netherlands (COBRA) as well as the new connection to Germany through the offshore wind farm at Kriegers Flak (see below the section on Interconnectors for more on this).

Figure 5.5 Electricity trade by country, 1990-2016



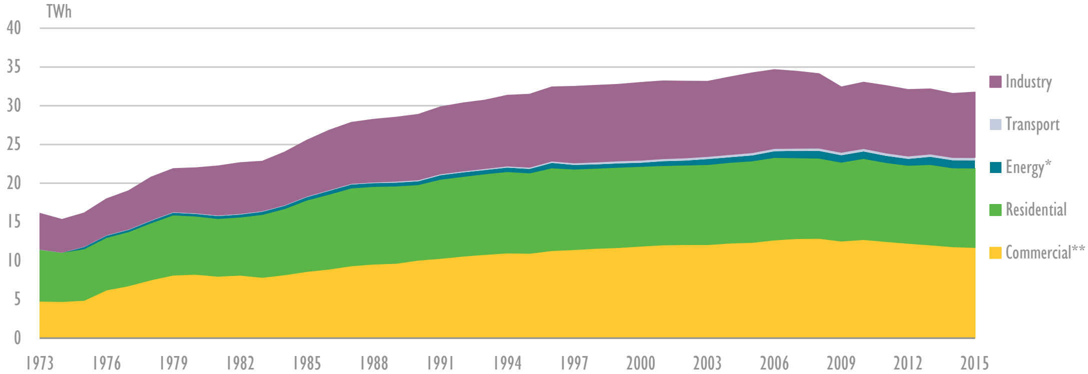
Source: IEA (2017b), *Electricity Information 2017*, www.iea.org/statistics/.

Consumption

Electricity consumption totalled 31.7 TWh in 2015, down from 34.2 TWh in 2005. The commercial sector was the largest electricity consumer, at 37.0% of the total, followed by the residential sector (32.1%), industry (26.5%), other energy (3.3%), and transport (1.3%).

The decline in consumption occurred in nearly all sectors, the only exception being the "other energy" sector. The main contributor to this decline, though, is industrial consumption, which decreased from 10.3 TWh in 2005 to 8.4 TWh in 2015. Industry's electricity consumption fell in 2009 in the aftermath of the financial crisis. Thanks in large part to energy efficiency improvements, consumption has not picked up since.

Figure 5.6 Electricity consumption by sector, 1973-2015



* *Energy* includes energy own-use and the transformation sector.

** *Commercial* includes commercial and public services, agriculture, fishing and forestry.

Source: IEA (2017b), *Electricity Information 2017*, www.iea.org/statistics/.

Institutions and legal framework

Institutions

A number of Danish institutions have some relevance to or authority over electricity policies and planning.

The Danish Ministry of Energy, Utilities and Climate has broad responsibility for policies on energy and climate change, among other topics. It also has authority over a number of relevant departments, agencies and institutions, in particular the Danish Energy Agency (DEA), and Energinet.dk. The minister also appoints the director and the Board members of the Danish Energy Regulatory Authority (DERA) in accordance with EU regulation. However, the DERA acts independently when carrying out their regulatory tasks.

The DEA, under the authority of the Ministry of Energy, Utilities and Climate, is responsible for implementing government policies that relate to all aspects of energy production, transmission and consumption. In the context of electricity, this includes ensuring fair competition in the power sector, protecting consumer rights, and organising renewables tenders, among other things. It also acts as a “one-stop shop” for the permitting of offshore projects, including wind projects.

The DERA is a fully independent regulatory body that oversees the energy market. It regulates the electricity transmission system operators (TSOs) and distribution system operators (DSOs), as well as the wholesale and retail markets, supervises the implementation of the EU network codes, and co-ordinates with the rest of the Nordic regulators through the Nordic Energy Regulators forum, or NordREG.

Energinet.dk is Denmark’s sole TSO. It is fully owned by the Danish government, and is responsible for the entire high-voltage (130 kilovolts and above) transmission network. It is ultimately responsible for ensuring security of supply.

The **Nordic Regional Security Coordinator** (RSC) is a new institution set to open at the end of 2017. It is being established by the four Nordic TSOs.[1] Development of the Nordic

RSC is being driven in large part by the European Network Codes, in particular the System Operation Guideline, which is part of the Third Energy Package.[1] In addition, however, the Nordic countries see the RSC as a tool for enhancing co-operation among the TSOs. The Nordic RSC will have five primary responsibilities: developing and managing a common Nordic data model; performing optimised transmission capacity calculations; performing a common security analysis; outage co-ordination; and short- and medium-term adequacy forecasting. This role may evolve, however, depending on the outcome of negotiations of the "Clean Energy Package", currently in draft.

Legal framework

Denmark's **Energy Strategy 2050** lays out the long-term goal of achieving 100% independence from fossil fuels in the energy mix by 2050. This goal has since changed to becoming a "low-carbon society", though the principles remain essentially the same. In particular, the Strategy sets a 2050 goal of having 100% of electricity generated from renewable sources.

The **2012 Energy Agreement** set out the energy framework for the period 2012 to 2020. It followed the previous "Green Growth Agreement", which covered 2010 to 2012. The 2012 Energy Agreement covers all energy sectors and includes a number of targets of partial or direct relevance to electricity, including: achieving more than 35% renewable energy in final energy consumption; increasing the share of wind power in electricity consumption to approximately 50%; and reducing gross energy consumption by 7.6% below its level in 2010 (EFKM, 2012). This agreement expires in 2020, and a new agreement is being prepared.

Also in 2012, Denmark passed the **regulation on net metering**, which exempts self-production of energy from tariffs, duties and the value-added tax (VAT) for all electricity injected into the grid. Net metering is limited by size and only applies to generation fully owned by the consumer and installed at the point of consumption.

One of the more critical recent developments is the **agreement to phase out the public service obligation (PSO)**. The PSO is an additional levy applied to the retail tariff, on top of taxes and other charges, that has in recent years been the primary funding source for the renewables support schemes. Between 2017 and 2022 the PSO is being phased out and is being replaced with renewables funding from the general state budget.

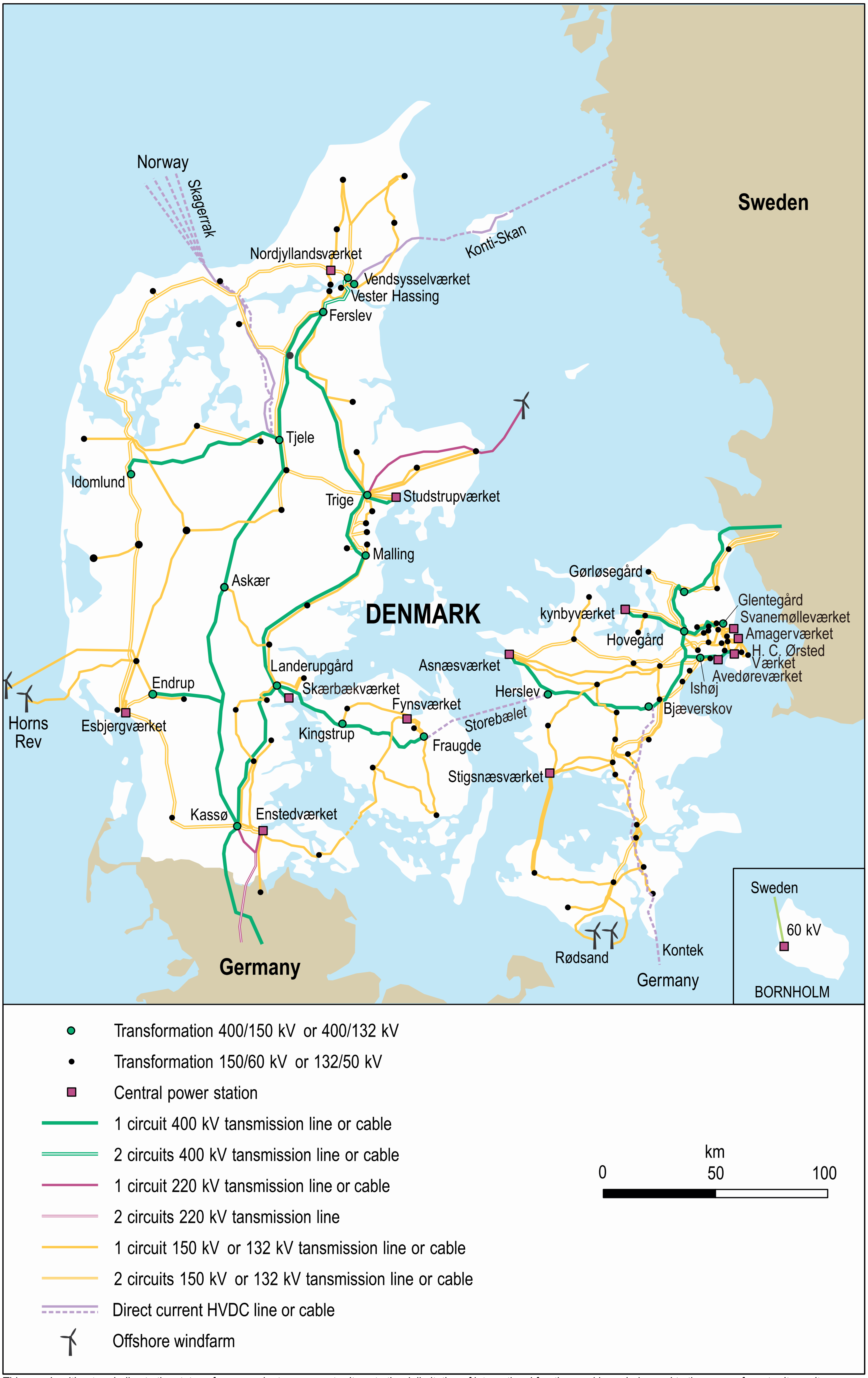
Transmission and distribution systems

Transmission system

Energinet.dk owns and operates the entire Danish transmission system, consisting of 132 kV lines and above. There are currently 6 913 km of transmission lines in Denmark. Congestion is managed through a process developed jointly with the other three Nordic TSOs.

[1] The System Operation Guideline actually encompasses three network codes: Operational Planning and Scheduling (NC OPS), Operational Security (NC OS), and Load Frequency Control and Reserve (NC LFCR). Although the Guideline has been adopted, it has not yet been formally approved by the European Parliament. Still, many regions have moved forward with the development of RSCs, including the Nordic region.

Figure 5.7 The Danish electricity transmission system

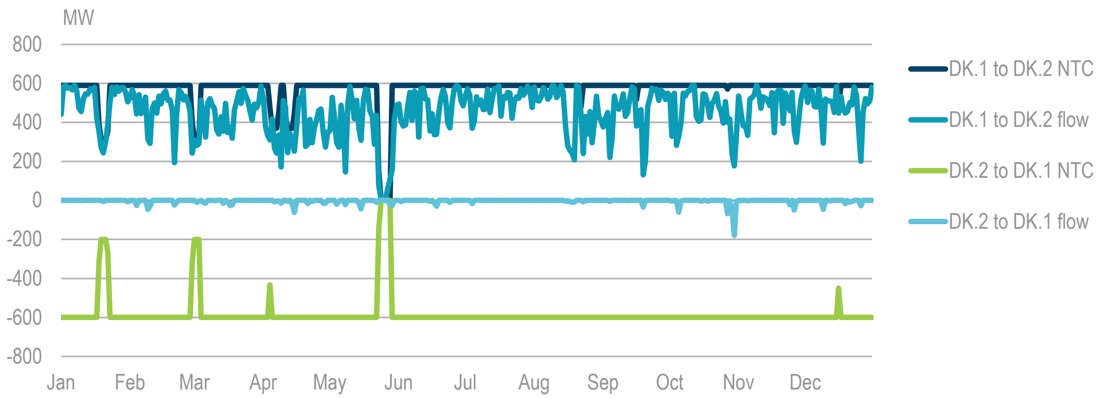


This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

The Danish transmission system is somewhat unusual in that it is divided into two distinct grids: DK.1, or the western grid, which covers Jutland and Funen, and DK.2, or the eastern grid, covering the islands of Zealand and Bornholm. Energinet.dk is responsible for both grids but they are operationally distinct. DK.1 is synchronised with Germany and the rest of continental Europe, while DK.2 is synchronised with Sweden and the rest of the Nordic region. The only direct interconnection between DK.1 and DK.2 is the Great Belt Power Link, a 400 kV direct current line with a capacity of 600 megawatts (MW).

Relative to local demand, generating capacity within DK.2 is tighter than capacity within DK.1. For example, in 2016, total production in DK.1 was 19.3 TWh, compared to 19.1 TWh of electricity consumption – or enough to meet demand on average. In DK.2, total production was 8.0 TWh compared to 13.1 TWh of electricity consumed (Nord Pool, 2017). DK.2 is nearly always a net importer of power from DK.1. For example, in 2016, DK.2 imported from DK.1 96% of the time (Figure 5.8). At the same time, the relatively limited capacity of the Great Belt Power Link means that this interconnection between DK.1 and DK.2 is often constrained. In 2016, the thermal limit of the Great Belt interconnector was reached 32% of the time, and 52% of the time flows were within 5% of the limit (Energinet.dk, 2017a).

Figure 5.8 Daily average power flows between DK.1 and DK.2, 2016



Note: NTC = Net transfer capacity.

Source: Energinet.dk (2017), *Market Data*.

Every year Energinet.dk develops a new transmission system development plan. The most recent one was published in December 2016. It also collaborates on the development of regional transmission planning and contributes to the Ten-Year Network Development Plan (TYNDP) process organised by the European Network of Transmission System Operators for Electricity (ENTSO-E).

One of the most significant domestic transmission projects currently under consideration is a 95 km, 400 kV reinforcement of the grid between Endrup and Idomlund in DK.1. This upgrade is important in particular to allow for increased wind development (Energinet.dk, 2017b), and is linked to a separate project – the proposed DC Viking link to the UK – that is also under consideration. In addition, Energinet.dk has noted that a significant portion of its 132/150 kV grid is nearing the end of its operating life (Energinet.dk, 2016a). Spare parts for the relevant equipment can be hard to find, and therefore much or all of the ageing infrastructure will likely need to be replaced.

Energinet.dk also develops a series of long-term scenario forecasts, based on a forecasting framework developed by ENTSO-E. This exercise covers four different scenarios: *Moderate Nations*, which assumes limited co-operation among EU member states and weak progress on climate; *Moderate Europe*, which assumes stronger collaboration among EU members but still weak progress on climate; *Green Nations*, which assumes weak collaboration but strong national progress on climate; and *Green Europe*, which assumes strong EU collaboration and strong progress on climate (Energinet.dk, 2016b). These scenarios are distinct from the grid planning exercise; they are by nature more detailed, but they do feed into the grid planning process, in particular by offering a broader range of possible futures to compare the grid plan against. In 2017, the responsibility for the long-term scenarios will be transferred from Energinet.dk to the Danish Energy Agency.

Distribution system

Denmark has approximately 160 000 km of distribution lines which are owned and operated by 49 distribution system operators (DSOs). DSOs in Denmark have been unbundled since 2004. There are around 3.3 million distribution customers. DSOs in Denmark are relatively small, with on average just over 54 000 customers.

DSOs have historically been regulated by DERA under a revenue cap model, whereby revenues are fixed every year on the basis of the "regulatory price" of electricity distribution multiplied by the expected volume of electricity transported in kilowatt-hour terms. The cap is also adjusted to allow for necessary new investments, but generally aims to ensure that tariffs do not, on average, rise above the tariff in 2004. In addition, DERA caps the allowed rate of return on grid assets.

The cap may also be adjusted to reflect expected costs compared to a baseline estimate for the entire industry group. For example, in 2015 DERA lowered the revenue cap by around EUR 12 million, with the expectation that a lower cap would motivate additional efforts to improve efficiency (DERA, 2016).

Starting in 2018, DERA will move to a new, enhanced regulatory model developed by the DEA with input from the DSOs, DERA and consumers. While based on the revenue cap model, the new regulatory model will include an explicit incentive for efficiency improvements, a cap on returns from historical investments, future investments returns set according to a market-based weighted average cost of capital (WACC), and a reduction in the cap should the "quality of supply" decline (for example an increase in the number of outages).

In addition, a model allowing for more variation in how tariffs are set, in particular opening up the possibility to apply time-of-use (TOU) tariffs for all customers, has been introduced. Initially this would only be based on expected demand, as real-time access to consumption data is not available. This may change, though, as smart meters become more widely installed.

The new model also includes an additional "availability" tariff. This is aimed specifically at consumers who install distributed generation, for example rooftop solar photovoltaics (PV). The purpose is to ensure that consumers pay for their share of the grid costs, even if they do not utilise the grid 100% of the time. For large producers this tariff would be calculated on a case-by-case basis, but for small consumers (households) the tariff would be fixed and applied equally to everyone.

Though the model will not be in full force until 2018, DSOs can elect to move to the new model ahead of that date, with DERA's approval. As of 2016, 30 DSOs have done so.

Interconnectors

There are currently six cross-border interconnectors: three with Sweden (one from DK.1, and two from DK.2: Zealand and Bornholm); two with Germany (one from DK.1 and one from DK.2); one between DK.1 and Norway (Figure 5.9). There is also the internal Great Belt cable between bidding zones DK.1 and DK.2. Energinet.dk co-owns interconnectors with the relevant neighbouring TSO.

In total, these lines provide 6.4 gigawatts (GW) of export capacity and 5.7 GW of import capacity – more than enough to cover Denmark's typical peak demand. In addition, around 2.0 GW of new interconnections are under construction, and an additional 2.4 GW are under consideration (Table 5.2). Denmark's significant interconnector capacity is unusual. To put this in context, among the countries Denmark is already connected to or is considering developing interconnections with, the second-highest level of interconnector capacity relative to peak demand is in the Netherlands, at 40% (EFKM, 2016).

Table 5.2 Interconnector capacity and net transfer capacity

Existing interconnectors	**Nominal capacity (MW)**	**NTC in MW (% of nominal)***
East Denmark (DK.2) – Sweden**	Export: 1 700 Import: 1 300	1 539 (90.5%) 1 245 (95.8%)
East Denmark (DK.2) – Germany (Kontek)	Export: 585 Import: 600	542 (92.5%) 568 (94.7%)
West Denmark (DK.1) – Sweden (Konti-Skan)	Export: 740 Import: 680	536 (72.4%) 528 (77.6%)
West Denmark (DK.1) – Norway (Skagerrak)***	Export: 1 632 Import: 1 632	1 407 (86.2%) 1 333 (81.7%)
West Denmark (DK.1) – Germany	Export: 1 780 Import: 1 500	235 (13.2%) 864 (57.6%)
Under construction		
West Denmark (DK.1) – Netherlands (COBRA)	Export: 700 Import: 700	-
West Denmark (DK.1) – Germany	Export: 860 Import: 1000	-
East Denmark (DK.2) – Germany (Kriegers Flak)	Export: 400 Import: 400	-
Being investigated		
West Denmark (DK.1) – UK	Export: 1 400 Import: 1 400	-
West Denmark (DK.1) – Germany	Export: 1 000 Import: 1 000	-

* Data for 2015.
** This does not include a 60 MW interconnection between Bornholm Island and Sweden.
*** This includes 100 MW of capacity that is reserved for balancing purposes.
Source: DERA (2016), *National Report Denmark 2016.*

While additional transmission capacity is planned between Denmark and Germany, internal transmission constraints within Germany often prevent Denmark from fully taking advantage of the capacity that already exists. For example, though the export capacity between DK.1 and Germany is rated at 1 500 MW, in 2015 the actual export net transfer capacity (NTC) was only 235 MW, or 13.2% of the total. Import NTC was 864 MW, also significantly below the rated capacity of 1 650 MW.

Denmark and Germany recently agreed to a new plan aimed at improving trade between the two countries (EFKM, 2017). While the long-term solution still requires investing in additional grid capacity in Germany, in the near term Denmark and Germany have agreed to regular, incremental increases in the minimum available NTC (Table 5.3). In the event grid constraints make it impossible to meet the minimum NTC, Denmark and Germany will use countertrading to reduce grid constraints until the minimum is reached.

Kriegers Flak represents something of a new model for interconnector development in Europe. Rather than acting solely as a transit path for power to and from Denmark and Germany, Kriegers Flak connects a planned 600 MW offshore wind farm to both the Danish and German power systems. This means that, when operating, the wind farm can sell power into either the German or Nord Pool wholesale markets, depending on market conditions, and, when the wind farm is not operating, it can serve as additional interconnector capacity between DK.2 and Germany.

Day-ahead interconnector capacity is allocated on an implicit auction basis as part of the Nord Pool wholesale market (see wholesale market section below), which is in turn part of the multi-regional coupling (MRC) effort now covering 19 countries, or about 85% of European power consumption. In addition, some of the day-ahead interconnector capacity between Denmark and Germany is auctioned off as physical transmission rights on a monthly and annual basis.

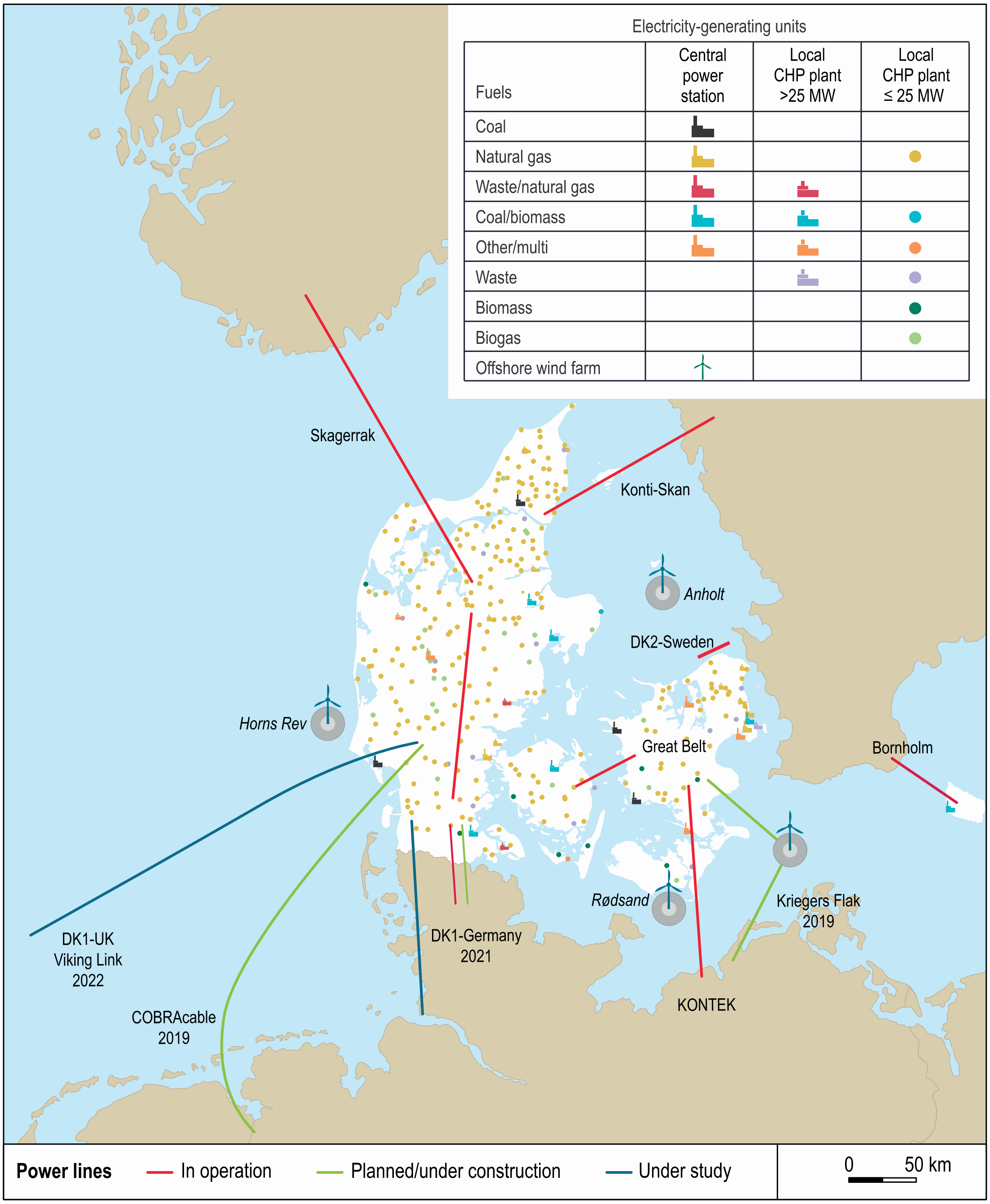
Table 5.3 Schedule of Denmark-Germany border NTC increases

Period	Minimum NTC (MW)
November 2017 – December 2017	400
January 2018 – December 2018	700
January 2019 – March 2019	900
April 2019 – December 2019	1 000
January 2019 – March 2019	1 100

Source: EFKM (2017), *Denmark and Germany agree on increasing electricity trade between their countries (press release)*.

Most intraday capacity is also allocated on an implicit basis. The exception is the interconnector between Denmark and Germany, which is instead allocated through an explicit auction process. This should change as part of the cross-border intraday project, which, in line with the Framework Guidelines on Capacity Allocation and Congestion Management (CACM), will ensure that all intraday interconnector capacity is allocated on an implicit basis (Nord Pool, 2014).

Figure 5.9 Interconnectors that exist, are planned or are under study



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Source: Energinet.dk (2017).

Both DK.1 and DK.2 are on average net importers of power. However, the level and direction of flows vary significantly depending on the interconnector in question. As Table 5.4 shows, in 2016 DK.1 was a net importer of nearly 5.1 TWh from Norway and more than 2.3 TWh from Germany, while at the same time it was a net exporter to Sweden of nearly 3.4 TWh. In DK.2, on the other hand, Denmark was a net importer from Sweden of 1.2 TWh and a net exporter to Germany of less than 0.2 TWh.

As these figures suggest, Denmark often acts as a transit country for power flows between the Nordic region and the rest of Europe. Moreover, because of the high levels of constraints across the Great Belt Link, it is likely that there are occasions when Denmark is exporting and re-importing power to and from Sweden. Again looking at 2016, in hours where DK.1 was exporting to Sweden, DK.2 was importing from Sweden 44% of the time. During these same hours, the Great Belt Link was completely constrained 10% of the time.

Table 5.4 Net imports/exports for DK.1 and DK.2, 2016

Interconnector	Net flow (GWh)*	% of hours importing
DK.1 and Norway	5 058	73%
DK.1 and Sweden	- 3 399	13%
DK.1 and Germany	2 311	27%
DK.2 and Sweden	1 245	41%
DK.2 and Germany	- 158	57%

* A positive value means net imports.
Source: Nord Pool (2017), *Historical Market Data,*

Electricity markets

Wholesale market

Denmark participates in the Nord Pool wholesale market, along with the other Nordic countries and the three Baltic states, Estonia, Latvia and Lithuania. Nord Pool is fully owned by the seven member TSOs, with Energinet.dk owning an 18.8% share. Nord Pool has two physical markets: Elspot, the day-ahead market; and Elbas, the intraday balancing market. Denmark joined Elspot in 2000 but, because of its split grid, it joined the Elbas in phases. Eastern Denmark (DK.2) joined in 2004, while western Denmark (DK.1) joined in 2007.

The vast majority of trading occurs in the Elspot market. In 2016, 373 TWh was cleared in Elspot for the entire Nord Pool region, nearly the same volume as in 2015. The volume of Elspot purchases in Denmark was 31.2 TWh, while Elbas purchases in Denmark were only 0.9 TWh.

Nord Pool is the only power exchange currently active in the Nordic region, though this could change as, under the EU network codes, additional power exchanges must be allowed access to EU markets.

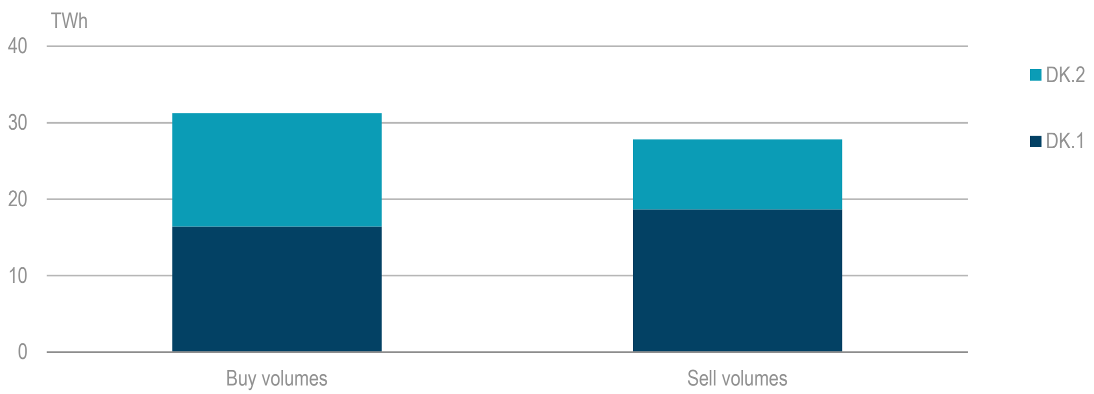
Denmark, along with the rest of the Nordic region, is part of the MRC, and coupled to large parts of Europe. This means, among other things, that wholesale prices in Nord Pool and the majority of Europe should accurately reflect the expected direction of power flows. It also means that developments in markets across Europe can have an impact on wholesale prices in Denmark and in the Nord Pool region more broadly. In 2015, Denmark also designated Nord Pool as the nominated electricity market operator (NEMO), making it responsible for day-ahead and intraday market coupling operations in both zones.

As noted above, Denmark tends to be a net importer of power, and this was again the case in 2016. The picture differs, though, between the western and eastern parts of the country. In DK.1 Denmark was a net seller of electricity, with 19 TWh of sales compared to 16 TWh of purchases. In DK.2, on the other hand, Denmark bought 15 TWh but sold only 9 TWh.

Because of the structural congestion between DK.1 and DK.2, wholesale prices between the two zones often diverge, generally in the direction of higher prices for DK.2. In 2016, prices were higher in DK.2 in 42% of hours and equal in 52% of hours. Prices in DK.1 were higher in only 1% of hours.

Wholesale prices in Denmark tend to be higher than in the rest of the Nordic region, but lower than prices across the rest of continental Europe. For example, in 2015 the average price in Denmark was EUR 23.7/MWh, compared to a Nord Pool average price of EUR 21.0/MWh and an average EPEX SPOT[2] price of EUR 31.7/MWh (DERA, 2016). This is due primarily to Denmark's geographic position, sitting between relatively inexpensive hydro in Norway and relatively more expensive thermal generation across the rest of the continent.

Figure 5.10 Elbas buy and sell volumes by zone, 2016 (TWh)



Source: Nord Pool (2017), *Historical Market Data.*

Retail market

Denmark has a fully liberalised retail market, with 74 active retailers. Switching rates, however, have historically been relatively low, especially for customers that consume less than 100 000 kWh/year. Table 5.4 shows the switching rates for the past three years.

Table 5.5 Retail switching rates by consumption level, 2014-16

Size of consumer	2014	2015	2016
Less than 100 000 kWh/year	6.2%	7.2%	6.3%
More than 100 00 kWh/year	11.9%	9.0%	9.8%

Source: Energinet.dk (2017c), *DataHub Market Report.*

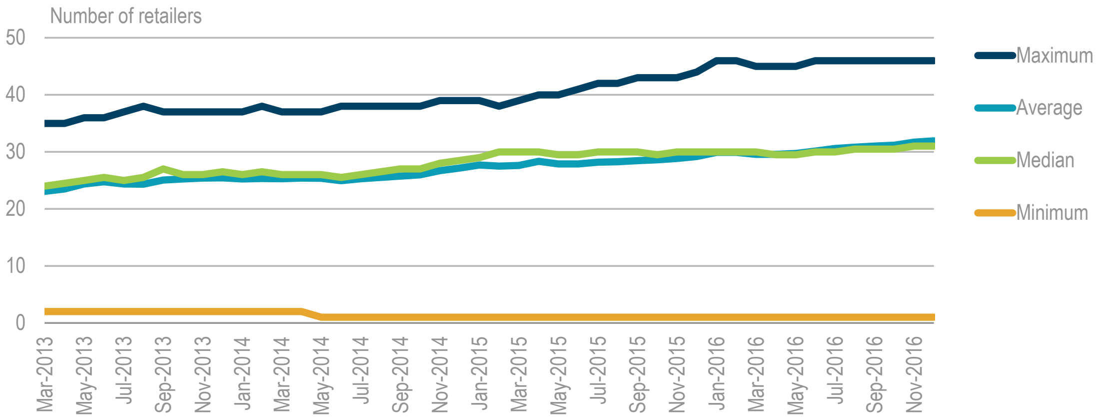
In an attempt to increase retail market competition, Denmark began the process of phasing out the regulated retail prices on 1 October 2014. As part of this phase-out, all

[2] EPEX SPOT manages power exchanges in Germany and Austria, France, the Netherlands, Belgium and Switzerland.

customers who had not chosen to switch supplier were automatically moved to a non-regulated product. As of the end of 2015, more than 90% of customers were on a non-regulated product. Approximately 50% customers, though, were moved because they had not actively switched to a new supplier (DERA, 2016).

With a few exceptions, the number of retailers active in the various distribution territories has increased over the past few years. At the end of 2013, there were on average 23 retailers active in each service territory. By the end of 2016, the average number of retailers had increased to 32, and the maximum had increased to 46.

Figure 5.11 Maximum, minimum, average and median number of retailers across all service territories, 2013-16.



Source: Energinet.dk (2017c), *DataHub Market Report.*

On 1 April 2016, Denmark introduced three additional changes to the retail market. First, DERA took over responsibility for managing a price comparison website[3] intended to give consumers an easy overview of all of the retail products available to them.

Second, the Danish retail sector moved to a "supplier centric model". Under this model, consumers receive a single bill from their supplier, which includes taxes and levies related to the use of the network, as well as the energy price. The retailer is then responsible for distributing the appropriate payments to the DSO and other beneficiaries, and is also responsible for customer contact.

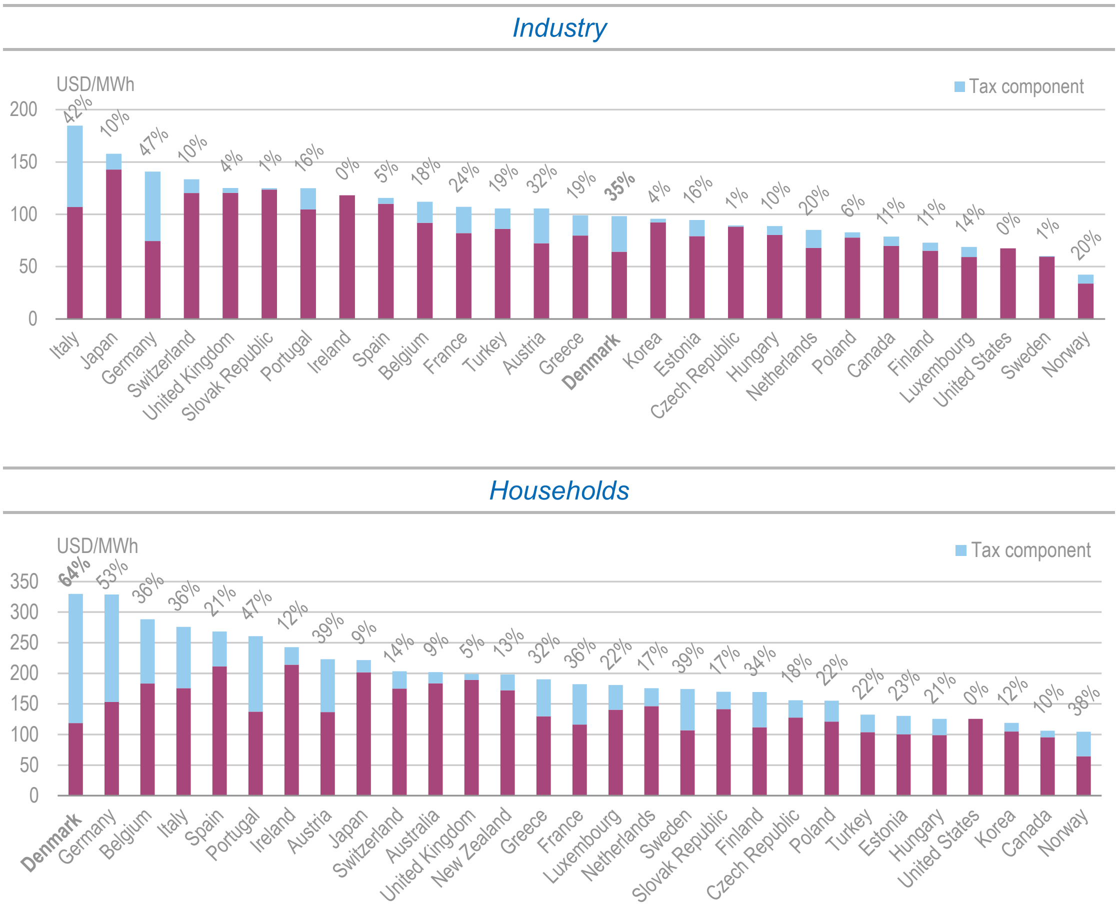
Third, and related to the supplier centric model, Denmark introduced the so-called DataHub operated by Energinet.dk. The DataHub is a single repository for all relevant consumer data on electricity. Customers retain complete ownership of their data, and suppliers must be granted permission to access and use these data. Since April 2016 customers have been able to grant access rights to third-parties. Similar data repositories have been introduced in the other Nordic countries, and in theory these should eventually allow for the development of a common retail market across the region.

[3] Elpris.dk (the price comparison website).

Retail prices

Among the IEA countries, Denmark has the highest electricity prices for households and the highest taxes on household electricity. In 2016, households paid USD 330/MWh on average, of which taxes accounted for 64% (see Figure 5.12). This is the highest share of taxes in Europe, though it will decline with the phase-out of the public service obligation. Taxes are also reduced for consumption above 4 000 kWh for households registered as being heated by electricity. Electricity prices for industrial consumers were significantly lower at 98 USD/MWh, of which taxes accounted for 35%.

Figure 5.12 Industry and household electricity prices in IEA countries, 2016

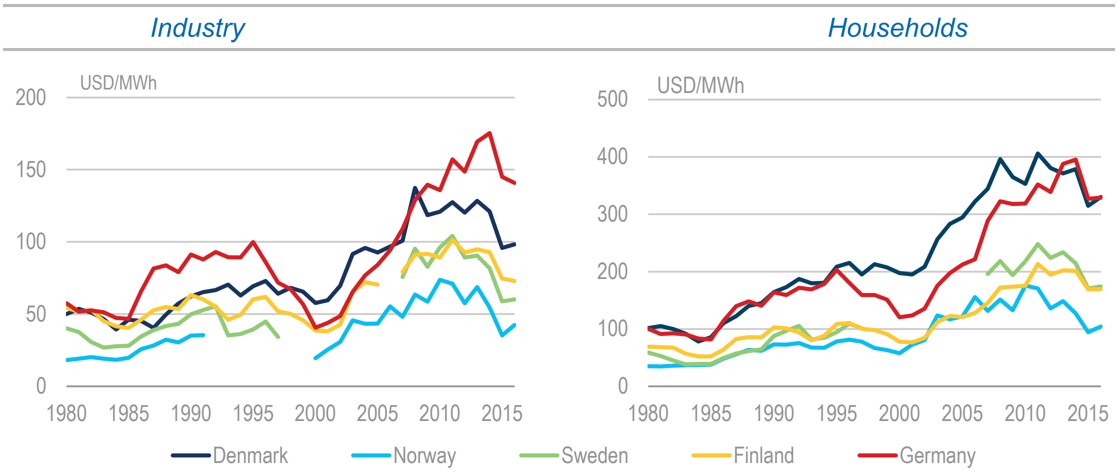


Note: Industry data for Australia and New Zealand, and tax information for the United States are not available.
Source: IEA (2017c), *Energy Prices and Taxes, Third Quarter 2017*, www.iea.org/statistics/.

Given the active electricity trade in the region, Nordic countries follow the same price trend (see Figure 5.13). Danish household electricity prices, however, have historically been higher than in its neighbours, as a result of relatively high production costs and high taxes. In a sharp contrast, Danish consumers pay the highest price in the IEA countries, and Norwegian consumers, who are connected to the same electricity market, pay the lowest price in the IEA comparison. In 2015, Danish household prices fell by 16% compared to the year before, after having more than doubled since 2000.

Through the price comparison website Elpris.dk, consumers can potentially choose from a number of different retail products. The products available depend on the retail suppliers operating in a given region, but generally break down into three categories: fixed price products, variable price products, and "climate" products, or retail options that include particular low-carbon suppliers. Retailers may also offer "temporary" price options, where a more attractive price may be offered for a limited time, after which the customer is automatically switched to a fixed or variable product, depending on the nature of the agreement.

Figure 5.13 Electricity price trends in Denmark and in selected IEA countries, 1980-2016



Note: Industry data are not available for Norway 1992-1999, Sweden 1998-2006, and Finland 2006.
Source: IEA (2017c), *Energy Prices and Taxes, Third Quarter 2017*, www.iea.org/statistics/.

Security of supply

The Danish power system is one of the most reliable in Europe. In 2015, Denmark had only 48 seconds of non-supplied electricity per client from transmission grid outages, 12 seconds less than its target of 60 seconds, though a slight increase from 2014, when it was only 41 seconds (Energinet.dk, 2016a). This is due in large part to the fact that distribution lines are generally buried. Though more expensive than lines installed above ground, underground lines are significantly less likely to go out of service because of weather-related issues. Very few of the outages occurred at the high-voltage level, suggesting no negative impact of increased variable renewable energy (VRE) penetration on reliability.

In terms of resource adequacy, Denmark's installed capacity of 14 GW is well above its peak load requirement of 5.6 GW, suggesting the country's significant capacity surplus. The figure becomes even more striking considering that there is also 5.7 GW of import capacity. This statistic, however, is somewhat misleading as there are both physical and economic constraints on how often Denmark's generation can operate.

The most pressing area of concern for Energinet.dk when it comes to near-term resource adequacy is DK.2. Generating capacity within DK.2 is limited, and is at times dependent on imports to meet peak demand needs. In 2015 Energinet.dk attempted to resolve this problem through the development of a strategic reserve, but its tendering proposal was found to be in violation of state aid rules by the European Commission, and so was struck down (Energinet.dk, 2016a).

Current efforts to address this adequacy concern focus on prioritising the development of new assets and the renovation of those assets that contribute to or help reduce resource adequacy needs. Over the long term, however, Energinet.dk expects a reduction in the amount of available dispatchable generation, and so continued reliance on interconnectors is likely in any case. To this end, Energinet.dk is also working on increased co-ordination with neighbouring TSOs to limit interconnector constraints.

Despite making up only 36% of installed capacity, wind produces nearly 50% of Denmark's generation. With average capacity factors of around 32%, the fact that wind makes up such a large share of total generation suggests that a significant amount of non-wind capacity lays idle.

This is certainly the case for natural gas generation. Between 2004 and 2015, natural gas generation declined from 9.8 TWh (its historical peak) to 1.8 TWh (its lowest level in absolute terms in more than 20 years). In terms of capacity factor, the natural gas fleet operates on average only 12% of the time.

The low levels of natural gas-fired generation relative to installed capacity suggest that much of the fleet is uneconomic. This excess capacity remains in large part available because of a capacity subsidy provided by the Danish government. This subsidy is due to expire in 2019, after which it is likely that much or all of the excess natural gas capacity will be retired. If this subsidy is not replaced by either a new subsidy scheme or some kind of capacity mechanism, incentives for ensuring resource adequacy will come primarily from Nord Pool, the energy-only wholesale market.

Though Nord Pool prices can be volatile, price spikes have been rare since Nord Pool was founded in 1996 (Norden, 2016). Prices in the day-ahead market have been capped at EUR 3 000/MWh since 25 November 2013, an increase from the previous cap of EUR 2 000/MWh (Nord Pool, 2013). The EUR 2 000/MWh cap was reached in DK.1 in two hours on 7 June 2013. Since the cap was raised, the highest price seen was EUR 214.25/MWh, in DK.2 on 1 January 2016.

The most recent Nordic Winter Power Balance Forecast, covering the period 2016-17, found that, for the Nordic region as a whole, peak demand under a one-in-ten winter scenario would have reached 72 100 MW (ENTSO-E, 2016a). This is above the assumed available installed capacity of 70 500 MW in the region[4] although that gap could be easily met through imports.

Under these same assumptions, peak demand in Denmark would have reached 6 100 MW, while available domestic installed capacity would have been only 4 900 MW[5] – a gap of 1 200 MW. The gap would have been particularly tight in DK.2, which, as noted earlier, is more constrained than DK.1. To maintain system reliability, DK.2 would have been completely dependent on imports from DK.1, Sweden and Germany.

It should be emphasised that this represents an extreme scenario. In reality, Denmark's power system experienced no resource adequacy issues over the 2016-17 timeframe.

[4] This figure excludes TSO contracted reserves.

[5] This assumes wind operates under these conditions with a capacity factor of 5%, and no operating solar PV.

A number of studies have examined how Denmark's system would operate during a period of stress. For example, ENTSO-E performs a ten-year resource adequacy assessment for all of Europe, the medium-term adequacy forecast (MAF). The most recent MAF found, under its base case, that Denmark could face resource adequacy issues[6] in 2025 (ENTSO-E, 2016b). This is driven in large part by an assumed decrease in thermal generation that is only partially offset by an increase in renewables. Natural gas capacity is expected to decline from 1 716 MW in 2015 to 1 255 MW in 2025, while coal capacity declines to 380 MW. Net wind capacity, on the other hand, is expected to increase to 6 790 MW, while solar PV reaches 1 140 MW. Interconnector capacity over this time period is forecast to increase to 10 380 MW, while peak demand reaches 6 980 MW.

These findings are broadly supported by Energinet.dk's own analysis, which also found that, if no actions are taken, security of supply will become increasingly dependent on imports, and that, by 2025, DK.1 could be experiencing electricity shortages beyond an acceptable range (Norden, 2016). Analysis by the DEA, meanwhile, found that resource adequacy could lead to power shortages in DK.1 as soon as 2020 (DEA, 2015).

Assessment

Denmark's power system has undergone a remarkable transformation over a relatively short time span. It has moved from a system relying almost entirely on fossil generation to one where more than half of generation comes from renewable sources in only a few decades, without sacrificing the system's reliability in the process. This has been supported in large part by effective grid management and strong regional co-operation with the other Nordic countries.

Denmark's ambitious goals mean this transformation will continue at a rapid pace. The challenges of integrating large shares of wind and solar into the grid will have a profound impact on the power system. These issues are addressed more specifically in Chapter 9 on pushing the limits of variable renewable energy (VRE) integration.

Looking at the power system more broadly, however, there are a few issues that can and should be addressed: first, security of supply may become a pressing issue sooner than later, both as the amount of VRE in the system increases and as the subsidy for natural gas generating capacity expires; second, more can be done to improve competition in the retail sector; and third, retail pricing should be reformed to reduce distortions on the consumer side.

Maintaining resource adequacy during the transition

In pure capacity terms, Denmark has a significant surplus. While a significant amount of this capacity is in the form of weather-dependent renewables, even if the renewables are completely discounted, Denmark has more than enough capacity to meet peak demand needs, and that is before taking into account its (growing) interconnector capacity.

[6] Defined as a loss-of-load expectation (LOLE) in excess of one hour.

However, there are reasons to be concerned that this situation will not last. First, a significant portion of the natural gas fleet lies idle, and only remains in the market because of a subsidy that will expire in 2019. Second, the medium- and long-term goals to increase the share of renewables in the power system imply that the share of VRE in the generation mix will only increase.

Denmark and the rest of the Nordic countries have indicated a preference for energy-only markets. Moreover, Denmark's previous attempt to implement a strategic reserve was stopped after the European Commission's involvement and questioning of the necessity for such a capacity mechanism. It is therefore reasonable to assume that, after the subsidy expires, the electricity wholesale market prices will become the primary driver of investment in new generating capacity.

Economic theory suggests that energy-only markets should be able to encourage sufficient levels of investment to maintain resource adequacy, as long as there is sufficient demand response and price caps are not set too low (IEA, 2016). Demand-side flexibility is limited in Denmark, though this may change in the future, in particular given that flexibility needs will increase as the penetration of VRE in the system rises.

Wholesale prices in Denmark have remained fairly low over the last few years. The surplus of capacity and the availability of low-cost resources from the rest of the Nordic region are almost certainly primary reasons for this. This has been partly driven by divergent approaches to the implementation of renewable energy support schemes, which has distorted investment patterns throughout the region, as well as through Europe more broadly. As a result, wholesale prices have remained well below the price cap since the cap was raised in 2013. As things stand, therefore, there are no price signals from the wholesale market suggesting a need for investment. The more critical question is how prices will respond should most of the natural gas fleet retire. In theory, should resource adequacy become an issue at that point, wholesale prices will increase and price spikes should occur more frequently. So long as the price cap is high enough – that is, so long as it accurately reflects the value of lost load (VOLL), or the price at which consumers would prefer to have their power cut off rather than pay for an additional kilowatt-hour – this, combined with price signals from other markets such as balancing and intraday, should encourage new entry into the market.

While it is not clear today if the price cap is set at the appropriate level, Denmark, along with the other Nordic and eight more countries, did commit in 2015 to eventually removing the price cap completely (IEA, 2017d). Assuming that this is done, however, policy makers are still faced with the challenge of trusting that these price spikes will encourage new entry without unduly burdening consumers with high prices.

In the near term, Denmark's attention would be better focused on removing some of the structural issues that make resource adequacy a concern in the first place. Increasing interconnector capacity is one important step, though, considering the ongoing internal capacity issues in the German grid, it is not clear how much the Kriegers Flak transmission capacity between DK.2 and Germany will help beyond adding an additional 600 MW of offshore wind capacity. Increased collaboration between Energinet.dk and TenneT-Germany is an important step, but it is a second-best solution to resolving the grid constraints in Germany. In addition, the Nordic countries could minimise the impact of their renewable energy sources support programmes by harmonising them across the region.

Energinet.dk does regularly evaluate whether the Great Belt interconnector should be increased; at present there does not appear to be a clear economic rationale for doing so. It is worth asking, however, whether a possible increase in capacity between DK.1 and DK.2 should wait for an economic rationale to emerge, or if security concerns are sufficient to warrant investment in the near term. Increasing interconnector capacity to Sweden could also be considered.

Improving competition in the retail sector

Though consumers do have a number of retailers and retail products to choose from, supplier switching rates suggest there may be room for improvement. In Norway for example, households' switching rate in 2014 was 13%, more than double Denmark's rate of 6.2% in the same year. While there are two distribution service territories where competition is completely absent, in the vast majority of areas consumers have a fair number of retailers to choose from. The low switching rates, therefore, are more likely to have some other cause.

After liberalisation of the retail energy market, incumbent utility corporations were allowed to keep their retail business, albeit unbundled as an autonomous entity, separated from the DSO division of the corporation.

Using a similar name and brand for both retail and distribution operations within the utility corporations may confuse consumers, who may not even realise they are dealing with two separate businesses. This can create a competitive advantage against new entries on the retail energy market. Therefore, the Danish Parliament passed a bill in June 2017 which seeks to enhance competition on the retail market by requiring vertical unbundled companies to apply different brands. Hence, according to the new legislation, a DSO division and a retailer division within the same corporation are not allowed to use the same brand name and logo. The DSO divisions have until the 1st of July 2018 to comply with the new rules.

In this regard, Denmark can and should do more to reduce distortions created by retail tariffs. In practice, retailers have control over a relatively limited portion of the final tariff. Grid charges are determined by the distribution company (subject to regulatory approval), while taxes and the PSO are set by the government. The PSO, as noted earlier, is being phased out over the next few years. Taxes on household consumption, though, remain relatively high. These high taxes reduce the incentive to consume electricity and hinder consumers from switching away from the use of fossil fuels for heating and transportation.

Options for reforming taxes are limited, but some changes are conceivable. Reducing taxes for electric space heating, as is already done, is a good step in the right direction, but could be taken further. For example, the tax on heating could be reduced further to near zero. The way heating consumption is defined could also be more robust – in particular as smart meters are rolled out – by separately metering electric heat. Similar steps should also be considered for new usages, such as electric vehicles and batteries.

Recommendations

The government of Denmark should:

- ☐ Continue to work with Energinet.dk to ensure that power system reliability remains high as the share of variable renewables increases. In particular, ensure that resource adequacy will not become a concern when thermal capacity retires.
- ☐ Promote electrification, in particular in the heat and transport sectors, at a pace consistent with the deployment of renewable energy.
- ☐ Ensure that distribution companies' unbundling is effectively implemented and that incumbent utilities do not abuse their position to limit competition in their service territories.
- ☐ Work to reduce distortions in the retail price by examining ways to reduce the excise tax and by ensuring that the transmission and distribution tariff portion and other levies reflect actual costs, in both level and structure.

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6. Energy and climate change

Key data

(2015)

CO_2 emissions from fuel combustion: 32.0 $MtCO_2$, -34% since 2005

CO_2 emissions by fuel: coal 22.7%, oil 51.2%, natural gas 20.9%, other 5.1%

CO_2 emissions by sector: transport 36.0%, power and heat generation 33.0%, industry 10.6%, other energy industries 6.9%, commercial 6.9%, residential 6.6%

CO_2 (energy-related) intensity per GDP: 0.13 $kgCO_2$/USD GDP PPP (IEA average 0.25)

Overview

Total emissions of greenhouse gases (GHGs) in Denmark amounted to 51.9 million tonnes of carbon dioxide-equivalent ($MtCO_2$-eq) in 2015. Energy-related emissions accounted for 74% of total emissions, followed by the agriculture sector (21%), industrial processes (3%) and the waste sector (2%). Over the past decade, total emissions from all sectors have been reduced by 27%.

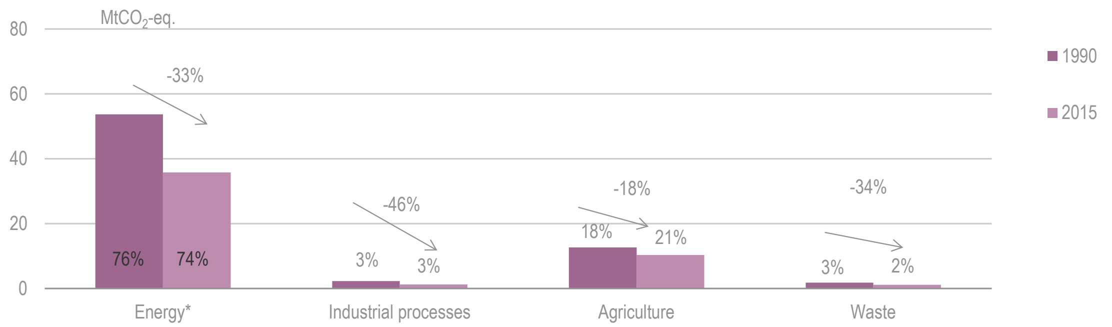
Carbon dioxide (CO_2) is the dominant GHG, accounting for 75% of total emissions (in CO_2-equivalents). Remaining emissions consist of methane (CH_4), nitrous oxide (N_2O), accounting for 14% and 11%, respectively.[1]

Denmark is strongly committed to climate change mitigation and has set ambitious national targets for emissions reductions. Given the dominance of energy-related emissions, targets and policy measures largely focus on the energy sector. Most importantly, the government aims to cover half the energy demand by renewable energy sources by 2030 and become a low-emission society independent of fossil fuels by 2050 (see Chapter 2).

The government has adopted various measures to help reduce emissions, such as supporting renewables and promoting energy savings and energy efficiency. Denmark's participation in the EU Emissions Trading Scheme (ETS) and implementation of EU-driven standards and requirements also contribute to the national efforts.

[1] Source: The Danish 2016 submission to the UNFCCC does not provide information on F-gases (hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride). http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/9492.php.

Figure 6.1 GHG emissions by sector, 1990 and 2015

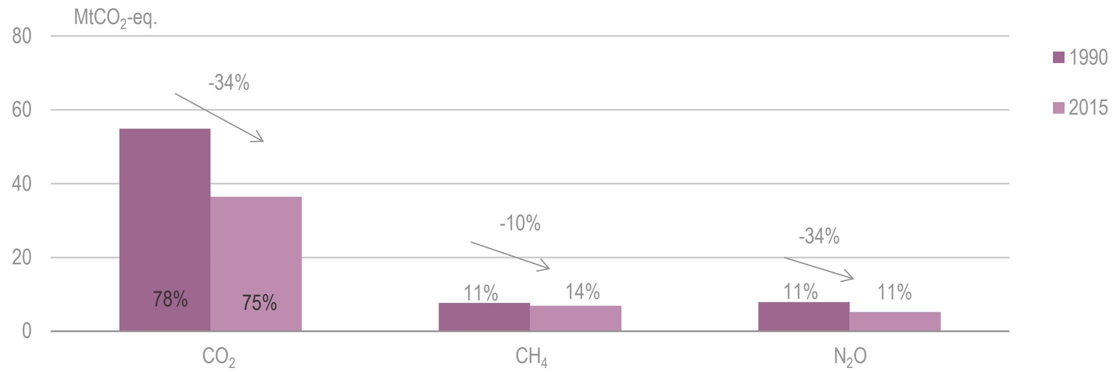


**Energy* includes emissions from transport, manufacturing and construction.

Note: Only carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are included in the calculations.

Source: DCE (2017), Denmark's National Inventory Report 2017, Danish Centre for Environment and Energy, Aarhus.

Figure 6.2 GHG emissions by gas, 1990 and 2015



Source: DCE (2017), *Denmark's National Inventory Report 2017*, Danish Centre for Environment and Energy, Aarhus.

Energy-related CO_2 emissions

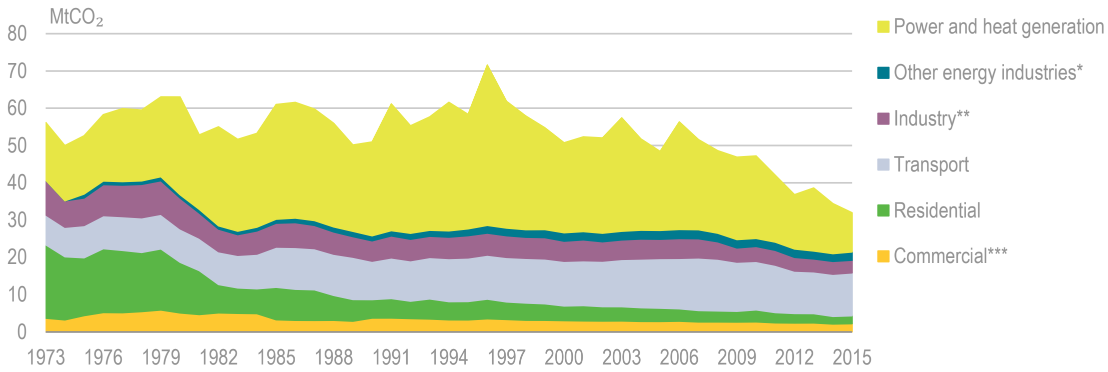
Emissions by sector and by fuel

Denmark's energy-related CO_2 emissions were 32.0 $MtCO_2$ in 2015, a 34% reduction since 2005. Transport (36% of the total) and power generation (33%) were the main emitters in 2015 (see Figure 6.3). The other sectors, namely residential, commercial, other energy and industry, accounted for less than one-third of the total.

Emissions declined in all sectors over the last decade, but most prominently in power and heat production, where they halved. In power generation, emissions were reduced mainly as result of a large increase in wind power generation which replaced carbon-intensive coal and gas power. Over the past decade, the share of renewables increased from 29% to nearly 70% in power generation. Furthermore, total electricity generation declined by 20% over the same period, partly through decreased demand and partly through increased net imports. In heat production, biomass is the main contributor to CO_2 emissions reduction. Heat generated from biomass increased by 58% from 2005 to 2015, and accounts for over half the total district heat generation.

Thanks to this significant emissions reduction, the power and heat generation sector lost its position as the highest emitting sector to the transport sector for the first time in 2015. While power and heat generation accounted for about two-thirds of emissions reductions over the past decade, other sectors also reduced their emissions. The residential sector's emissions were reduced by 41%, industry emissions by 34%, commercial emissions by 21%, transport emissions by 14%, and emissions from other energy industries by 7%.

Figure 6.3 Energy-related CO_2 emissions by sector, 1973-2015



**Other energy industries* includes other transformation and energy own-use.

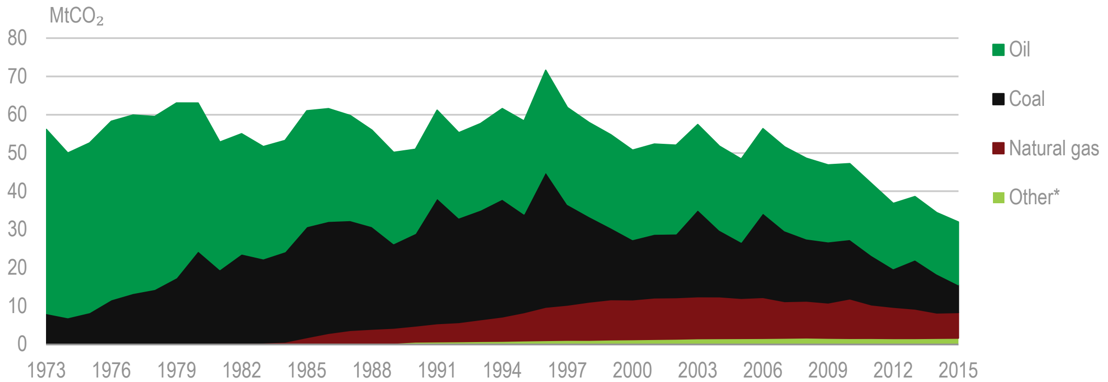
***Industry* includes CO_2 emissions from combustion in construction and manufacturing industries.

*** *Commercial* includes commercial and public services, agriculture/forestry and fishing.

Source: IEA (2017), *CO_2 Emissions from Fuel Combustion 2017*, www.iea.org/statistics/.

In 2015, oil accounted for more than half total energy-related CO_2 emissions, followed by coal (22.7%) and natural gas (20.9%). As a large share of fossil fuels in total primary energy supply (TPES) was replaced by renewables, emissions from all fossil fuels decreased over the past decade. Emissions from coal declined most, by 51%, those from natural gas by 36% and those from oil by 24%.

Figure 6.4 Energy-related CO_2 emissions by fuel type, 1973-2015



**Other* includes emissions from combustion of non-renewable municipal waste.

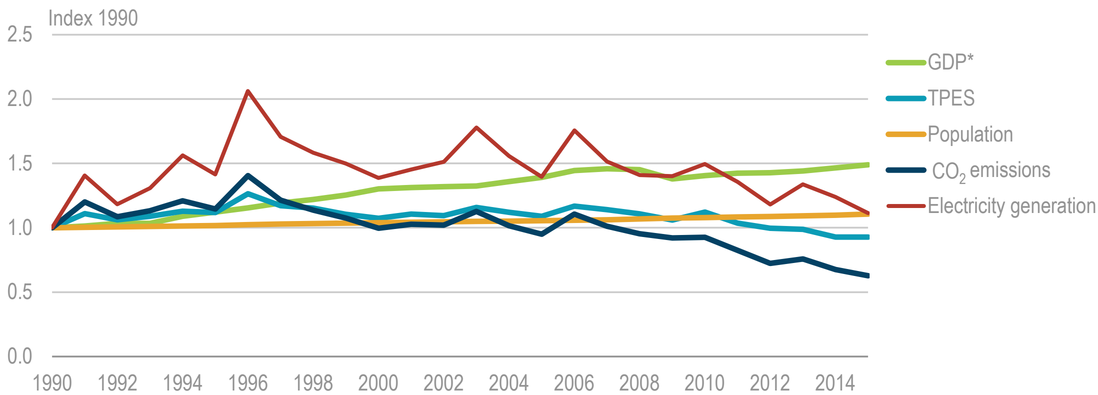
Source: IEA (2017), *CO_2 Emissions from Fuel Combustion 2017*, www.iea.org/statistics/.

ENERGY SYSTEM TRANSFORMATION

Carbon intensity

Denmark has decoupled economic growth from carbon emissions. From 2005 to 2015, the country's GDP adjusted for purchasing power parity (PPP) grew by 7%, but energy-related CO_2 emissions declined by 34% (see Figure 6.5).

Figure 6.5 CO_2 emissions and main drivers in Denmark, 1990-2015

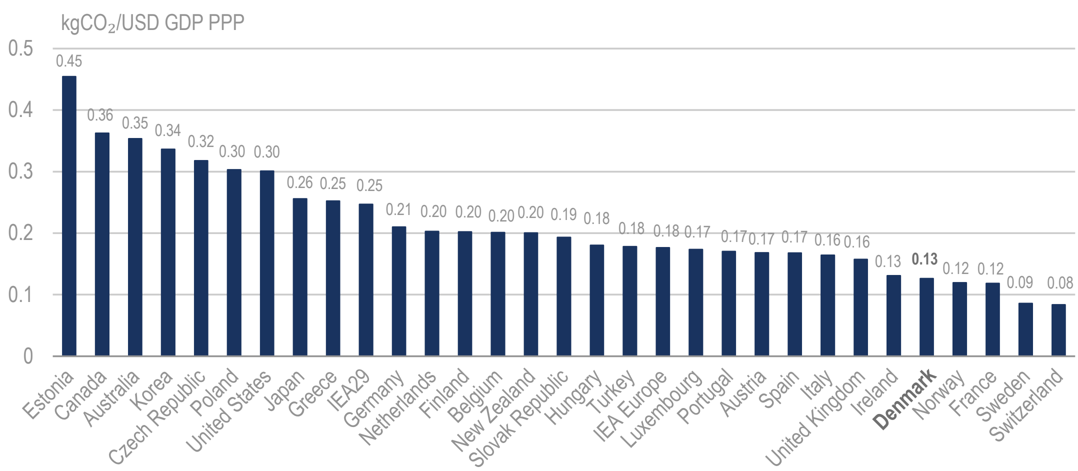


*Real GDP in USD 2010 prices and PPP.

Source: IEA (2017), *CO_2 Emissions from Fuel Combustion 2017*, www.iea.org/statistics/.

Carbon intensity, measured as the ratio of emissions[2] per unit of GDP, is used as a common indicator to compare the impact of economies on climate. In 2015, Denmark's carbon intensity was 0.13 CO_2 per GDP PPP (kilogram of CO_2 per 2010 US dollar), a decline by 38% from 2005. This is the fifth-lowest carbon intensity among the IEA countries, after Switzerland, Sweden, France and Norway (Figure 6.6).

Figure 6.6 Energy-related CO_2 emissions per unit of GDP in IEA member countries, 2015



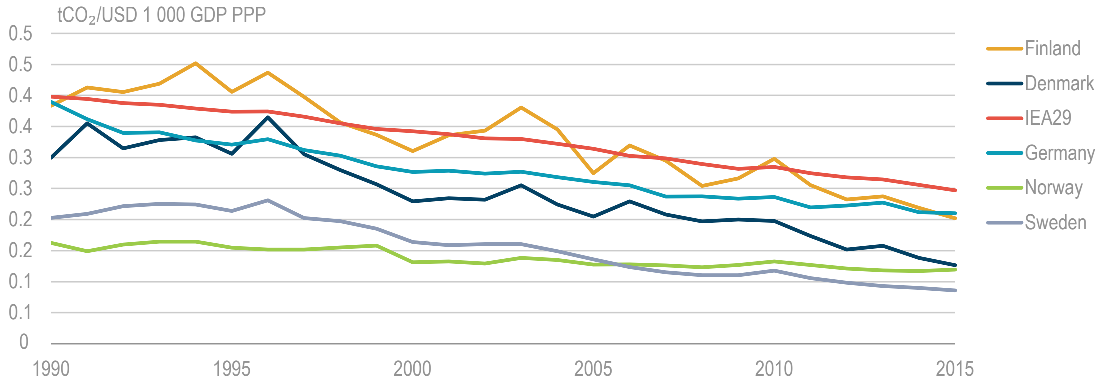
Source: IEA (2017), *CO_2 Emissions from Fuel Combustion 2017*, www.iea.org/statistics/.

In contrast to Denmark, the four countries with lower carbon intensity all have large shares of hydropower or nuclear power or both in their electricity generation. Over the

[2] Only energy-related CO_2 emissions are included in calculation.

past decade, Denmark's carbon intensity decreased faster than the IEA average and that of its neighbouring countries (see Figure 6.7).

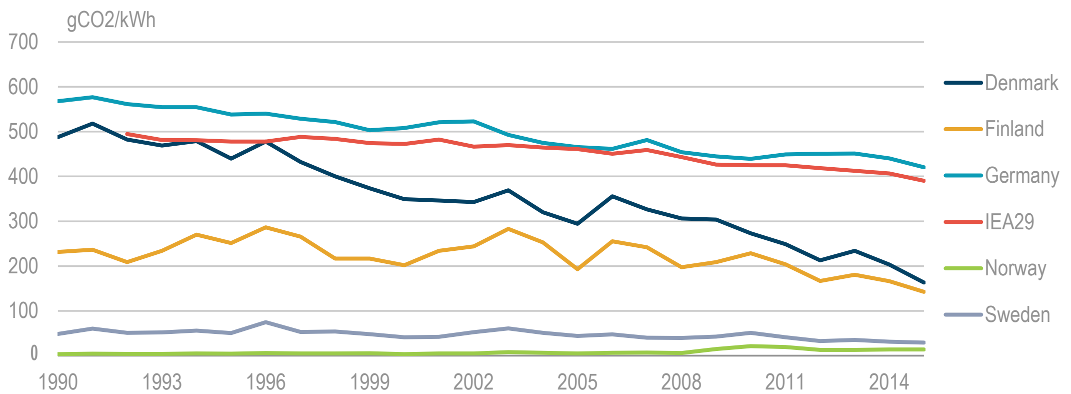
Figure 6.7 Energy-related CO_2 emissions per unit of GDP in Denmark and in other selected IEA member countries, 1990-2015



Source: IEA (2017), *CO_2 Emissions from Fuel Combustion 2017*, www.iea.org/statistics/.

CO_2 intensity in the power sector has fallen particularly fast in Denmark, compared to the IEA average, which was roughly equal to Denmark's average until the mid-1990s (see Figure 6.8). In 2015, Denmark's CO_2 intensity in electricity generation was 163.3 grams of CO_2 per kilowatt-hour (gCO_2/kWh), a 45% decline from 2005 and less than half the IEA average. Denmark's CO_2 intensity per kilowatt-hour remains higher than that of its hydro- and nuclear-based Scandinavian neighbours, although the gap has been reduced consistently.

Figure 6.8 Carbon intensity of power and heat generation in Denmark and in other selected IEA member countries, 1990-2015



Source: IEA (2017), *CO_2 Emissions from Fuel Combustion 2017*, www.iea.org/statistics/.

Institutions

The **Ministry of Energy, Utilities and Climate** is responsible for national and international policies to mitigate climate change, as well as for energy policy, among other issues. The ministry participates, on behalf of the Danish government, in international climate negotiations within the European Union and the United Nations.

The **Ministry of the Environment and Food** is responsible for policies and administrative and research tasks in the areas of environmental protection, farming and food production. It includes the Department itself, the Danish AgriFish Agency, the Danish Veterinary and Food Administration, the Environmental Protection Agency (EPA) and the Danish Nature Agency which includes the Danish Coastal Authority. The Ministry and the EPA are working on the country's adaptation to extreme climate-related weather events, such as storms, rising sea levels, and higher temperatures. Through the EPA, the ministry is responsible for integrating adaptation to climate change into legislation and planning.

The **Danish Council on Climate Change**[3] is an independent, academia-based body, whose members are appointed by the Minister of Energy, Utilities and Climate. It advises the government on how Denmark can most effectively and cost-efficiently undertake the transition to a low-carbon economy.

Municipalities are responsible for the practical implementation of climate change adaptation and many climate change mitigation measures.

Denmark has a large number of public and private institutions actively contributing to climate policy making and implementation some of which are listed below.

"State of Green"[4] is a public-private partnership founded by the government, the Confederation of Danish Industry, the Danish Energy Association, the Danish Agriculture and Food Council and the Danish Wind Industry Association. Crown Prince Frederik is patron of State of Green. State of Green brings together key Danish players in the fields of energy, climate, water and environment, and builds relations with international stakeholders.

The **Danish Meteorological Institute (DMI)'s Climate Services**[5] collects data on climate and delivers services and products related to the climate for decision makers and other stakeholders.

The **Danish Centre for Environment and Energy (DCE)**[6] at the Aarhus University provides science-based advice to the Ministry of the Environment and Food, the Ministry of Energy, Utilities and Climate, and other stakeholders in the areas of nature, environment, climate and energy.

Climate change mitigation

GHG targets

Denmark is a Party to the United Nations Framework Convention on Climate Change (UNFCCC) and to the Kyoto Protocol and the Paris Agreement. In the first commitment period 2008-12 under the Kyoto Protocol, the European Union committed itself to reducing GHG emissions on average to 8% below the level in the base year. The

[3] http://klimaraadet.dk/en/node/4.
[4] www.stateofgreen.com.
[5] http://services.dmi.dk/en/klima-services/.
[6] http://dce.au.dk.

reduction target of Denmark was 21% in the EU-15 Burden-Sharing Agreement. Both Denmark and the Union fulfilled these targets. Denmark's emissions were down by 27% in 2015. The decline is projected to continue and reach 37% by 2020.

For the Kyoto Protocol's second commitment period 2012-20, the Union is committed to reducing its overall GHG emissions to at least 20% below 1990 levels. Under the EU Effort-Sharing Decision, Denmark must reduce its GHG emissions from the sectors not covered by the EU Emissions Trading Scheme (ETS) by 20% in 2020 below the 2005 level. These sectors include transport, agriculture, buildings and waste (except for large waste incineration plants). To comply with this commitment, between 2013 and 2020, Denmark is required to meet binding annual GHG limits, known as annual emissions allocations (AEAs), listed in Table 6.1.

Table 6.1 Denmark's annual emissions allocation for 2013-20 (MtCO2-eq)

2013	2014	2015	2016	2017	2018	2019	2020
35.873	34.997	34.120	33.242	32.365	31.488	30.611	29.734

Note: The annual emissions allocation is calculated by applying global warming potential values from the second Intergovernmental Panel on Climate Change (IPCC) assessment report.

Source: Commission Decision of 26 March 2013 on determining member states' annual emission allocations for the period from 2013 to 2020 pursuant to Decision No 406/2009/EC of the European Parliament and of the Council.

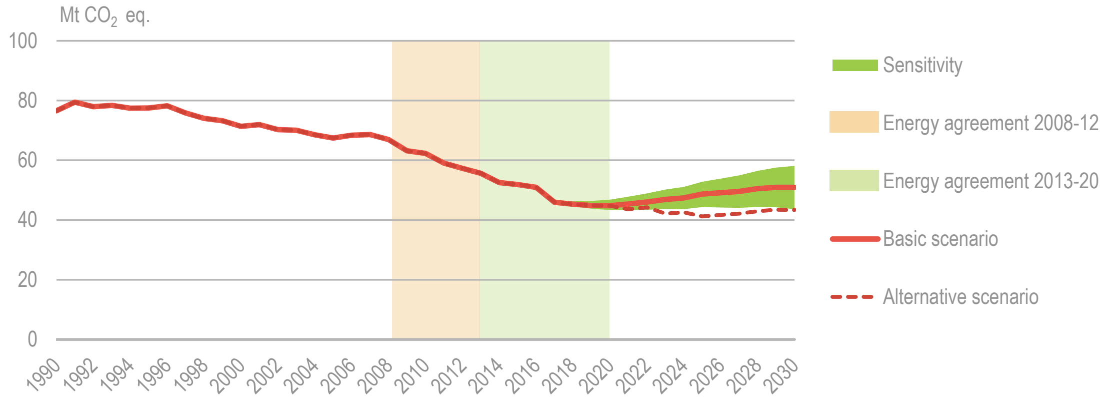
Beyond 2020, the EU countries agreed to reduce jointly total GHG emissions by at least 40% in 2030 below the 1990 level. This commitment is stated in the Nationally Determined Contribution of the European Union and its member states under the Paris Agreement. The sectors covered by the EU-ETS shall reduce emissions by 43% in 2030 compared to 2005, and non-ETS sectors by 30%. According to the European Commission's burden-sharing proposal, Denmark would have to reduce its GHG emissions in the non-ETS sector by at least 39% in 2030. This proposal was still under negotiation at the time of writing. However the Danish government has expressed its willingness to accept an ambitious 2030 target.[7]

In addition to the international commitments, Denmark has a national long-term goal to cover at least 50% of energy demand by renewable energy in 2030 and to become a low-emission society independent of fossil fuels by 2050.

The Danish Energy Agency (DEA) projects that the country will reach its GHG and renewable energy targets to 2020 without any additional measures (with the exception of a renewable energy share in transport). Since most of the existing policies and measures expire around 2020, the projections show an increase in GHG emissions after 2020 in the absence of any new initiatives (Figure 6.9). The government is working on proposals for new energy and climate policies, as discussed below and in Chapter 2.

[7] http://en.efkm.dk/climate-and-weather/the-climate-initiative-in-denmark/ accessed on 6 June 2017.

Figure 6.9 Danish GHG emissions in the Frozen Policies scenario ($MtCO_2$-eq)



Source: DEA (2017), *Denmark's Energy and Climate Outlook 2017*, Danish Energy Agency, Copenhagen, March.

Climate policy overview

Several Danish energy policy measures originally introduced to pursue other objectives (security of supply, diversification, reducing import dependence, fiscal) have gradually become important also from a climate perspective, and have remained key tenets of the Danish approach to limiting GHG emissions. Along the way, these measures have been complemented with policies specifically pursuing a climate objective: Denmark introduced CO_2 taxation on energy commodities in 1992 and pioneered CO_2 emissions trading for the power sector as of year 2000, helping to pave the way for the EU-ETS a few years later.

The Climate Change Act, adopted in June 2014, establishes an overall strategic framework for Denmark to progress to a low-carbon society by 2050. The Act defines this low-carbon society as “a resource-efficient society with an energy supply based on renewable energy with markedly lower greenhouse gas emissions from other sectors, which at the same time supports growth and development”.[8] The Act also stipulates measures, which contribute to transparency and public awareness about the status, direction and momentum of Denmark's climate policy. The Act sets up the following:

- The Danish Council on Climate Change, an independent body composed of seven members appointed for a four-year term. It evaluates the progress towards the long-term targets and provides recommendations on climate policy, including mechanisms and transition scenarios. It also assesses the best solutions for Denmark in the short, medium and long term, taking into consideration the country's security of supply, competitiveness and opportunities for continued growth and citizens’ welfare.
- An Annual Climate Policy Report. The government must provide a yearly climate policy statement to the Parliament**,** which should include: *i)* the status on emissions in different sectors; *ii)* policy initiatives to reach national, EU, and international climate commitments; and *iii)* a response to the recommendations of the Climate Council.[9]
- A process for establishing new national climate targets. New national climate targets shall be set every five years with a 10-year perspective.

[8] Act No. 716, translated by the Danish Council on Climate Change.
[9] If the government does not follow the recommendations of the Climate Council, it must explain the reasons.

In 2017, the government is preparing several proposals which will shape the country's energy and climate policies:

Proposals for a new Energy Agreement after 2020 (see Chapter 1)

- A "Climate Plan" outlining the government's climate initiatives, both national and international.
- A cost-efficient strategy for reaching the 2030 target in non-ETS sectors.

Reductions in Danish GHG emissions are mostly driven by initiatives to stimulate energy efficiency (see Chapter 7) and renewable energy (see Chapter 8). Other, targeted policies and measures are discussed below.

Taxation

Energy taxes have been used since the 1970s to reduce demand for energy, particularly for fossil fuels, and to promote energy efficiency, which has also helped limit GHG emissions. However, the recent developments in wind, biomass and heating have given rise to public debates about the need to optimise taxation. Energy-related taxes and levies are discussed in more detail in Chapter 1.

The Danish CO_2 tax, introduced on 1 March 1992, is imposed on several types of energy products relative to their CO_2 intensity (see Table 1.1 in Chapter 1). Industrial processes benefit from a tax reduction. On 1 January 2010 a structural change and an increase in the CO_2 tax was implemented as an adaptation to the EU Emissions Trading Scheme. Large waste incineration facilities are included in the EU-ETS from 1 January 2013 and therefore exempted from the CO_2 tax to avoid double taxation.

Emissions Trading Scheme

The emissions from the Danish energy sector and heavy industry are regulated under the EU Emissions Trading Scheme (see Box 6.1). Companies covered by the ETS can either reduce their emissions where they consider it most cost-effective, or buy allowances from other companies to offset their emissions. However, the current surplus of allowances has weakened the ETS as an effective decarbonisation tool. Therefore, the Danish government supports structural reforms of the ETS to reduce the surplus of allowances and ensure stronger price signals. A market stability reserve of allowances will start operating from 2019 to allow the supply of allowances to respond to changes in demand. The European Commission's proposal to revise the EU-ETS for the period after 2020 reduces the overall number of emission allowances with an annual rate of 2.2% compared to the current 1.74%, in order to implement the ETS target of a 43% reduction in GHG emissions by 2030 below the 2005 level. The government has pushed for further measures to strengthen the ETS and reduce the surplus of emission allowances.

Denmark's GHG emissions in the ETS sectors have declined more sharply than the EU average. This tendency is expected to continue to 2020: ETS emissions are expected to drop by more than 40% below the 2005 level, compared to the European average decline of 21%. This is largely the result of other policies that affect the ETS sectors (particularly support for renewable energy and measures to stimulate energy savings in industry), rather than the effect of the ETS itself. Chapters 7 and 8 on energy efficiency and renewable energy provide more details on policies and measures that influence the ETS sectors.

Box 6.1 The EU Emissions Trading Scheme (EU-ETS)

The EU-ETS is one of the key tools for reducing greenhouse gas emissions in the Union. It operates in 31 countries and limits their emissions from more than 11 000 power stations, industrial plants and airlines operating in these countries, covering around 45% of the GHG emissions in the European Union.

The EU-ETS works as a “”cap and trade” system. A cap is set on the total amount of certain GHGs that can be emitted by installations covered by the scheme. The cap is reduced over time, ensuring that total emissions fall. Within the cap, companies obtain emission allowances, which they can trade with one another. Trading brings flexibility that stimulates emissions reductions at least cost.

Every year, a company must submit enough allowances to cover all its emissions, otherwise it is fined. If a company reduces its emissions, it can keep the spare allowances to cover its future needs or sell them to another company. In 2013-20 the EU-ETS operates in its third phase, which has the following key characteristics compared to the first two phases:

- a single, EU-wide cap on emissions instead of the previous system of national caps
- auctioning as the default method for allocating allowances (instead of free allocation), and harmonised allocation rules for the allowances still given away for free
- more sectors and gases included
- 300 million allowances set aside in the New Entrants Reserve to fund the deployment of innovative renewable energy technologies and carbon capture and storage.

Beyond 2020, the proposed EU target for ETS is a 43% reduction in GHG emissions by 2030 relative to the 2005 level.

Source: European Commission (2017), “Climate Action”, webpage, https://ec.europa.eu/clima/policies/ets_en, accessed on 6 June 2017.

Non-ETS sectors

The key non-ETS sectors are transport (discussed below), buildings (discussed in Chapter 7 on energy efficiency) and agriculture. Emissions from agriculture are partly energy-related (combustion of fuels for machinery, heating, etc.) but the majority is non-energy-related GHG emissions, which are beyond the scope of this review. By 2020, the non-ETS emissions are expected to represent some 70% of the overall GHG emissions. Of these non-ETS emissions, around 80% are from transport and agriculture.

The DEA expects total reductions in non-ETS GHG emissions in the period 2013-20 to exceed the target by 8 to 11 million tonnes of carbon dioxide-equivalent (MtCO_2-eq). The annual intermediate target for year 2020 is expected to be missed, but this will be offset by overachievements in the previous years.

However, additional efforts will be needed to achieve the reduction target in the period 2021-30. Projections show that without any new policies, in 2030 the Danish non-ETS emissions will remain 20% to 26% lower than in 2005, which falls short of the expected binding target of -39%. Therefore, the country will need additional reduction efforts, the options for which are currently being developed and analysed. As the Danish Energy Commission's report points out, reductions in the energy sector alone will not be sufficient to meet the expected obligation for the period 2021-30.

Denmark may be able to close some of the gap by using flexibilities allowed under the non-ETS rules. However, the Climate Council issued advice on this matter in March 2017, recommending that Denmark should use the flexibilities proposed by the European Commission in relation to land use, land-use change and forestry (LULUCF), but not the flexibilities allowing to use ETS allowances to offset emissions in the non-ETS sector, unless decisions are taken before 2020 to very significantly reduce the accumulated EU-ETS allowance surplus. The recommendation was based on an analysis finding that cancelling allowances from the ETS in the present state seems unlikely to deliver similar reductions elsewhere in the system within a relevant time frame.

Transport

To reduce GHG emissions in the transport sector, Denmark implements a number of measures adopted at EU level, including:

- CO_2 emission standards for new cars and vans
- CO_2 labelling of cars
- fuel quality requirements: the GHG intensity of vehicle fuels must be cut by 6% by 2020
- monitoring, reporting and verification requirements for ships.

Denmark also has several policy actions in the transport sector, summarised in Table 6.2. In addition to national policies, there are many regional and municipal initiatives. Box 6.2 provides an example of green mobility initiatives in Copenhagen.

Many of the national, regional and municipal initiatives to reduce GHG emissions listed in table 6.2 in general also reduce air and noise pollution from transport, such as electrification initiatives and investments in cycling lanes.

The restructuring of car taxation in 2007 has had a significant impact on consumers' choices. There has been a positive trend for purchasing more energy-efficient cars, which emit less CO_2 per kilometre. Since 2008, the average emissions from new cars in Denmark have been below the EU average, and the EU 2015 requirement of 130 grams of CO_2 per km was reached five years earlier in 2010. CO_2 emissions from new cars sold in Denmark dropped by more than 12% in three years from 125 g/km in 2011 to 110 g/km in 2014. Further efforts are needed to reach the new EU target of 95 grams of CO_2/km in 2021.

The government expects continued decoupling of the transport sector performance and energy consumption. In 2020, energy consumption in transport is projected to reach 214.5 petajoules and CO_2 emissions 13.1 Mt (similar to current level).

Table 6.2 Policies and measures in transport

Measures for energy efficiency in public transport	- Conversion from diesel to electric trains on main lines. In January 2014, the former government agreed on a DKK 28.5 billion investment plan to electrify the rail network by 2024-26. The conversion is being financed by Togfonden (the Train Fund). -Energy efficiency requirements for taxis.
Measures to make public transport more attractive	- Tariff reductions and investments for improving public transportation (as part of the Transport Agreement adopted in 2012). -Metro development in Copenhagen (Cityringen, Nordhavnsmetroen, Sydhavnsmetroen). -Establishment of light railways in Aarhus, Odense and Letbane.
Measures to encourage eco-driving	- Mandatory refresher courses for professional drivers include "green driving". The refresher courses are mandatory under EU law, but "green driving" is a Danish national element.
Financial support for sustainable transport measures	- Togfonden (the Train Fund) for improvement and electrification of railways. The parliament has allocated DKK 5.9 billion for electrification of the Danish rail network. - Funding pools to finance projects under the Green Transport Policy. Under the 2009 Green Transport Policy Agreement, funds have been allocated to, *inter alia*, bicycle traffic and the promotion of goods by rail.
Tax incentives	- In 2007, vehicle taxation change reduced the registration tax for cars with low fuel consumption. - A green owner's tax related to the vehicle's fuel consumption has existed since 1997. - Electric and hydrogen vehicles were exempt from the vehicle registration tax until 2015 inclusive. From 2016, they benefit from a reduced vehicle registration tax, which will be gradually increased every year. The reduced rate will be maintained until Denmark reaches the government's objective to have 5 000 electric vehicles (by the end of 2018).
A blending obligation for 0.9% advanced biofuels	Adopted in 2016, this obligation is expected to meet the EU requirement to have 0.5% of advanced biofuels in transport fuels by 2020.

Source: Government of Denmark (2017), *National Energy Efficiency Action Plan*, submitted to the European Union in May 2017.

Box 6.2 Green mobility in Copenhagen

Following the adoption of the Climate Plan for Copenhagen in 2009, the City Council approved in 2012 an updated CPH 2025 Climate Plan, which sets the ambition for Copenhagen to become the first carbon-neutral capital by 2025. The Climate Plan sets up goals and initiatives in a holistic manner within four focus areas: Energy Consumption; Energy Production; Green Mobility and City Administration Initiatives.

The green mobility goals for 2025 include:

- 75% of journeys in Copenhagen are done on foot, by bike or by public transport
- 50% of all journeys to work or education in Copenhagen are done by bike
- 20% more passengers using public transport compared to 2009
- public transport is carbon-neutral
- 20% to 30% of all light vehicles use new fuels
- 30% to 40% of all heavy vehicles use new fuels.

The Action Plan for Green Mobility, adopted by the City of Copenhagen in 2012, sets up several initiatives, including: extending the metro supplemented by light railways and priority bus routes; expanding the overall coherence of the cycling lane network, the PLUSnet and super-cycle lanes connecting Copenhagen with neighbouring municipalities; IT-regulated signalling systems; extensive refurbishment of stations; a better interaction between the various modes of transport; providing better information to enable users to select the best mode of transport.

Since 2005 DKK 1 billion has been invested in bike lanes and super cycle highways. Up to 45% of the locals cycle to work or school every day. Integrated transport and cycling solutions have reduced congestion and improved the air quality.

Sources: Copenhagen City Council (2012), "CPH 2025 Climate Plan: The State of Green", website, https://stateofgreen.com/en/Profiles/City-of-Copenhagen, accessed on 28 June 2017.

Flexibility mechanisms

To meet the future target for non-ETS sectors, Denmark can use international flexibility mechanisms allowed under the non-ETS rules. So far, these flexibility instruments have been used only very little in the European Union and not at all in Denmark.

As regards future commitments, the analysis of the Danish Council on Climate Change demonstrates that some of the available flexibility options will not result in real reductions up to 2030. Therefore, the Council recommends that Denmark should limit the use of these mechanisms, in particular avoid buying reductions from abroad in the form of allowances from the ETS or credits in the non-ETS sector.

Carbon capture and storage (CCS)

The Danish Subsoil Act was amended in 2011 to implement the EU Carbon Capture and Storage Directive. While preparing these amendments, it was decided that the government would strive to introduce CO_2 injection and storage in North Sea oilfields in order to enhance oil production, provided that this can be done in a safe and environmentally sound manner. The Geological Survey of Denmark and Greenland (GEUS) is involved in projects to estimate CO_2 storage potential and to study the possibility for such enhanced oil recovery in the North Sea. Chapter 11 on energy RD&D provides more details.

As for storing CO_2 in the subsoil, during the preparation of the 2012 Energy Agreement it was agreed to postpone the principal political debate on this matter. The government will wait until experience from other projects is available before deciding whether to endorse CO_2 storage in Danish onshore areas. The Parliament must discuss and make a decision-in-principle on onshore CO_2 storage before it can be introduced. The same applies to offshore CO_2 storage if the aim of such storage is not tied to improving oil recovery from Danish oilfields.

Adaptation to climate change

The national climate change adaptation policy is the responsibility of the Ministry of the Environment and Food and its Environmental Protection Agency (EPA). The responsibility for adapting the energy system to climate change lies with the owners of infrastructure. The Danish electricity and gas transmission system operator (TSO), Energinet.dk, ensures the security of electricity and gas supply, including the systems' resilience to climate change. As part of investment planning, Energinet.dk assesses climate-related risks, such as floods. This ensures that transmission networks and operating systems are adapted to changing climate conditions. The municipal authorities, electricity, gas and district heating utilities also take decisions on the adaptation of the relevant energy infrastructure.

In 2008, the government adopted a Strategy for Adaptation to a Changing Climate with a twofold objective: to initiate an information campaign highlighting the effects of climate change, and to ensure that climate change is incorporated into planning and development.

To implement this strategy, several measures have been taken:

- The Ministry of the Environment and Food and the EPA launched a dedicated web portal http://en.klimatilpasning.dk/ containing knowledge and tools for municipalities, citizens and businesses.
- In March 2012, the DEA published a background report which assesses impacts, vulnerability and opportunities for adaptation. The report also includes practical recommendations for conducting a socio-economic analysis of climate change adaptation initiatives.
- In December 2012, the government adopted an *Action plan for a climate-proof Denmark*, which provides an overview of the initiatives that the government has implemented or planned to improve Denmark's resilience to climate change.
- Municipalities have developed local action plans for adaptation to climate change.
- National regulation of several sectors has been adjusted to accommodate more efficient adaptation to increased risks of flooding.

- The Danish Meteorological Institute (DMI) has established climate services to policy makers and other stakeholders. Among other actions, DMI projects future climate developments as a consequence of the anthropogenic GHG emissions and operates global climate models to study interactions between atmosphere, ocean, land surface and ice on a larger scale.
- Monitoring indicators and methodologies are being developed.

Air quality

Emissions from the energy sector have an impact not only on climate change but also on air quality. For example, diesel trains, still common in Denmark, emit fine particles, among other pollutants, which are harmful for people's health. The rail electrification plan (see Table 6.2) is expected to improve air quality in addition to reducing GHG emissions.

In Denmark, air quality is the responsibility of the Ministry of Environment and Food and its Environmental Protection Agency (EPA). Danish requirements for air quality are all based on provisions adopted by the European Union. The Danish regulations that set the limit values for polluting substances date from 2010. EPA ensures that the levels of these substances – including sulphur dioxide (SO_2), nitrogen dioxide (NO_2), nitrogen oxides, lead, particulate matter, benzene, carbon monoxide and ozone as well as certain heavy metals – are regularly measured. According to the EPA, Denmark usually meets the limit values for most substances.

EPA also ensures compliance with the international regulations on air pollution from ships.

Air pollution from stoves

Denmark has about 750 000 wood-burning stoves and about 45 000 boilers, which contribute significantly to air pollution with particles, poly-aromatic hydrocarbons (PAH), and dioxins. Testing certificates are necessary for wood-burning stoves and central heating boilers running on solid fuel that are sold, transferred or connected after 2008. The requirements for the quality and efficiency of such stoves and boilers were strengthened under a January 2015 statutory order.

Throughout several heating seasons, the EPA has conducted nationwide information campaigns on cleaner wood burning, for example the most recent campaign "Quit Smoking for Wood Stoves". In 2015, a scrapping scheme for old wood stoves (DKK 45 million) was launched. Households possessing an old wood stove from 1990 or before could apply for DKK 2 150 if they scrapped the old one. The scheme ended in 2016 when about 20 000 old wood stoves had been scrapped. Since 2008, the Danish Eco Innovation programme has invested more than DKK 20 million into analysis and demonstration of technologies to reduce pollution from wood stoves and boilers.

Traffic emissions

In compliance with the EU legislation, Denmark has introduced common standards, known as Euro norms, which define maximum allowed values for exhaust emissions from car engines. Other measures to reduce emissions from transport include green zones. Major Danish cities have established low-emission zones in which heavy-duty vehicles are obliged to have filters that reduce the emission of particulate matter. Driving without particle filters is not allowed in these zones. Road charging is not widely applied in Denmark except for heavy duty goods vehicles where the charge is time-based rather than distance-based. The latter may have to change under a recent proposal by the European Commission.[10]

Assessment

Overview

Denmark has a long tradition of a proactive climate policy, which is in many respects aligned with the principles of environmental sustainability and the "polluter pays" policy embedded in the IEA Shared Goals (see Annex C). Danish climate policy has evolved around national targets and international commitments taken in the context of the United Nations Framework Convention on Climate Change (UNFCCC). It has relied on a broad range of measures, including national regulation, voluntary agreements, and market based instruments, as well as initiatives adopted at the EU level.

The Danish policy mix has been successful in significantly reducing GHG emissions, and it has done so mainly domestically, while international flexibility mechanisms have been little used. Denmark is to be praised for over-achieving its commitment under the Kyoto Protocol, as well as for impressive decoupling of economic growth from carbon emissions: from 2005 to 2015, GDP adjusted for purchasing power parity (PPP) grew by 7%, but energy-related CO_2 emissions decreased by 34%. Emissions declined in all sectors, but most flagrantly in power and heat production. As a result, Denmark's carbon intensity declined by 38%, most in relative terms among the IEA member countries. Today, Denmark has the commendable fifth-lowest carbon intensity among IEA countries, only behind the countries with high shares of nuclear and large hydro in electricity generation.

Key challenge: Non-ETS sectors

By 2020, the non-ETS emissions are expected to represent some 70% of the overall GHG emissions. In the period 2021-30, Denmark would have to reduce its non-ETS emissions by 39% compared to 2005 if the EC proposal is adopted. Projections demonstrate that additional measures will be needed to meet this target. As the Danish Energy Commission's report points out, reductions in the energy sector alone will not be enough. The government is preparing a strategy for the non-ETS sector in 2017. In developing this strategy, it should emphasise the deployment or development of further measures for transport and agriculture, as they are the largest contributors to GHG emissions in the non-ETS sectors. While such measures currently may not always be the most cost-effective from a GHG perspective alone, measures should also be assessed against their contribution to meeting other longer-term, environmental and socio-economic objectives and targets.

The transport sector is the largest emitter of energy-related CO_2 emissions, at 36% of the total in 2015, and the largest emitter in Denmark's non-ETS sector. Reducing CO_2

[10] COM(2017) 275 final, http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52017PC0275

emissions in the transport sector is particularly challenging in all IEA countries. Denmark is not an exception.

Nevertheless, several possibilities are tested in other IEA countries to speed up the de-carbonisation of transport, including more aggressive use of sustainable liquid biofuels and biogas; more stringent efficiency standards for vehicles; electrification of road and rail transport; increasing the efficiency of the transport system (by promoting public transport, optimising speed limits and managing flows in the road networks). The government has already taken measures to reduce the carbon intensity of transport, such as conversion of diesel trains to electricity. However, it could place an even greater emphasis on road transport emissions. The transport sector is closely linked to the rest of the energy sector and can significantly help reach the energy and climate targets.

The penetration of electric vehicles in Denmark is rather low, but this technology can also help decarbonise the transport sector. In addition, smart charging can provide system services to the electricity system. Therefore, the IEA recommends lowering the registration tax for electric vehicles for a longer period. The government could also consider other measures to promote penetration of electric vehicles, such as the free use of bus lanes, free or cheaper parking, etc.

To meet the future target for non-ETS sectors, Denmark may be able to close some of the gap by using flexibilities allowed under the non-ETS rules. However, taking into account the analysis of the Danish Council on Climate Change, which demonstrates that some of the available flexibility options will not result in real reductions up to 2030, it is prudent to adopt an approach that enhances national efforts to reduce emissions in the transport and agriculture sectors at an early stage.

Emissions trading

Because of the surplus of allowances, the EU Emissions Trading Scheme (ETS) is not currently a sufficiently effective decarbonisation tool. Emissions reductions in the Danish sectors covered by the ETS have been impressive so far, but they are largely the result of renewable energy and energy efficiency policies rather than the effect of the ETS itself. Therefore, the Danish government is encouraged to continue its support for structural reforms of the ETS to reduce the amount of emission allowances and ensure stronger price signals.

As long as the EU-ETS prices are not adequate to drive a structural shift towards low-carbon options, the Danish government will need an effective strategy for the sectors covered by the ETS (especially industry). See Chapter 7 on energy efficiency and Chapter 8 on renewable energy for a more detailed discussion.

Carbon capture and storage

The Danish decision to support environmentally sound CO_2 injection and storage in oilfields in order to enhance oil production is commendable. However, the IEA recommends not only to focus these efforts on the single objective of enhanced oil recovery (EOR) but rather to try to co-optimise both oil recovery and CO_2 storage. This could help achieve a win-win solution for both the oil industry and the climate change mitigation efforts by offering commercial opportunities for oil producers while also ensuring permanent storage of large quantities of CO_2 underground in a cost-effective way. IEA analysis demonstrates that, in a carbon-constrained world, it is feasible to "co-exploit" the storage of CO_2 with oil extraction to generate more profits by using two different revenue streams; however, this is unlikely to happen in the short to medium term without additional incentives because of increased initial costs and additional risks (IEA, 2015). Therefore, the IEA encourages the Danish government to create a favourable policy framework for innovative ways of conducting both CO_2 storage and enhanced oil recovery (EOR).

Adaptation

As regards climate adaptation, comprehensive and often exemplary action has been taken since 2008, when Denmark's first adaptation strategy was adopted. Impacts of climate change on the Danish economy have been assessed, as well as vulnerability and opportunities for adaptation. Action plans have been adopted by industrial branches and individual companies at both the national and municipal levels. New climate services and research activities have been launched at the Danish Meteorological Institute where monitoring, indicators and methodologies are being developed. The Danish approach has been successful in mobilising stakeholders and authorities at the national and municipal levels. It has also been a source of inspiration and replication at the EU level.

Recommendations

The government of Denmark should:

- ☐ Adopt national targets and policy measures for the short and medium term (2021-30) designed to be cost-effective also when taking into account further reductions needed in subsequent decades in view of the Paris Agreement and Denmark's objective to become a low-emission society by 2050.
- ☐ Prepare a cost-efficient strategy for reducing emissions in the non-ETS sectors given their high and increasing share of Denmark's overall emissions and the country's future obligations in these sectors. The strategy should be based upon an adaptive approach combining timely action with ongoing stocktaking of the emissions and assessments of cost-efficient reduction pathways.
- ☐ As part of the strategy, consider increasing the ambition in the transport sector while taking into account the cost-efficient possibilities in the other non-ETS sectors as well.
- ☐ Only make use of flexibility mechanisms available where and to the extent that these, with a high degree of certainty, represent real, equivalent emissions reductions within a similar timeframe,

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7. Energy efficiency

Key data

(2015/16 provisional)

Energy supply per capita: 2.9 toe (IEA average 4.4 toe), -23% since 2006

Energy intensity: 64 toe/USD million PPP (IEA average: 109), -22% since 2006

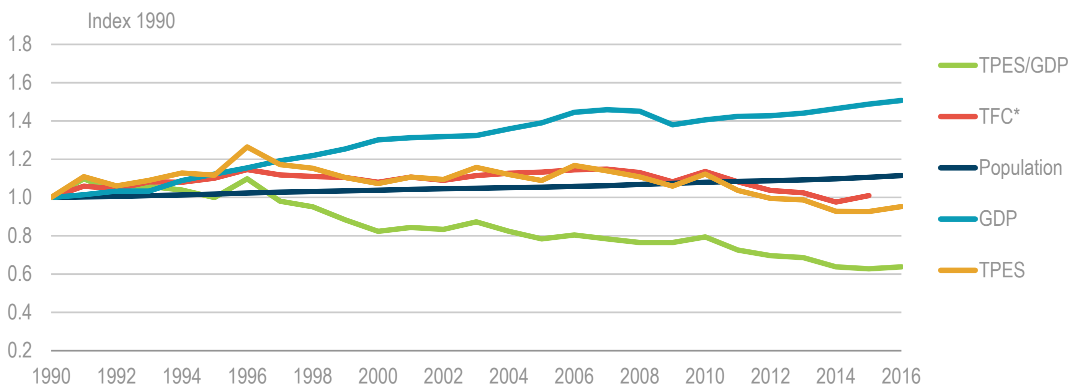
TFC (2015): 13.3 Mtoe (oil 39.1%, electricity 19.8%, heat 18.1%, biofuels and waste 10.9%, natural gas 10.9%, coal 1.0%), -11% since 2005

Consumption by sector (2015): residential 32.0%, transport 30.5%, commercial and public services including agriculture, forestry and fishing 19.8%, industry 17.7%

Overview

Denmark's total final consumption (TFC) has decreased in the last years despite economic growth and population increase (see Figure 7.1). In 2015, TFC was 13.3 million tonnes of oil-equivalent (Mtoe), an 11% reduction below the level in 2005. Falling energy demand is mainly attributed to improvements in energy efficiency. The Danish energy intensity has fallen at a faster rate than the IEA average. In 2015, it ranked the third-lowest among all IEA members.

Figure 7.1 Energy intensity drivers in Denmark, 1990-2016



* The latest available consumption data are for 2015.

Note: 2016 data are provisional.

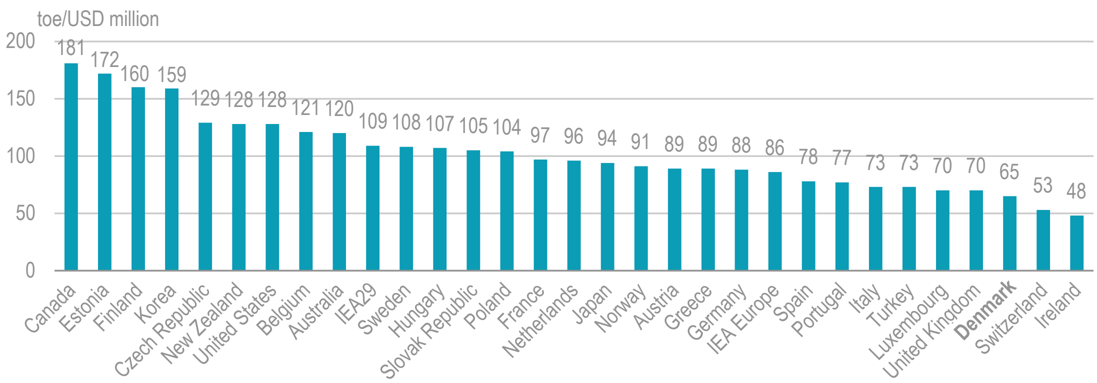
Source: IEA (2017a), *World Energy Balances 2017,* www.iea.org/statistics/.

Energy efficiency has been a focus area of Danish energy and environmental policy. Denmark has reported an indicative 2020 target to the European Union for primary energy consumption (gross energy consumption, excluding consumption for energy purposes), which corresponds to a 14.5% reduction compared with 2006, and the government is implementing policy measures in all end-use sectors towards meeting it.

Energy intensity

Denmark's energy intensity, measured as the ratio of total primary energy supply (TPES) per unit of real gross domestic product adjusted for purchasing power parity (GDP PPP), was 65 toe/USD million GDP PPP in 2016. Energy intensity has been reduced by about one-fifth since 2006, remaining considerably lower than the IEA total (109 toe/USD million PPP). It is the third-lowest among the IEA member countries, after Ireland and Switzerland (see Figure 7.2). GDP and TFC have trended in different directions in recent years, and Denmark has decoupled energy consumption and economic growth (GDP).

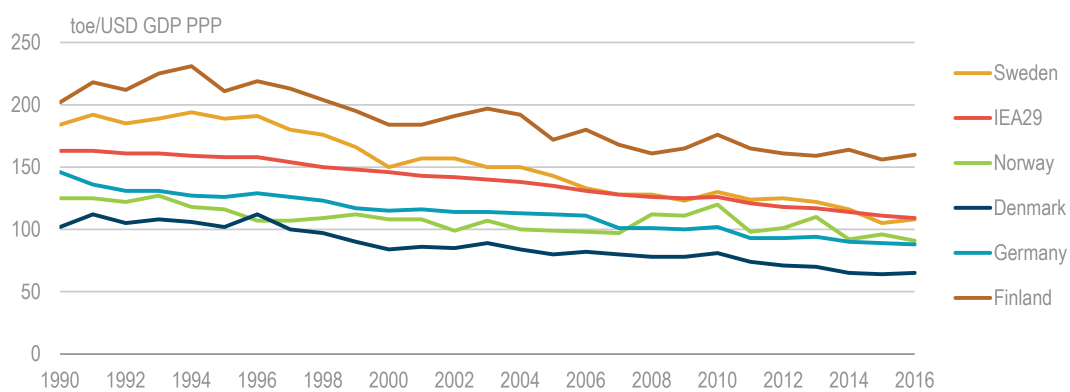
Figure 7.2 Energy intensity (TPES/GDP) in IEA countries, 2016



Note: Data are provisional for 2016.

Source: IEA (2017a), *World Energy Balances 2017*, www.iea.org/statistics/.

Figure 7.3 Energy intensity (TFC/GDP) trends in IEA countries, 1990-2016



Note: Data are provisional for 2016.

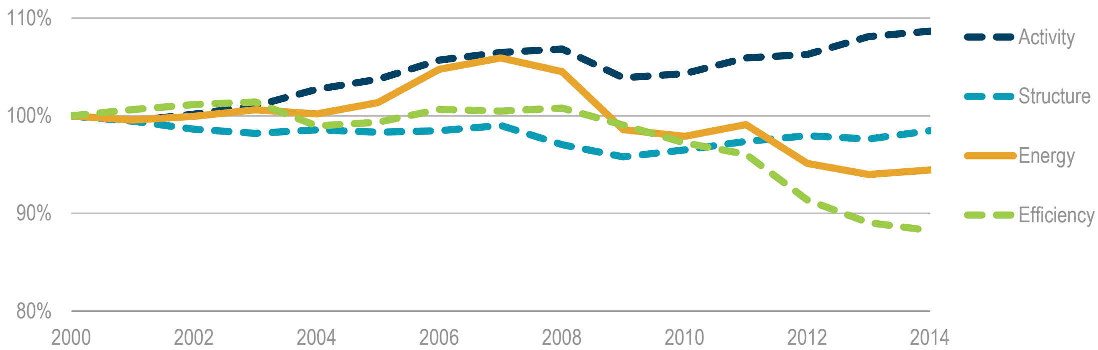
Source: IEA (2017a), *World Energy Balances 2017*, www.iea.org/statistics/.

Decomposition analysis of energy consumption

TFC can be broken down into activity, structural and efficiency factors. Activity, which comprises various factors such as growth in industry production, population in the residential sector and person-kilometre in transport, drives up energy consumption. Structural effects, such as structural changes in the industry sector, floor area per person in the residential sector and modal shift in the transport sector, also have impacts on energy consumption. Finally, energy efficiency improvements can lead to decoupling between the activity and TFC. A decomposition analysis provides a picture of how much energy efficiency has contributed to energy consumption falling (see Figure 7.4).

In 2014, Denmark's total activity factor was 9% higher than in 2000, while the actual energy consumption was only 94% of TFC in 2000. The decomposition analysis on Danish TFC shows that the downward trend in TFC is mainly the result of energy efficiency improvements with a little contribution from changes in the structure of the economy.

Figure 7.4 Changes in TFC broken down by activity, structure and efficiency effects, 2000-14



Source: IEA (2017b, forthcoming), *Energy Efficiency Indicators 2017*.

Energy consumption by sector

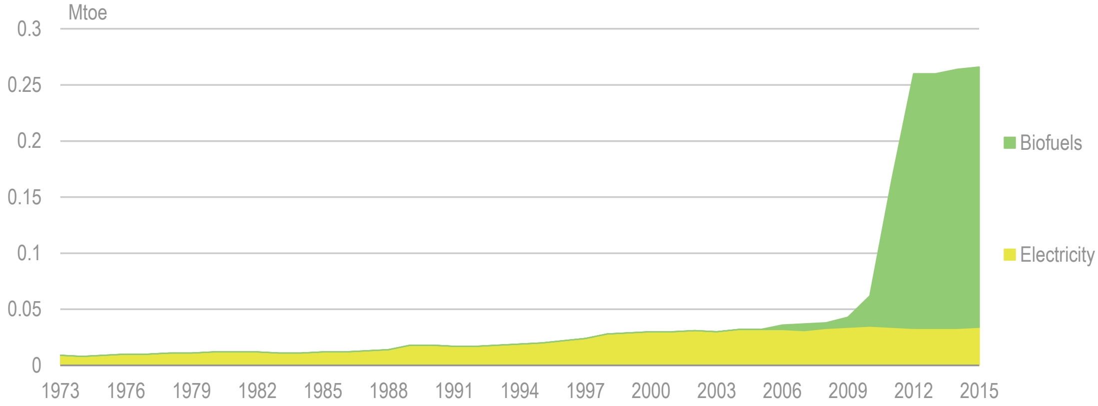
Transport

The transport sector has the second-largest energy consumption in Denmark after the residential sector, with transport consuming 4.1 million tonnes of oil-equivalent (Mtoe) in 2015, accounting for nearly one-third of TFC. Energy demand in the sector declined by 9% since 2005, but its share in TFC has increased slightly. Oil is the absolute dominating energy source, accounting for 93.4% of energy consumption in transport. However, the dominance of oil has been reduced compared with a decade ago when oil accounted for nearly 100% of the sector's energy demand. Denmark began to use biofuels in 2006 and its share increased rapidly to over 5% of total transport fuels in 2012, thanks to support policies and measures, such as an exemption from the CO_2 tax and a 5.7% blending obligation (see Chapter 8), after which the biofuel volume has been stable around 0.23 Mtoe (Figure 7.5).

Electric vehicles (EVs) sales increased significantly in 2014-15 as a result of financial support policy, but the total number of EVs is still modest. Electricity accounted for less than 1% of energy consumption in transport in 2015.

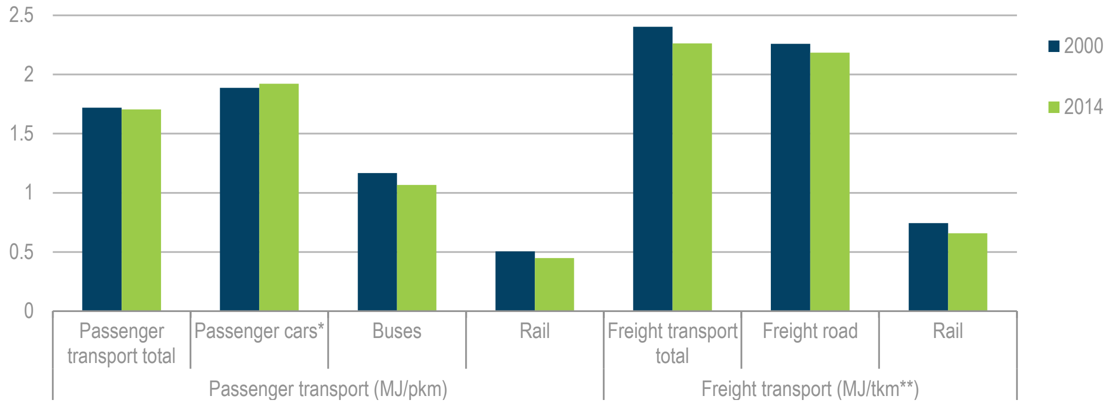
Energy intensity in the transport sector has been relatively stable in recent years, with a 5% decline for freight transport and less than 1% decline in passenger transport in the years 2000-14 (see Figure 7.6).

Figure 7.5 Renewable energy consumption by the transport sector, 1973-2015



Source: IEA (2017a), *World Energy Balances 2017,* www.iea.org/statistics/.

Figure 7.6 Energy intensity in the transport sector, 2000 and 2014



*Passenger cars include cars, sport utility vehicles and personal trucks.

** tkm refers to tonne-kilometres.

Note: Transport excludes international marine and aviation bunkers, pipelines, and when possible fuel tourism.

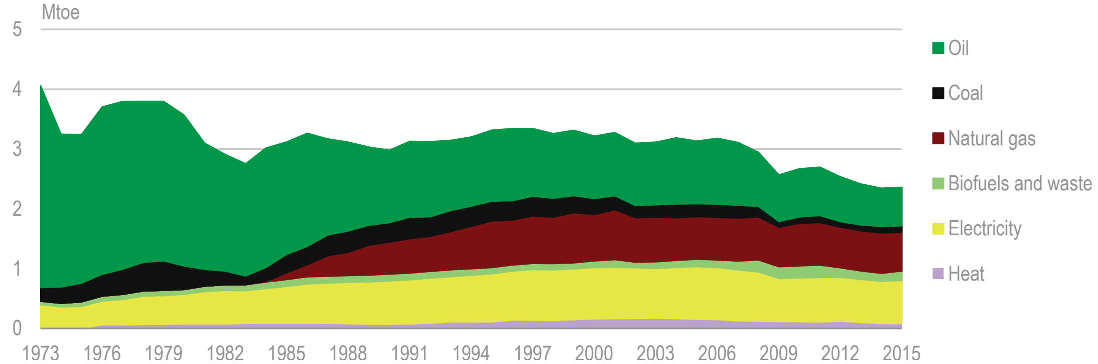
Source: IEA (2017b, forthcoming), *Energy Efficiency Indicators 2017*.

Industry

Industry represented 17.7% of TFC in 2015, with final consumption of 2.4 Mtoe. Electricity is the largest energy source in industry, accounting for 31% of total energy consumption of the sector in 2015. Oil and natural gas are almost equally important, 27.3% and 27.6% respectively, and the remainder was made up of biofuels (7%), coal (4%) and heat (3%) (Figure 7.7). The industry sector consumption includes oil used to process feedstock, which accounts for around 10% of total industrial fuel consumption. Energy demand of the sector fell by 25% from 2005 to 2015 (in part, because of the economic crisis), which was faster than in other sectors. Over half this decline was caused by a decrease in oil consumption as a result of switching from oil to gas, electricity and biomass.

The food industry and non-metallic minerals industry together are the largest energy-consuming industries in Denmark, accounting for nearly half of total industrial consumption (see Figure 7.8). Non-metallic minerals industry is also by far the most energy-intensive of the largest industries, despite improving in recent years (see Figure 7.9).

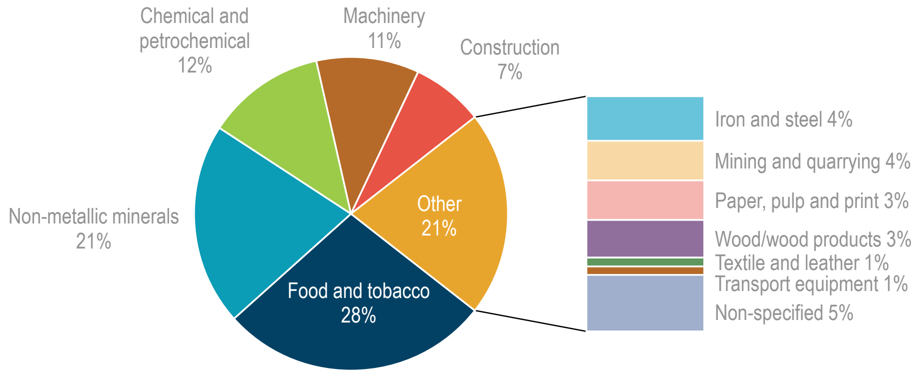
Figure 7.7 TFC in industry by source, 1973-2015



Notes: *Industry* includes non-energy consumption. "Heat" means heat sold to third parties. Heat generated directly by the end-users (e.g. in on-site oil- or gas-fired boilers) is not included in this category.

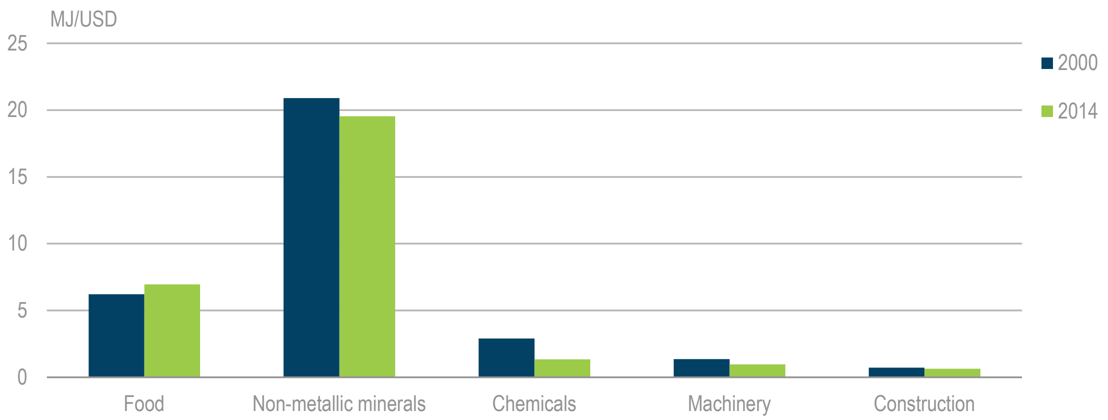
Source: IEA (2017a), *World Energy Balances 2017,* www.iea.org/statistics/.

Figure 7.8 Total final consumption in the industry sector by industry, 2015



Source: IEA (2017a), *World Energy Balances 2017,* www.iea.org/statistics/.

Figure 7.9 Energy intensity in industry in selected sectors, 2000 and 14



Source: IEA (2017b, forthcoming), *Energy Efficiency Indicators 2017*.

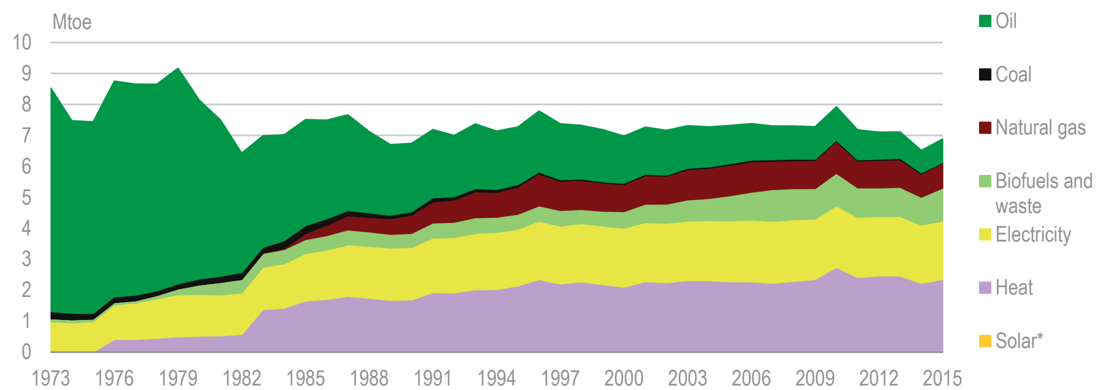
Residential and commercial

The residential and commercial sectors account for over half the TFC in 2015, of which nearly two-thirds was consumed in the residential sector. Energy demand fell over the past decade by 4% in the residential sector and by 9% in the commercial sector.

Heat supplied by district heating companies[1] is the most consumed energy source in the residential and commercial sectors, accounting for 33.9% in 2015, followed by electricity (27.4%). Over the past decade, district heating consumption remained at similar level while electricity consumption decreased slightly. Solid biofuel combustion is the third-largest energy source after heat and electricity, accounting for 15.5% of total energy consumption in the sectors. The majority of biofuels is used in the residential sector. It is the only main energy source that increased between 2005 and 2015.

Demand for fossil fuels has continuously decreased in the residential and commercial sectors. The share of fossil fuels in energy consumption was reduced from 31.0% in 2005 to 23.1% in 2015, mainly because of a large decrease in oil demand. Oil was the third-largest energy source in 2005, but demand declined sharply by 39% until 2015, especially in the residential sector.

Figure 7.10 TFC in the residential and commercial sectors by source, 1973-2015

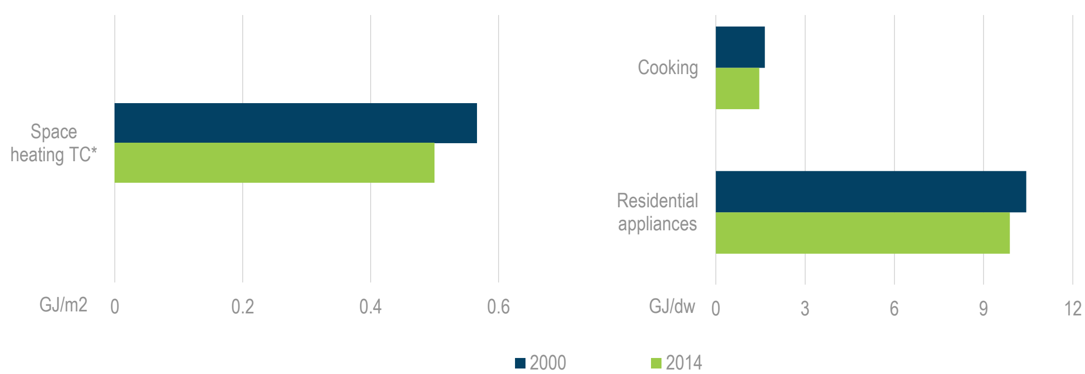


*Negligible.

Notes: The commercial sector includes commercial and public services, agriculture, forestry and fishing. "Heat" in IEA statistics means heat sold to third parties (i.e. heat supplied by district heating companies). Heat generated directly by the end-users (e.g. in oil- or gas-fired boilers) is not included in this category.

Source: IEA (2017a), *World Energy Balances 2017,* www.iea.org/statistics/.

Figure 7.11 Energy intensity in the residential sector by energy use, 2000-14



*Space heating is temperature corrected in the comparison and includes water heating.

Note: GJ/dw = GW per dwelling.

Source: IEA (2017b, forthcoming), *Energy Efficiency Indicators 2017*.

[1] In IEA statistics, *heat* is equal to the sum of the net heat production for sale by all plants within a country, reduced or increased by exports or imports from abroad. Only heat sold to third parties is reported under this category.

Space and water heating accounted for around 82% of total energy consumption in the residential sector in 2014, followed by residential appliances with 16% and by cooking with the remaining 2%. District heating supplies almost half total space and water heating in the residential sector. Household combustion of biofuels, natural gas or oil account for most of the remaining heat. Electricity accounts for only a few percentages of residential heat demand, but is the only source of energy for household appliances and for most of cooking.

Institutions

The Ministry of Energy, Utilities and Climate is responsible for the overall energy policy, including energy efficiency policy. The Danish Energy Agency (DEA) holds the responsibility for the implementation of energy efficiency policy and legislation. The Ministry of Transport, Buildings and Housing is responsible for the building code, which includes energy standards for buildings.

Danish local authorities (municipalities) play the key role in heat supply planning, which includes planning of energy efficiency improvements on the supply side. According to the Law on Heat Supply, local authorities develop and update municipal heating plans and have the responsibility for approval of heat supply projects (district heating network, gas distribution network and district heating production units) according to socio-economic criteria.

Policies and measures

The Danish legal and regulatory framework related to energy efficiency is driven to a very large extent by European Union requirements set in the Energy Efficiency Directive, the Energy Performance of Buildings Directive, Fuel Quality Directive, etc.

In 2016, the Ministry of Energy, Utilities and Climate started conducting a review of the existing portfolio of energy efficiency instruments. The objectives of the analysis are: *i)* to develop an inventory of existing policies and measures supporting energy efficiency, and *ii)* establish the optimum economic balance between policies on the demand side (energy efficiency) and supply side (expansion of renewable energy production capacity).

The existing and planned policies and measures are outlined in the Danish National Energy Efficiency Action Plan (NEEAP) submitted to the European Union in April 2017.

Targets

Denmark has no binding overall energy efficiency target. Pursuant to Article 3 of the EU Energy Efficiency Directive, Denmark's indicative national target is to reduce gross energy consumption (excluding consumption for non-energy purposes) by 727.63 petajoules (17.38 Mtoe) by 2020, which corresponds to a 14.5% reduction in 2020 compared to 2006. The corresponding indicative target for final energy consumption (excluding consumption for non-energy purposes) in 2020 is 602.36 PJ (14.39 Mtoe). This represents a 9.7 % reduction below the 2006 level. The indicative targets are based on the DEA baseline projection that assumes that current policies are implemented and no further policies are introduced.

According to Article 7 of the EU Energy Efficiency Directive, Danish distributors subject to the energy saving obligation scheme (see below) must jointly achieve annual savings equivalent to at least 1.5 % of the total annual energy sales to final customers, averaged over the most recent three-year period before 1 January 2013 (EU, 2012).

In November 2016 the European Commission submitted a proposal for revision of the Energy Efficiency Directive and suggested a new binding target of 30% improvement in energy efficiency by 2030. According to the proposal, the target will not be allocated to individual countries but will be reached through binding instruments adopted at the EU level.

Energy distributors: Energy Savings Obligation Scheme

Since 2006, the grid and distribution companies in the areas of electricity, natural gas, district heating and oil are subject to the Energy Savings Obligation Scheme (ESOS). Nearly 500 entities were part of the ESOS in 2016: approximately 70 electricity companies, six natural gas distribution companies, around 400 district heating companies, and six oil companies. The Energy Agreement of 2012 established the following total targets for the ESOS: 10.7 PJ/year in 2013 and 2014, equivalent to 2.6% of final energy consumption and 12.2 PJ/year in 2015 corresponding to approximately 3.0% of final energy consumption (excluding transport). In the latest agreement from December 2016, the target was reduced to 10.1 PJ (0.241 Mtoe) per year from 2016 to 2020 because the costs of reaching the previous targets had increased. In 2016-20, the total target is spread among the distributors according to their volume of distributed energy.

In 2016, 43% of energy savings under ESOS were implemented in the manufacturing sector, including in companies covered by the Emissions Trading Scheme (ETS). A further 29% of the savings is implemented in households, 6% in the public sector and 18% in the commercial sector.

Obligated energy distributors can save any fuel, whether or not they sell that energy carrier. They can use a variety of measures from advice to grants to end-users, or a combination of different measures. The costs of the energy efficiency obligation (around DKK 0.02/kWh) can be included in the grid tariff and passed on to the end-user. There is a catalogue of eligible measures together with deemed savings that are awarded for each measure. In order to stimulate the measures that provide the greatest long-term benefits, weighting factors have been introduced that depend on the lifetime of the energy efficiency measures. To implement energy-saving measures, the network and distribution companies co-operate with various players, including installers, consulting engineers and energy-trading companies (IEA, 2017a).

The savings are measured or calculated using one of the three principal methods:

- Deemed savings: based on the results of previous energy improvements with the same technologies.
- Metered savings: direct measurement of the actual energy use before and after an intervention.
- Engineering calculations: estimates of savings based, for example, on physics or performance parameters.

The obligated companies are responsible for monitoring and evaluation (M&E). They must have a quality control system in place and must carry out an annual audit. Every second year, the audit may be carried out internally by the company itself, while in alternate years audits must be carried out externally by an independent auditor. The DEA does an independent random control every year.

Trading of savings credits among obligated parties (horizontal trading) is permitted in Denmark: compliance credit is given to the purchasing entity and subtracted from the performance reports of the selling entity (IEA, 2017a; Government of Denmark, 2017).

Cost-effectiveness and additionality (net impact) are the two aspects of the ESOS that receive a lot of attention in public debate. Some stakeholders argue that the current scheme does not exclude possible abuses, and that some distributors may artificially inflate the costs of implementing energy efficiency improvements. As these costs are recovered anyway through the tariffs, distributors do not necessarily have incentives for cost-efficiency.

Studies conducted by the DEA in 2008, 2012 and 2014 show that the additionality of the scheme is only around 20% in the residential sector, and around 50% in industry, *i.e.* about half the energy savings in businesses and about 80% of energy savings in households would have been implemented within three years anyway.[2] However, the studies demonstrate that even with this low level of additionality, the ESOS still achieves considerable socio-economic benefits (ENSPOL, 2015).

Because of growing costs of energy efficiency measures, as well as reported irregularities in implementing the ESOS, additional resources have been allocated to the DEA and the Danish Energy Regulatory Authority (DERA) since June 2017 to step up oversight and control of reported savings and of the expenses and accounting of the grid operators. In the second half of 2017, DERA establishes a Centre for Energy Savings to control and monitor network and distribution companies efforts to save energy. This Centre will focus mainly on the costs, economic and accounting issues, while the DEA will increase the monitoring and control of the energy savings realised.

Industry and other businesses

Voluntary agreement scheme

Since 1996, the DEA has concluded energy efficiency agreements with large, energy-intensive businesses. In the current scheme, effective from 2015, businesses that enter into a binding three-year agreement with the DEA and commit to energy efficiency improvements obtain a reduction of the PSO levy.[3] To pay this subsidy, a fund of DKK 185 million has been allocated annually for the period 2015-20.The future of the scheme is unclear after 2020 since the PSO will be phased out.

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[2] The methodology of the evaluation of additionality was heavily disputed, particularly as regards households.

[3] From 1996 to 2013, businesses had to agree to implement energy management and improve energy efficiency in their production in exchange for a substantial rebate on their energy saving tax. Following the removal of the energy saving tax (formerly CO_2 tax) on electricity for production processes from 2014, a new scheme was introduced in 2015, based on the PSO rebate.

In the framework of this agreement, the company commits to implement and maintain an energy management system certified to the international energy management standard DS/EN ISO 50001; complete energy-saving projects with a specified, simple payback period of less than five years: conduct special investigations of the business's energy consumption; and conduct thorough analyses of production processes and possibilities to introduce new technologies in order to reduce energy consumption in the long term.

This voluntary agreement scheme was amended in 2016 to include more participants. As of 2017, the scheme includes approximately 170 production sites throughout Denmark, which are operating in different energy-intensive sectors such as manufacturing of iron and plastic, food production, and manufacturing of glass-based products.

Renewable energy for production processes

The 2012 Energy Agreement allocated DKK 1.2 billion from 2013 to 2020 to support enterprises that replace fossil fuels with renewable energy in their production processes or switch to district heating. The scheme can provide grants for conversion of fossil fuel installations, connection to district heating, conversion of large energy systems producing energy for production processes for enterprises, and energy efficiency improvements in connection with conversion projects. When the Agreement was adopted, the expected effects of this scheme in 2020 were as follows:

- reduction in fossil energy: around 16 PJ/year (in 2017, the reduction achieved was 7.2 PJ)
- increase in share of renewables: around 1.1% (or 6.3 PJ)
- reduction in CO_2 emissions: around 1.5 % below the 1990 level, corresponding to 0.5 Mt per year.

Energy audits in large enterprises

In 2014, in compliance with Article 8 of the EU Energy Efficiency Directive, the Danish government adopted Order 1212 on energy audits in large enterprises. The Order requires large enterprises to conduct audits of their energy consumption on transport, processes and buildings every fourth year. The purpose of these mandatory energy audits is to identify cost-effective energy-saving potentials and to report on these results. There is no obligation to implement the energy-saving proposals. Companies that are ISO 50001-certified (i.e. have a voluntary agreement in place) are not required to comply with this audit obligation. The energy audit reports under this first round were submitted to the DEA from most of the large enterprises in Denmark in early 2017.

Secretariat for Energy Savings in private companies

The Secretariat for Energy Savings was established by DEA in 2014 to promote energy savings in private companies, especially in small and medium-sized enterprises (SMEs) and large non-ETS companies. It disseminates knowledge, advice and guidance on energy efficiency and conducts business-oriented studies, technology assessments, behavioural analysis and field work with the objective to support existing and future initiatives that can improve energy efficiency.

In 2016, the DEA launched a campaign, which screened lighting among more than 1 200 non-energy-intensive SMEs in private commerce and services. The campaign has demonstrated that retail enterprises on average can save DKK 31 million over a seven-year period by switching to light-emitting diodes (LED) lighting. In 2017 the campaign is extended to other SMEs within private commerce and services as well as agricultural farms with livestock.

Buildings

Denmark implements the EU Energy Performance of Buildings Directive, which includes the following requirements, among others:

- energy performance certificates must be included in all advertisements for the sale or rental of buildings
- inspection schemes for heating and air-conditioning systems (or measures with equivalent effect)
- all new buildings must be near-zero-energy buildings by 31 December 2020 (public buildings by 31 December 2018)
- minimum energy performance requirements for new buildings, for the major renovation of buildings, and for the replacement or retrofit of building elements.

In November 2016 the EU Commission proposed an update to the Energy Performance of Buildings Directive to help promote the use of smart technology in buildings and to streamline the existing rules.

Existing buildings

The Danish policy on existing buildings is based on the assumption that energy efficiency should be improved as part of the regular maintenance of the building stock, so that the investment in improving efficiency remains marginally above the cost of regular maintenance or renovations. Three types of measures are used to stimulate energy efficiency improvements. First, the high energy taxes provide strong incentives for building users to reduce energy consumption (see Chapter 1). Second, there are rules and regulations, mainly in the form of building codes (see below). Third, there are initiatives to raise awareness among building owners and users on possible options to improve efficiency, as well as their costs and benefits.

Implementing the 2012 Energy Agreement, the Danish government at the time launched in 2014 a strategy for the energy renovation of buildings (Box 7.1). It includes 21 specific initiatives aimed at different areas of the building stock and different stakeholders – from professional operators to private home-owners. These initiatives are expected to reduce energy consumption for heating in existing buildings by 35%.

The building code

The Danish building code plays a key role in ensuring energy efficiency in both new and existing buildings. The code is reviewed and updated at least every five years to reflect developments in technology and prices. It contains minimum energy performance requirements for new buildings and rules for upgrading energy efficiency as part of the renovation of existing buildings.

As regards new buildings, the energy requirements have been strengthened considerably over the last 25 years. A norm "*lavenergiklasse 2015"* (low-energy class 2015) became a legal requirement in 2015, and "*bygningsklasse 2020"* (building class 2020) is currently voluntary.

Box 7.1 Danish Strategy for the Energy Renovation of Buildings

The Strategy for the Energy Renovation of Buildings, adopted by the Danish government in 2014, includes 21 specific initiatives:

1. Initiatives aimed at all building segments

1.1. Upgrade energy standards for the building envelope, windows excluded

1.2. Upgrade energy standards for windows

1.3. Upgrade energy standards for installations in buildings

1.4. Ensure increased compliance with building regulations

1.5. Introduce voluntary energy classes for existing buildings

1.6. Upgrade energy standards for new buildings

1.7. Improve information and communication about energy renovation and energy efficiency in buildings

1.8. Target energy companies' energy-saving efforts

1.9. Ensure an effective and targeted energy labelling scheme for buildings

1.10. Ensure better data and tools decisions pertaining to energy renovation

1.11. Advance good financing frameworks for energy renovation

1.12. Present strategy for building policy

2. Initiatives aimed at one-family houses

2.1. Advance energy renovation in one-family houses through the "BedreBolig" scheme.

2.2. Advance prevalence of alternatives for oil- and gas-fired boilers using renewables

3. Initiatives aimed at multi-family buildings, office buildings and public buildings

3.1. Advance energy renovation of larger buildings through guaranteed offering

3.2. Advance energy renovation of council housing

3.3. Advance energy renovation of private rental properties, housing co-operatives and house-owners' associations

3.4. Advance energy renovation of commercial leases

3.5. Advance energy-efficient public buildings

4. Initiatives aimed at strengthening competences and innovation to advance energy renovation

4.1. Strengthen the development of education and competences within energy renovation

4.2. Strengthen research, innovation and demonstration of energy renovation

Source: The State of Green (2014), New Danish Strategy for Energy Renovation of Buildings, State of Green website accessed on 19 July 2017: https://stateofgreen.com/en/news/new-danish-strategy-for-energy-renovation-of-buildings

Compliance with the code requirements for new buildings is ensured through the licensing process. The authorities can only issue building permits if it is proved that the new building meets the applicable energy requirements. Furthermore, once a building has been constructed, an independent expert has to review the building and issue an energy performance certificate documenting that the building meets the requirements in the building permit.

As regards existing buildings, there are two separate requirements applicable in different situations. When certain building components are replaced, the new component must comply with a minimum energy efficiency requirement. This applies to windows, boilers, ventilation systems, etc. The standards are identical to the standards that apply to new buildings, so that there is no market for components that do not meet the standards. Regarding the insulation of walls, ceilings and floors, certain energy efficiency requirements shall be fulfilled if the payback time of the marginal investment to improve insulation is shorter than the lifetime of the investment multiplied by 0.75. Information on the building code requirements is provided to building owners. Furthermore, constructors are requested to inform the building owners on the rules, and can be held responsible if the rules are not followed.

Energy labelling of buildings

Denmark has introduced the energy labelling of buildings into Danish law in order to target end-user consumption in existing buildings. The purposes of the labelling include: *i)* to make energy specifications of buildings visible to different stakeholders, including owners, buyers, renters, etc.; and *ii)* to deliver a plan with recommendations for possible measures to improve efficiency and reduce energy demand. The label, plan and documentation are elaborated by an energy consultant and are paid by the seller/owner of the house. Several studies suggest that there is a positive correlation between the labelling grade and the market price for individual houses, i.e. houses with higher grades have higher selling prices (DEA, 2015). However, the impact of this correlation on stimulating renovation is unclear.

BedreBolig (Better Homes)

BedreBolig (Better Homes) is a scheme introduced on 1 January 2014 focusing on promoting the energy retrofitting of residential buildings. It creates a “one-stop shop” that offers comprehensive expert advice throughout the energy renovation process to make it easier and quicker for home-owners to renovate their homes. BedreBolig focuses on, among other things, developing co-operation between home-owners and financial institutions. The programme targets all forms of energy consumption, including space heating and cooling, water heating and lighting. BedreBolig provides specialised education to professionals such as architects, engineers, craftsmen, energy consultants and building designers to become advisors on renovation in private homes and apartment buildings with a focus on energy efficiency.

Energy efficiency in central government

Since 1992, all ministries have been obliged to reduce their energy consumption. In the period 2006-20, the ministries must reduce their energy consumption by 14%. They are free to choose the measures. The reduction target is an implementation of the EU Energy Efficiency Directive’s article 5, which sets a requirement to increase the energy performance of buildings owned and occupied by central government.

In addition to the binding targets, the regulation in force requires the ministries to: *i)* adopt energy-efficient behaviour; *ii)* consider energy-saving measures as part of public procurement (e.g. integration of occupancy sensors and daylight sensors in lighting control); and *iii)* make their energy and water consumption available for public scrutiny in the database *Offentligt Energiforbrug* ("Public Energy Consumption"). Over the last years, several tools for total cost-of-ownership calculations in the investments of different categories of products have been developed for *Udbudsportalen* (the Tenders Portal).

The evaluation conducted in 2016 demonstrates that, overall, the ministries are well on track towards meeting the 2020 target. In total, ministries have reduced their energy consumption by 10.4% from 2006 to 2015 despite a significant growth in the number of employees.

Appliances

Several policies and measures targeting buildings, industry and/or other end-user sectors, also have an impact on the energy efficiency of appliances. For example, the building regulations from 2015 (BR15) increased requirements for new buildings to a level where the energy efficiency of fixed lighting systems now *de facto* requires installation of high-efficiency LED lighting.

Measures that specifically target appliances are as follows.

Ecodesign and energy labelling

The Danish policy for energy-efficient appliances is mainly driven by the EU Ecodesign Directive (2009/125/EC) and the Energy Labelling Directive (2010/30/EU). The Ecodesign requirements set minimum standards for the amount of energy allowed to be consumed by appliances sold in the internal EU market. The Ecodesign rules can also include environmental parameters. The objective of eco-labelling is to visualise the products' energy consumption and to allow the consumer to make informed choices. In addition, a number of voluntary schemes are used in Denmark, including the Energy Star, the EU Flower, the Nordic Swan Ecolabel and the EU Code of Conduct.

By the end of 2016, ecodesign regulations covered more than 50 product categories ranging from household appliances to building components and products used by enterprises, such as power transformers and professional refrigerated storage cabinets. Furthermore, the standby regulation has requirements for standby and off-mode power consumption applying to a broad range of household and office equipment.

The DEA enforces the implementation of the Energy Labelling and Ecodesign legislation in Denmark via internet controls, shop controls, document inspections and measurement inspections. The Secretariat for Ecodesign and Energy Labelling is responsible for the practical elements of the market surveillance on behalf of the DEA.

In 2013, the DEA conducted an analysis to calculate the impact of the ecodesign requirements to be 5.640 GWh in 2020, corresponding to 5% of energy consumption in 2011, excluding transport.

Raising awareness

Danish authorities actively disseminate information targeted on private and professional energy consumers in order to enhance the market uptake of more energy-efficient products. The main platform for this is the web page www.sparenergi.dk supplemented by printed guidelines about purchasing and using various energy-consuming products from household appliances to building service equipment (ventilation units, space heaters, and other) distributed by retailers. Those who sell energy-consuming products are being trained to understand and explain energy labels, e.g. by e-learning courses organised by trade associations.

Transport

Chapter 6 on climate change provides an overview of policies and measures in the transport sector. The instruments to enhance energy efficiency in transport include:

- fuel efficiency standards for passenger vehicles in line with EU standards
- vehicle taxation that encourages the purchase of cars with low fuel consumption
- energy efficiency requirements for taxis
- a "green driving" element in mandatory refresher courses for professional drivers
- electrification of the railway, etc.

Assessment

Progress to date

Denmark is to be praised for impressive decoupling of GDP growth from energy consumption growth. Over the last decade, total final consumption (TFC) of energy dropped in all sectors, with the most remarkable decline in industry. These reductions have been achieved thanks to the Danish efforts to set national energy efficiency objectives and to adopt various measures towards meeting these goals. Successful implementation of these measures has made Denmark a very energy-efficient country by international standards: Denmark's energy intensity is among the lowest in all IEA member countries.

The growing costs of implementing energy efficiency give the perception that the most cost-efficient measures ("low-hanging fruit") may have already been implemented. Nevertheless, the "low-hanging fruit" is likely to grow further in the future as the infrastructures, buildings and equipment become older and energy efficiency technologies improve. In these circumstances, the Danish government is to be praised for conducting a review of all existing energy efficiency measures, building on the country's success to date. Taking into consideration the very large shares of renewable power with low marginal cost, it is positive that the ongoing analysis aims not only at comparing the energy efficiency instruments between themselves but also at establishing – in a holistic manner – the optimum economic balance between policies on the demand side (energy efficiency) and on the supply side (expansion of renewable energy production capacity).

Current measures

The main measure on the supply side is the Energy Savings Obligation Scheme (ESOS) for grid and distribution companies in the electricity, natural gas, district heating and oil sectors. The ESOS is a market-oriented system which allows participants to choose the most cost-efficient measures to achieve savings. The annual saving targets set by the ESOS have always been fulfilled. However, the additionality of this scheme is rather low, especially in the residential sector. Moreover, possibilities for gaming have been reported, as well as the lack of incentives to reduce the costs of implementing the obligation. Another issue highlighted in public debate is the difficulty to implement meaningful measures without regular and direct contacts with the end-users. This is particularly valid for distributors of oil products who have direct contacts only with some large clients who have supply contracts.

The IEA praises the recent decision to allocate additional resources to the DEA to enhance oversight and control of the savings and to DERA to enhance oversight of the expenses and accounting of the grid operators. Furthermore, cost-effectiveness of the scheme could be increased and welfare losses reduced by more systematically verifying the additionality of the measures. The government could also consider shifting the obligation from the distributor to the supplier, because the supplier has direct contact with the end-users, and can therefore implement energy savings more effectively. As for distributors, they should not interfere in the relation between the supplier and the end-user to avoid competition distortion.

A further cost-effective measure in the Danish industry sector is the Voluntary Agreement Scheme for energy-intensive businesses. The businesses have to agree to implement energy management and improve energy efficiency in their production in exchange for a substantial reduction of their PSO levy. However, by 2022, the PSO will be phased out and its function transferred to the general budget. With this shift, the financial basis for the incentive scheme disappears and resources are only allocated to the scheme until 2020. How the system will continue needs to be clarified. The ongoing assessment of energy efficiency measures can be used to compare the voluntary agreement scheme with the ESOS in terms of cost-effectiveness and additionality of energy savings to prevent overlapping measures and double counting of savings. An option to continue with the Voluntary Agreement Scheme is to increase the electricity tax (or other energy taxes) in industry (DKK 0.004/kWh at the moment), except for those committing to efficiency agreements. Special rules for SMEs could be considered in order to keep their administrative burden proportionate.

For smaller energy-consuming companies that cannot participate in the voluntary agreement scheme, especially SMEs and non-ETS companies, the DEA promotes energy savings by dissemination of knowledge, advice and guidance on energy efficiency. Such measures are very important because the savings potential in smaller companies is often very high, but these companies tend to lack knowledge of energy efficiency opportunities, costs and benefits.

The building sector lowers its energy intensity mainly through the high standards for new buildings, which have been strengthened considerably. Regarding existing buildings, despite numerous initiatives launched over the last several years, the rate of renovations is still quite low. The improvement of the existing building stock remains one of the major challenges in the future. One particular area that may require the government's attention is the energy labelling of buildings. Studies show that the grade has an impact on real estate selling prices. The impact of labelling on renovations is not clear.

Going further

As stated above, the Danish government is to be commended for the attempts to look at both energy efficiency and renewable energy development in a holistic manner in order to find the optimal balance between supply-side and demand-side policies. In pursuing this direction, however, the government should not forget the multiple benefits of energy efficiency beyond energy demand reduction and lower GHG emissions. An IEA study (IEA, 2014) highlights the important role of energy efficiency in generating a broad range of positive outcomes, including those that improve citizens' wealth and welfare. These potential benefits of energy efficiency should be captured so as to offer a possibility to send better socio-economic signals to complement market signals.

In designing future energy efficiency policies, the Danish government is encouraged to pay even greater attention to market-based, cross-cutting solutions. A recent IEA study analysed energy efficiency obligations and auctions in different countries and found out that these market-based instruments are saving significant amounts of energy at a cost below the cost of supply. Across all programmes for which data are available, the average total cost per lifetime kilowatt-hour saved is less than USD 0.03, without taking into account the significant environmental and socio-economic benefits of efficiency improvements (IEA, 2017b).

The benefits of market-based instruments arise from the freedom given to private-sector actors to innovate and use the most optimal technologies and delivery routes. Denmark has already gained experience with market-based schemes and has a good basis for continuation. Its current ESOS can be improved by limiting the possibilities for the participants to "game" the system or to deliver suboptimal outcomes. To achieve this, it is essential to have high-quality monitoring, verification and evaluation, including regular reviews to take account of changing market conditions

The future market-based scheme design should consider the interaction with supply-side incentives and measures, particularly those encouraging renewable energy.

Recommendations

The government of Denmark should:

- ☐ Build upon the assessment of energy efficiency measures to develop an overall energy efficiency target beyond 2020 supported by policies and measures that ensure continuing energy efficiency improvements across all sectors of the economy.
- ☐ In shaping the future policies and measures, take into consideration possible overlaps between instruments, the interactions between demand-side and supply-side decarbonisation actions, as well as the multiple socio-economic benefits of energy efficiency.
- ☐ Ensure that appropriate resources are allocated for the oversight of energy efficiency instruments, particularly market-based schemes such as the Energy Savings Obligation Scheme, to ensure compliance, decrease possible gaming and increase their cost-effectiveness and welfare for consumers.

- Focus more policy attention on the existing building stock.
- Consider to place the Energy Savings Obligation Scheme on the supplier, rather than on the distributor, or other initiatives to facilitate more effective implementation of energy efficiency measures and to avoid potential competition distortion in the retail sector.
- Continue the voluntary agreements – while ensuring their complementarity and avoiding overlap with other instruments – in the absence of the public service obligation, by increasing the electricity tax (or other energy taxes) in the industry sector, except for those committing to efficiency agreements.

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8. Renewable energy

Key data

(2016 provisional)

Total supply: 5.4 Mtoe (32.4% of TPES) and 18.9 TWh (62.9% of electricity generation). IEA average: 9.9% of TPES and 24.4% of electricity generation.*

Biofuels and waste: 4.1 Mtoe (25.1% of TPES) and 5.4 TWh (17.9% of electricity generation)

Wind: 1.1 Mtoe (6.7% of TPES) and 12.8 TWh (42.5% of electricity generation)

Solar: 0.1 Mtoe (0.7% of TPES) and 0.7 TWh (2.5% of electricity generation)

Hydro: 0.002 Mtoe (0.01% of TPES) and 0.02 TWh (0.1% of electricity generation)

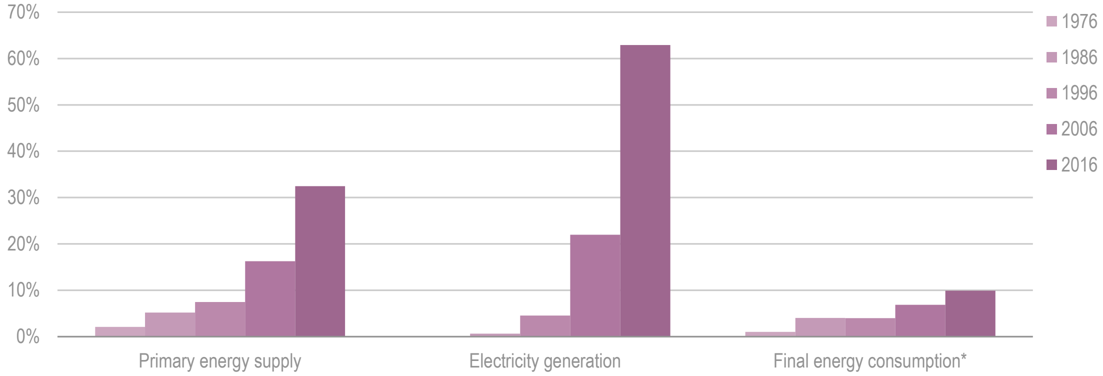
*Including 0.41 Mtoe of non-renewable municipal waste, which accounts for 10% of total biofuels and waste. Renewable energy, excluding non-renewable waste, was 5.0 Mtoe in 2016 (30.0% of TPES and 60.6% of electricity generation, compared to IEA averages of 9.6% of TPES and 24.2% of electricity generation).

Overview

Denmark has ambitious national targets related to renewable energy (RE): to meet at least 50% of energy consumption with RE in 2030 and to become a low-carbon society by 2050. In line with these goals, the share of renewables has increased significantly in both total primary energy supply (TPES), mainly from biofuels and waste, and in electricity generation, mainly from wind power. In 2016, wind power accounted for 42.5% of all electricity generation in Denmark, making the country the world leader in integrating variable renewable energy (VRE) sources in the electricity system. In terms of TPES, biofuels and waste are the biggest renewable source, at around one-quarter of TPES and 18% of electricity generation (16% if excluding non-renewable waste) in 2016. Biofuels and waste are mainly used for district heating and electricity generation in combined heat and power (CHP) plants. Non-renewable waste accounts for 10% of total supply of biofuels and waste. Solar energy accounts for only small shares in TPES and electricity generation, but it has been increasing significantly in recent years.

This chapter describes RE development trends and projections, as well as current policies and measures to support RE in electricity, heating and transport. Chapter 9 looks in more detail at integrating variable renewable energy generation in the energy system, and Chapter 10 focuses on the role of RE in heating.

Figure 8.1 Renewables share of TPES, electricity generation and final energy consumption, 1976-2016



*The latest consumption data are for 2015.

Notes: Includes shares of non-renewable waste. Data are provisional for 2016.

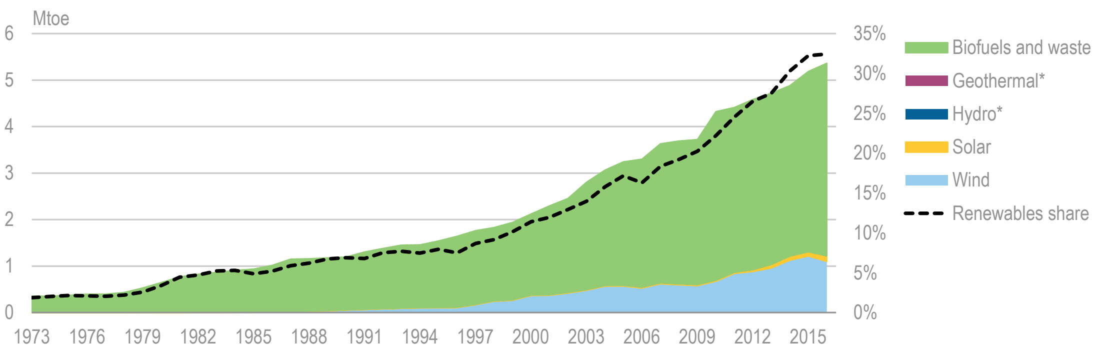
Source: IEA (2017a), *World Energy Balances 2017,* www.iea.org/statistics/.

Supply and demand

Renewable energy and waste in TPES

In 2016, Denmark's total renewable energy supply was 5.4 Mtoe, a 63% increase since 2006. As this increase occurred simultaneously with a considerable decline in total TPES, the share of renewable energy in TPES increased remarkably from 16% in 2006 to 32.4% in 2016 (see Figure 8.2). Denmark's share of renewable energy in TPES was the fifth-highest among IEA countries, behind Norway, New Zealand, Sweden and Austria (see Figure 8.3). Denmark's renewable energy mainly comprises biofuels and waste, wind and solar, and small amounts of hydro and geothermal.

Figure 8.2 Renewable energy and waste in TPES, 1973-2016

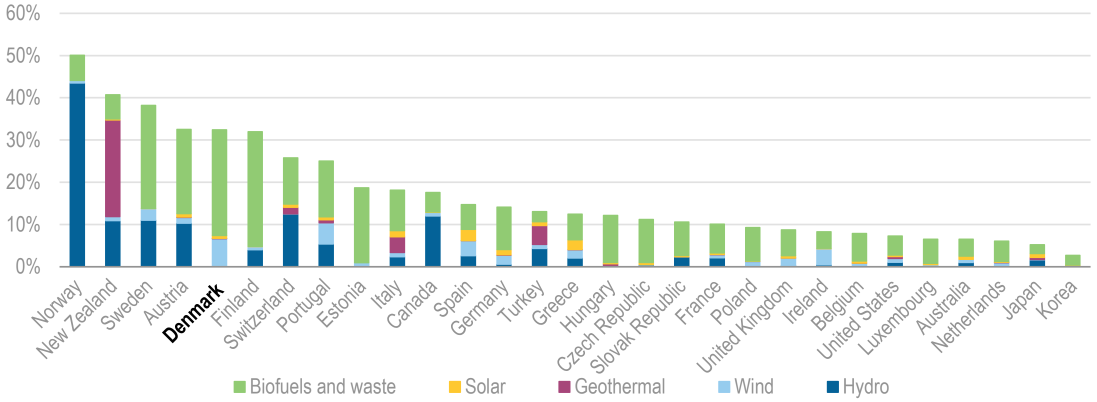


*Negligible.

Note: Data are provisional for 2016.

Source: IEA (2017a), *World Energy Balances 2017,* www.iea.org/statistics/.

Figure 8.3 Renewable energy and waste as a percentage of TPES in Denmark and in IEA member countries, 2016



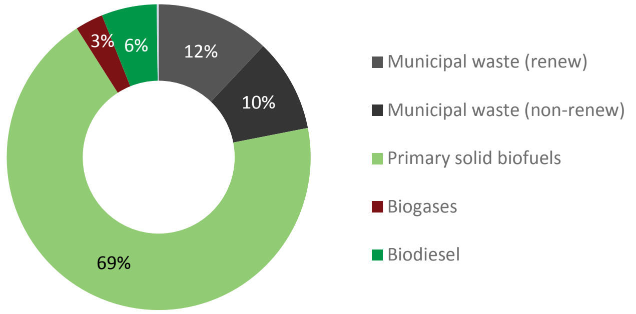
Note: Data are provisional.

Source: IEA (2017a), *World Energy Balances 2017,* www.iea.org/statistics/.

Biofuels and waste are the largest renewable energy source in Denmark, and the second-largest overall after oil, at one-quarter of TPES in 2016. The government has promoted biofuels and waste considering their importance as a renewable source to replace fossil fuels, particularly for heat production. As a result, biofuels and waste supply increased by 50% from 2006 to 2016.

Primary solid biofuels such as wood pellets, wood chips and straw, account for over two-thirds of TPES of biofuels and waste. Municipal waste is the second-largest fuel in the biofuel category, at one-fifth of total biofuels and waste, and little more than half of it is renewable waste. Finally, transport biodiesel accounts for 6% of total biofuels, and biogas for 3% (see Figure 8.4).

Figure 8.4 Supply of biofuels and waste, 2016



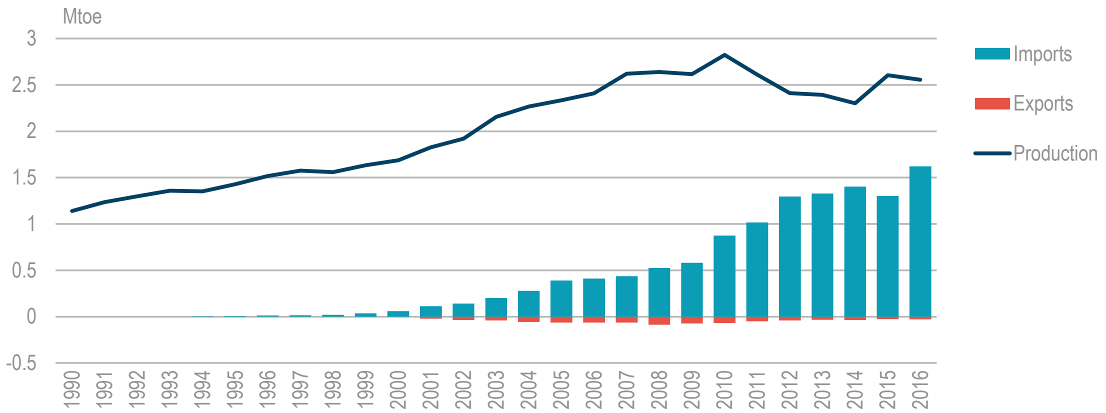
Note: Data are provisional.

Source: IEA (2017a), *World Energy Balances 2017,* www.iea.org/statistics/.

Most of biomass and waste are produced internally in Denmark in the years 2000; however, imports have increased significantly over the last decade. Net imports accounted for 39% of total supply of biomass and waste in 2016 (Figure 8.5). This includes biodiesels used in the transport sector, accounting for 17%, with the rest being primary solid biofuels and imported waste used in heat and power generation. Most of biomass and waste imports come from the Baltic region (Estonia and Latvia), followed by the Russian Federation.

Solid biofuels and waste are both mainly used for combined heat and power (CHP) production. Large-scale biomass CHP plants have been deployed since the early 1990s, and many coal-fired CHP plants have been converted into plants using biomass. In 2015, biofuels and waste accounted for over half total district heat production.

Figure 8.5 Production, imports and exports of biomass and waste, 1990-2016



Note: Data are provisional for 2016.

Source: IEA (2017a), *World Energy Balances 2017,* www.iea.org/statistics/.

Wind is also an important energy source for Denmark, accounting for 6.6% of TPES. Over the past decade, it has become the largest energy source for power generation, as it increased its share from 18% to 42.5% of total electricity generated in 2016. Solar energy accounted for only 0.7% of TPES in 2016. However, recent growth in solar PV is noteworthy and it is projected to continue to grow rapidly. From 2006 to 2016, it grew on average by 29% per year.

Electricity from renewable energy and waste

Nearly two-thirds of electricity was generated from renewable sources in 2016, compared to less than one-fifth in 2006 (see Figure 8.6). Over the past decade, electricity generated from renewable sources increased by 89% while total electricity generation decreased by 34%. Denmark's renewable energy share in electricity generation is the seventh-highest among IEA member countries (see Figure 8.7).

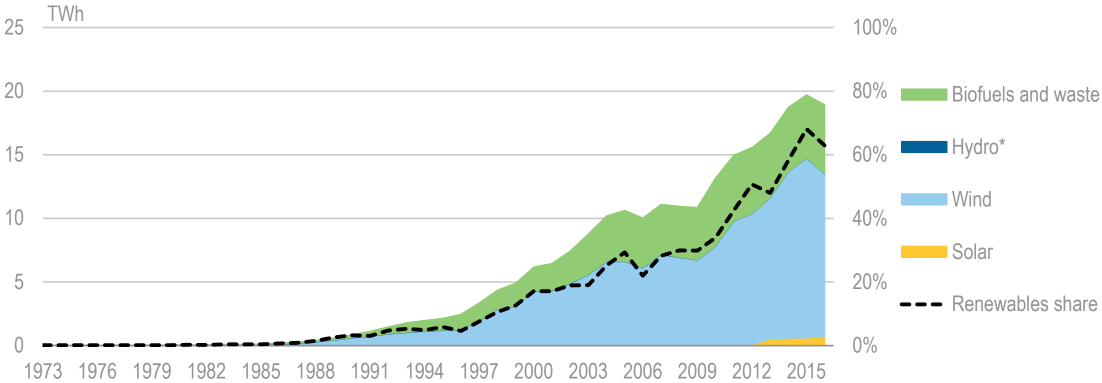
The growth in renewable electricity generation in Denmark has been possible thanks to a remarkable increase in wind power capacity. Only a decade ago, the energy mix for power generation was dominated by coal. However, electricity generation from wind has more than doubled from 2006 to 2016, while coal power generation dropped by more than half. Consequently, wind took over the dominant position, increasing its share to a record-high of 48.8% in 2015.

In 2016, the share of wind power in electricity supply fell back to 42.5% because of weather conditions. According to the Danish Wind Industry Association (Weston, 2016), 2015 had been the windiest year since 1994 with 14% more wind than on average, whereas 2016 had 10% less wind than on an average year. Nevertheless, Denmark is expected to exceed the goal of supplying 50% of electricity from wind in 2020 which was set in the 2012 Energy Agreement.

Biofuels and waste together are the second-largest renewable source for electricity generation, accounting for 17.9% of total generation in 2016. From 2006 to 2016, power generation from biofuels increased by 38%, mainly because of a fuel switch from coal to biomass in several CHP plants.

Solar accounted for 2.5% of total electricity generation in 2016, an increase from negligible levels in 2006. Subsidised investments in solar photovoltaics (PV) boomed in 2012 and have continuously grown since. Denmark achieved its 2020 goal of 200 megawatts (MW) of installed solar capacity already in 2012, and reached nearly 800 MW in 2015.

Figure 8.6 Renewable energy and waste in electricity generation, 1973-2016

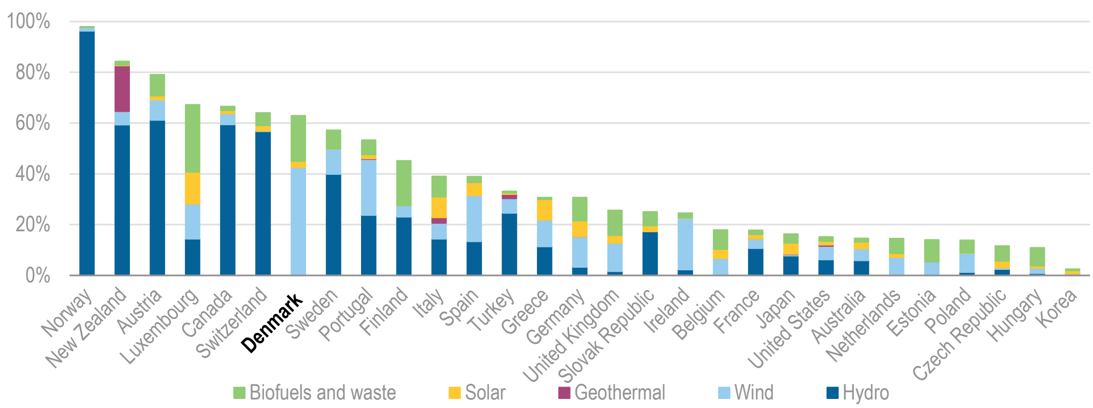


*Negligible.

Note: Data are estimated for 2016.

Source: IEA (2017a), *World Energy Balances 2017*, www.iea.org/statistics/.

Figure 8.7 Electricity generation from renewable energy and waste as a percentage of all generation in Denmark and IEA member countries, 2016



Note: Data are provisional.

Source: IEA (2017a), *World Energy Balances 2017*, www.iea.org/statistics/.

Renewable energy potential

Denmark has abundant wind energy resources. The average onshore wind speed at a height of 100 metres is between 6 and 10 metres per second (m/s). More than 7 300 km of coastline and low average sea depth lead to significant additional offshore and near-shore wind potential. Average offshore wind speed lies between 9 and 11 m/s, with the highest wind speeds occurring at the western coast (IRENA, 2016; IEA, 2016).

Solar resources are more limited because of Denmark's geographic position. During the period 2001-15, The country experienced a global horizontal irradiation (GHI) ranging between 950 kilowatt hours per square metre (kWh/m^2) and 1 050 kWh/m^2 per year. By comparison, South Africa's GHI can exceed 2 000 kWh/m^2 per year (IEA, 2016).

Studies commissioned by the government in 2014 estimate that it could be technically possible to increase the production of biomass in Denmark to up to 190 petajoules (4.5 Mtoe) per year by 2020 (Bentsen and Stupak, 2014) and to 205-245 PJ (4.9-5.8 Mtoe) per year by 2050 (DEA, 2014). However, the import of biomass is increasing for economic reasons and is expected to play a significant role in the future. Biogas potential from agriculture waste is estimated at around 56 PJ (1.3 Mtoe) per year, of which only 20 PJ (0.5 Mtoe) were used in 2010 (Ministry of Food, Agriculture and Fisheries, 2010).

Policies and measures

Targets and objectives

Denmark's national targets include: meeting at least 50% of Denmark's energy demand by renewable energy in 2030 and becoming a "low-emission society" by 2050 (see Chapter 6 on energy and climate change). In addition, Denmark has two binding EU obligations:

- Increase the share of renewable energy in gross final energy consumption to 30% by 2020, from 16% in 2005. Denmark has already exceeded the target with renewable energy accounting for 32.4% of the total in 2016. By 2020, the country is expected to reach 40% with existing measures.
- Reach the share of renewable energy in land-based transport of at least 10% by 2020. The baseline projections suggest that, with existing measures, Denmark will fall short and reach around 8.4% by 2020.

While no further policies are needed to meet the 30% RE target in 2020, additional actions are required to meet the 10% target in the transport sector and the 50% RE target in 2030. Most RE support schemes will expire in the near future, and negotiations on new measures are taking place in 2017.

Renewable energy – along with energy efficiency – is the key focus of the 2012 Energy Agreement, which includes the following targets, expectations, and measures:

- construction of 1 378 MW of offshore and "nearshore" wind capacity; increasing net onshore wind capacity by 500 MW despite decommissioning of old turbines
- conversion of CHP plants and heat-only boilers from coal to biomass
- increased use of biogas in CHP plants, industrial processes and transport, as well as increased injection of upgraded biogas into natural gas networks
- subsidies to promote efficient use of renewable energy and CHP in enterprises

- a ban on installing oil-fired and gas-fired boilers in new buildings from 2013 onwards, and on oil-fired boilers in existing buildings from 2016 onwards in areas with district heating or natural gas
- information campaigns on support for converting oil-fired and gas-fired boilers in existing buildings to renewable alternatives (solar, heat pumps, etc.)

As discussed in Chapter 1 on general energy policy, most of the envisaged outcomes of the Energy Agreement of 2012 have been almost achieved by end of 2016.

Overview of the support framework

Renewable energy is supported in Denmark by both direct subsidies (such as feed-in premiums) and indirect subsidies, which include taxation (tax exemptions on biomass, high tax on residential electricity, which stimulates own generation by RE-based systems), subsidised grid connection and balancing costs, and reinforcement of the grid to connect RE plants. Denmark also has used several funding ”pools”, such as the pool for RE technologies in district heating (geothermal energy and large heat pumps) in 2012-15 and the pool for RE in processing (2013-20).

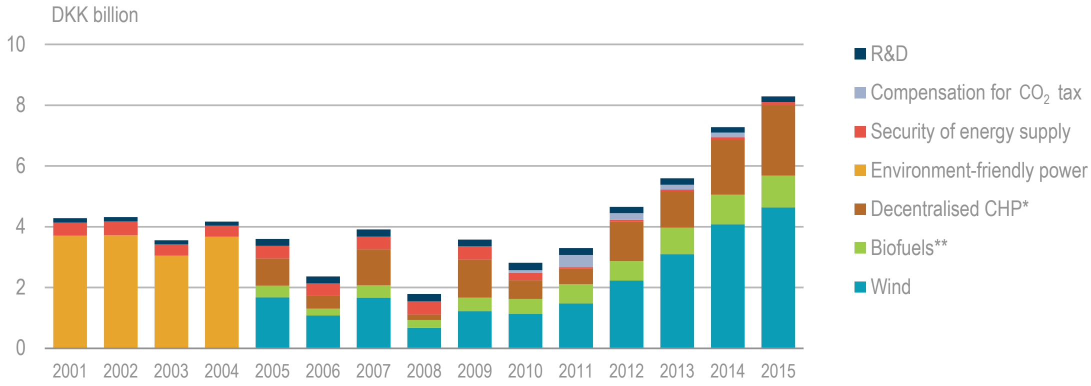
As regards administrative processes for developing RE projects, Denmark has implemented most of the requirements of the EU Renewable Energy Directive: one-stop shop (for offshore wind only); online application; maximum time limit for procedures; automatic permission after deadline; facilitated procedures for small-scale producers; and identification of geographical sites (EC, 2017). While the permitting, licensing and authorisation procedures are generally transparent and straightforward, some stakeholders complain that the administrative procedures to construct a RE power plant take a long time, which can be prohibitive for small-scale projects.

Most of the existing RE support measures are being financed by the public service obligation (PSO) levy added to the electricity price. The PSO is being phased out in 2017-21. In the future, RE development will be supported directly from the state budget through increased general taxation. This decision is driven by the following considerations:

- response to EU concern over possible trade distortion
- economic benefits due to reduced tax distortion
- reduced electricity consumer prices, which can stimulate increased electrification
- stronger state budget prioritisation and better cost control.

The overall costs of supporting RE via the PSO have increased quite sharply since 2010 (Figure 8.8) to over DKK 8 billion in 2015, mainly because of steadily growing RE generation eligible for support coupled with low electricity prices. In absolute terms, the payments for offshore wind and decentralised cogeneration were the largest in 2015, followed by payments for onshore wind plants (see Figure 8.8). The cost of support per unit of RE generation is the highest for biogas (Figure 8.9).

Figure 8.8 Increasing cost in financing RE in Denmark at current prices, 2001-15

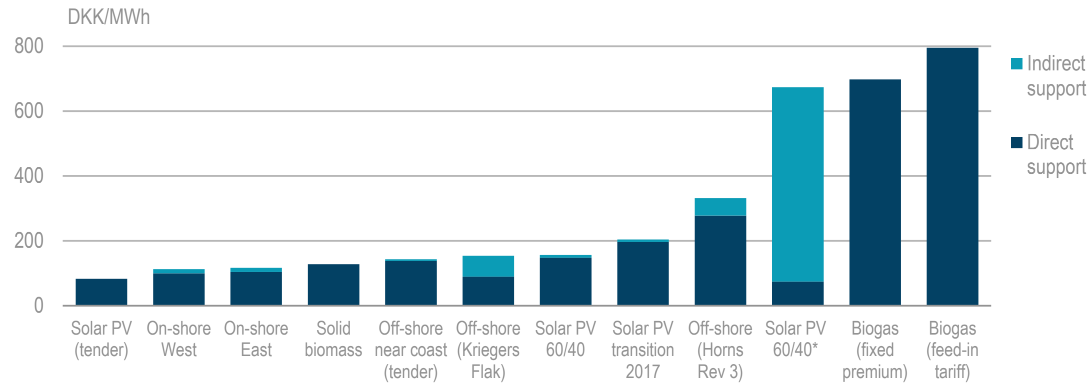


*CHP = combined heat and power.

***Biofuels* includes solid biomass and biogas.

Source: Danish Energy Agency.

Figure 8.9 Support rates for renewable energy technologies throughout the project lifetime



Source: Danish Energy Agency.

Future support framework

The Energy Commission, which published its recommendations on Danish energy policy after 2020 in April 2017 (see Chapter 1, Box 1.1), estimates that the costs of reaching the 50% RE target are manageable, provided Denmark can reduce the need for subsidies for renewable energy deployment, and in the long term make the development market-driven. The Commission recommends the use of market-based instruments in order to reduce prices and to minimise distortion in the electricity market. The Commission recognises the need for RE subsidies in the near future, and argues that support should no longer focus on individual renewable energy technologies, but rather on a principle of “technology neutrality” whereby different renewable energy technologies compete with one another. This technology neutrality principle, according to the Commission, should take into account the socio-economic costs of different technologies. This means that support schemes should account for positive and negative externalities of different technologies that are not priced by the market, for example noise generated by wind turbines or reduced nitrogen leaching by slurry-based biogas production.

The following factors will likely have an impact on the structure of the future support mechanisms:

- costs of RE technologies
- socio-economic costs and benefits of RE technologies
- electricity market prices
- the development of the EU Emissions Trading Scheme (ETS) (see Chapter 6, Box 6.1)
- EU Renewable Energy Directive
- EU State Aid Guidelines and other EU-driven requirements.

Electricity

Electricity production from RE has been mainly supported by premiums added to the electricity market price. The 2009 Law on the Promotion of Renewable Energy introduced two possible premiums:

- Variable feed-in premium (FIP) that covers the difference between average annual electricity prices and the target remuneration for a limited number of full-load hours of production.
- Fixed FIP: in this case, plant operators receive a fixed bonus per megawatt hour (MWh) on top of the market price for a limited number of full-load hours of production. A cap (maximum of bonus plus market price) is defined by law for certain technologies.

Since 2009, the RE law has been amended several times. The level of premiums has been set by political agreements for most technologies, except offshore wind. The premium for offshore wind plants has been decided through tenders.

According to the Council of European Energy Regulators' report on renewable energy subsidies in Europe (CEER, 2017), 62% of gross electricity in Denmark is produced with RE support, compared to only 1% in Norway (where most electricity is produced by large hydro plants that do not need subsidies) and an average of 16% across 26 EU countries. However, when comparing the unit support levels (direct cost per MWh of supported electricity) Denmark ranks the eighth-lowest at EUR 46.02/MWh (compared to the weighted average support across 26 countries of EUR 110.22/MWh, varying from EUR 16.20/MWh in Norway to EUR 183.82/MWh in the Czech Republic).

Onshore wind

Onshore wind plants commissioned since January 2014 benefit from a fixed FIP of DKK 250/MWh (EUR 33.6/MWh) on top of the market price for the first 22.000 full load hours. An additional premium of DKK 18/MWh (EUR 2.4/MWh) is paid to cover the cost of balancing out forecast errors. The maximum remuneration is capped at DKK 580/MWh (EUR 78/MWh). This support scheme expires in February 2018. As a replacement, the government has proposed a technology-neutral tender scheme between wind and solar in 2018-20.

Offshore wind

Offshore wind plants may be constructed following either a tender or an open-door procedure. In the latter, the project developer chooses a site among those that are not specifically designated for tendering and submits an unsolicited application for a licence to carry out preliminary investigations in that area. As of mid-2017, no offshore project has been completed under this regime.

In recent years, several tenders have been held for large offshore projects (Table 8.1). The Danish Energy Agency (DEA) conducts the tenders in several stages. In brief, it invites the pre-qualified applicants to submit a quotation for the maximum price at which the bidders are willing to produce a certain amount of electricity, calculated on the basis of a given number of full-load hours. For example, for the Horns Rev and the Rødsand 2 wind plants, the guaranteed remuneration (market price plus premium) applies to 50 000 full-load hours, which corresponds to 10 TWh generated, while for the larger Anholt and Horns Rev 3 plants, this corresponds to 20 TWh. This equals to approximately 12 to 15 years depending on wind conditions and operation efficiency. After this, the electricity produced has to be sold on market conditions. The premium is not paid in hours with a negative or zero spot price, which Denmark typically experiences a few hours per year. Access to the network is guaranteed to the winner of the tender: Energinet.dk is obliged to provide a transformer station and an underwater cable to connect the plant to the main network.

Effective tendering procedures (see Box 8.1) and technological advances in offshore wind have led to a reduction in cost of offshore wind by 48% since 2010. In 2016, the winning bid at Kriegers Flak – EUR 49.9 per MWh for 11 years – was at the time the world lowest cost for offshore wind power, even if grid costs were added (Figure 8.10).

As a result of the ambitious support policy for onshore and offshore wind, Denmark has become a global leader in wind energy technologies throughout the supply chain. The industry employs around 33 000 people, according to the Danish Wind Industry Association.

Table 8.1 Outcomes of large-scale offshore wind tenders

Offshore wind farm	Auction held	Size (MW)	Operator	Winning bid nominal price, øre/kWh (USc/kWh)	Winning bid fixed 2016-price	Duration of support (full load hours)
Horns Rev 2	Feb 2005	209	DONG Energy	51.8 (8.6)	64 (9.6)	50 000
Rødsand 2	April 2008	207	E.ON AB	62.9 (12.3)	70.6 (10.6)	53 000
Anholt	April 2010	400	DONG Energy	105.1 (18.7)	113.6 (17)	50 000
Horns Rev 3	Feb 2015	406.7	Vattenfall	77 (11.4)	78.2 (11.7)	50 000
Nearshore (2 projects)	Sep 2016	350	Vattenfall	47.5 (8.0)	47.5 (8)	50 000
Kriegers Flak	Nov 2016	600	Vattenfall	37.2 (5.6)	37.2 (5.6)	50 000

Sources: DEA (2016), *Offshore Wind in Denmark Setting New Global Price Record*; DEA (2017), *Danish Experiences from Offshore Wind Development*.

Box 8.1 Tenders for offshore wind plants

The Danish Energy Agency (DEA) prepares a tender for an offshore wind turbine project of a specific size within a specifically defined geographical area. The areas are identified through the spatial planning process, involving various stakeholders. The spatial planning committee, established in 1995, leads identification and validation of potential sites. The report *Future Offshore Wind Turbine Locations – 2025*, published in April 2007 and updated in 2011, identified 23 specific possible locations, where at each location about 400 MW of offshore wind capacity could be constructed. In addition, 15 suitable nearshore sites have been identified in a mapping exercise carried out in 2011, each with a possible capacity of up to 200 MW.

Ahead of the tender, the TSO Energinet.dk carries out the environmental impact assessment (EIA) as well as geophysical and some geotechnical surveys. The results of the preliminary assessments, as well as their costs, are published before the completion of the tendering procedure. The costs of the preliminary studies will subsequently be refunded by the winner. Energinet.dk also finances, constructs, owns and maintains the transformer station and the underwater cable between the land and the offshore wind plant.

In preparing the tender, DEA acts as a one-stop shop and co-ordinates consultation processes with other authorities. As a result, the winner of the tender gets all the necessary permits and authorisations (including grid connection), which include the terms and conditions not only from DEA and Energinet.dk but also from the Danish Nature Agency, the Danish Maritime Authority, the Danish Coastal Authority, the Danish Agency for Culture, the Ministry of Defence, etc.

The key steps in the tenders are as follows:

- **Technical dialogue with interested tenderers and investors**

The Danish Energy Agency invites potential tenderers and investors to a bilateral technical dialogue – on principles of equal treatment, transparency and proportionality – to enable adjustment of preliminary surveys and tender specifications to market requirements.

- **Publication of the contract notice and the full tender specifications**

DEA notifies the market that it wants to enter into a concession contract and publishes technical and financial criteria for pre-qualification of potential tenderers suitable for entering into this contract. The full tender specifications list the terms of the tendering procedure, the framework conditions for establishing the offshore wind farms, draft permits for preliminary surveys, establishment and operation of the offshore wind farms, as well as a draft concession contract.

- **Negotiation with prequalified tenderers**

Potential tenderers submit an application for pre-qualification. Applicants for pre-qualification must submit a documentation that proves they meet the suitability conditions (technical and financial capabilities). DEA negotiates the final design of specification requirements, contract proposal, etc. with the pre-qualified tenderers in order to clarify, specify and adjust the tender documents, if necessary. The items open for negotiation usually concern possibilities to improve the tender documents to lower prices.

- **Final call for tender**

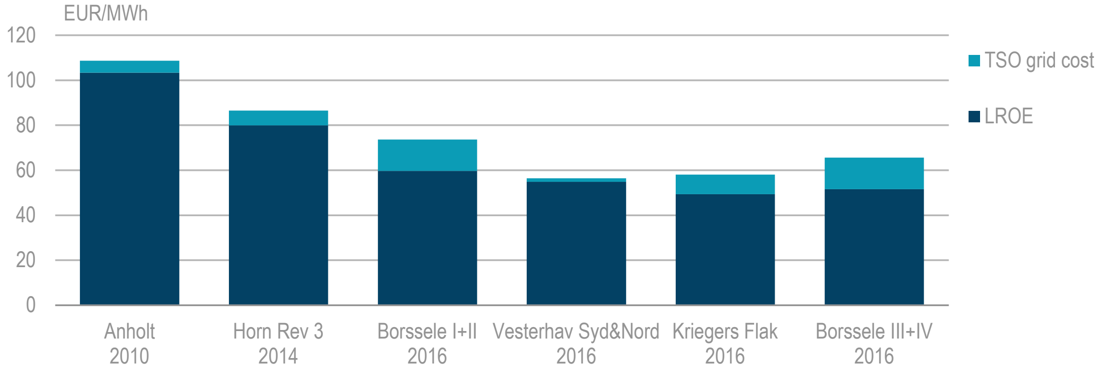
On the basis of the negotiations, the tender documents are adjusted. The participants submit their bids.

- **Selection of winner and drafting of contract**

The final winner will be selected on the basis of the award criteria in the tender documents. DEA enters into the concession contract with the winner and awards permits for preliminary surveys and establishment, subject to parliamentary approval.

Source: DEA (2017), *Danish Experiences from Offshore Wind Development*, Danish Energy Agency, Copenhagen, March.

Figure 8.10 Cost of offshore wind in Denmark (LCOE)



Note: LCOE = levelised cost of electricity.

Source: Danish Wind Industry Association.

Solar PV

The support scheme for solar PV has been revised several times over the last five years.

Between 20 November 2012 and 11 June 2013, eligible PV plants received a variable FIP up to DKK 1 450/MWh for a period of 10 years. An amendment reduced the premium, but a transitional measure was introduced for investors who entered an irrevocable agreement to purchase PV panels no later than 11 June 2013 and had requested planning permission or grid connection.

PV power plants connected to the grid after 11 June 2013 and not covered by the transitional measure received a variable FIP of DKK 600/MWh for the first 10 years, and DKK 400/MWh for an additional 10 years. This FIP system (also called 60-40) was withdrawn for new projects in May 2016, because Energinet.dk received too great a number of applications for support in the previous months (IEA, 2016).

In July 2016, Denmark and Germany signed a co-operation agreement on joint auctions for solar PV plants. This agreement opened up support schemes to cross-border participation encouraged by the European Union: solar PV projects in Germany were eligible to participate in the open part of the Danish auction while solar PV projects in Denmark were eligible to participate in the German auction. In December 2016, Denmark organised the first pilot auction for 20 MW commercial solar PV capacity, which was partly open to installations located in Germany. The winning bid was a fixed premium of øre 12.89/kWh (EUR 0.017/kWh) on top of the market price for 20 years. As part of the agreement, the German Bundesnetzagentur conducted in November 2016 a German auction for 50 MW fully opened to installations located in Denmark. Danish solar PV projects won the full capacity of both the German and the Danish auctions.

There have been several support schemes for solar PV in private households over the last decade, including net metering and feed-in premiums. The previous support measures had resulted in a rapid increase in rooftop PV systems in the early 2010s, driven by the simultaneous presence of the FIP scheme and net metering, which allowed electricity consumers to deduct from their billed annual electricity consumption the electricity produced by their PV systems over the course of a year. Against the background of Denmark's very high electricity prices (because of the large tax component), this was a lucrative opportunity (IEA, 2016).

The residential PV support system has reduced the tax revenue from electricity sales. In order to slow this trend down, the Danish Parliament changed the rules of the net metering scheme in December 2012: the period for which solar PV production could offset billed electricity consumption for new installations was reduced from the original one full year to one hour, i.e. solar PV generation in one hour can only be counted against electricity consumed during the same hour. This measure was intended to stimulate consumption during high PV generation periods; it also made net metering less attractive unless household electricity consumption fully matches solar PV production.

In addition, in 2008-15, Denmark had a DKK 25 million annual fund to promote the dissemination of small RE plants (*ForskVE-programme*).

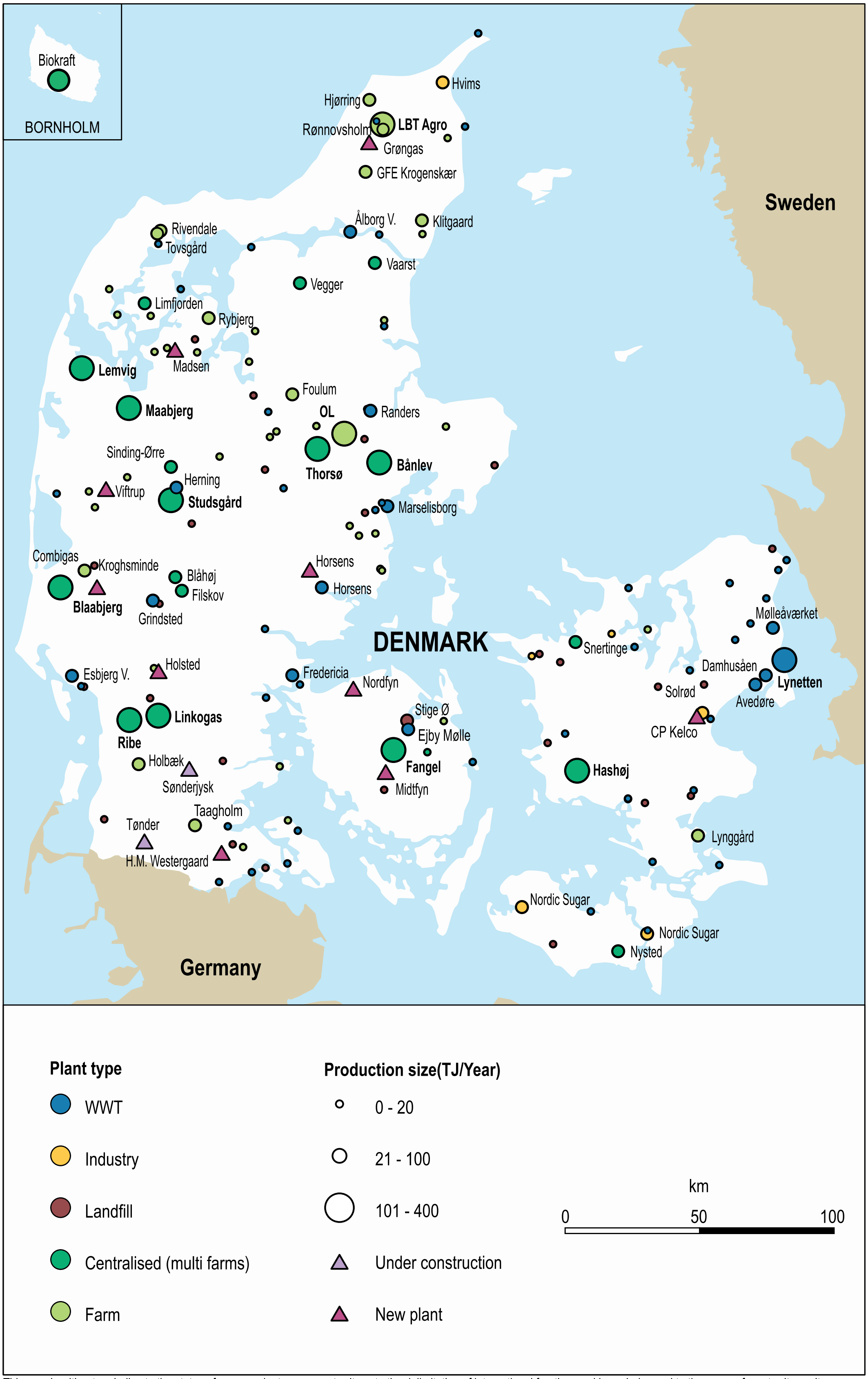
Biomass and biogas

Electricity produced from biomass receives a premium of DKK 0.15/kWh on top of the market price. The major part of this electricity is generated at combined heat and power plants (see Figure 8.11 and Chapter 10).

Support for biogas is very complex and several support schemes exist. Support is given to the use of biogas and not for the production of biogas. Support depends on the use of biogas (upgrading to natural gas grid, production of electricity, industrial processes, transport purposes, heating, etc.). The premium given to the production of electricity from biogas was DKK 1.02/kWh in 2016. The subsidy is dependent on the natural gas and the electricity prices and is regulated on a yearly basis. Biogas used for transport, heating or industrial processes receives a subsidy of about DKK 75/GJ and upgraded biogas injected into the gas grid receives a subsidy of about DKK 115/GJ. Both subsidies are dependent on the natural gas price.

The support policies have been rather effective and many biogas plants of different sizes have been constructed in Denmark (Figure 8.11). Many of them play the role of manure treatment facility for Denmark's highly intensive agricultural sector. Since 2011, 23 biogas plants have been connected to the Danish gas transmission and distribution network.

Figure 8.11. Biogas plants in Denmark, 2016



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Source: DEA website (www.ens.dk), accessed on 10 July 2017.

Heat

Biomass used to produce heat is tax-free, both in district heating and in residential use. Given the high level of taxation in the country, this exemption provides an important stimulus for switching from fossil fuels to biomass.

Denmark also has several other initiatives to reduce individual heating using oil and gas in buildings and to promote renewable alternatives. These include a prohibition to install oil-fired and gas-fired boilers in new buildings from 2013 and oil-fired boilers in existing buildings from 2016 onwards in areas with district heating or natural gas. These regulatory measures are accompanied by demonstration projects and awareness-raising actions such as providing advice on alternatives to oil and gas boilers.

Furthermore, Denmark has recently launched a support scheme to large electric heat pumps in district heating outside the ETS-sector.

In 2015, solid biomass (surplus straw, woodchips, wood pellets, bio oil, and biodegradable waste) accounted for around 45% of the total district heat generation. The conversion of coal- and natural gas-fired CHP plants to biomass is expected to continue in the next few years. Also, new biomass CHP plants and heating boilers are expected to be built. Denmark therefore imports and will continue to import large quantities of wood pellets, which raises questions among various stakeholders on availability and security of supply. Furthermore, the public debate on sustainability is expected to continue: some Danish stakeholders are concerned that Denmark imports large quantities of biomass without necessarily having full control of whether this biomass is produced in a sustainable way. Biomass used for electricity and district heating is covered by a voluntary agreement ensuring the sustainability of the biomass. It is expected that the European Union will establish a common set of criteria for the sustainable use of solid biomass.

Apart from CHP plants and large heat-only boilers, biomass is used in about 750 000 small-scale wood-burning stoves and boilers. Chapter 7 describes the requirements for quality and efficiency of these installations. Chapter 10 provides more details on RE in the heating sector.

Transport

Denmark has a fuel-mixing obligation introduced by the Act on Sustainable Biofuels (Act No. 468 of 12 June 2009). Importers and producers of petrol or diesel must ensure that biofuels make up at least 5.75% of the company's total annual sales of fuel to land transport, measured according to energy content. Biofuels must meet the EU sustainability criteria. Furthermore, biofuels are also exempt from the CO_2 tax levied on petrol and diesel.

As regards Denmark's EU obligation to have at least 10% renewable energy in transport by 2020, the government expects to reach approximately 8.4% in 2020 with current policies. Renewable electricity (for electric vehicles and electric railways) is expected to provide around one-fifth of the 10% RE-target (for more detail on electric vehicle policy, see Chapter 6 on energy and climate change).

Regarding the bio-components in transport fuels, Denmark has to meet EU requirements such as the Directive to Reduce Indirect Land Use Change for Biofuels and Bioliquids, adopted in 2015 (EU, 2015): This directive:

- limits the share of biofuels from crops grown on agricultural land that can be counted towards the 2020 renewable energy targets to 7%
- establishes an indicative 0.5% target for advanced biofuels as a reference for national targets
- harmonises the list of feedstocks for biofuels across the European Union whose contribution would count double towards the 2020 target of 10% for renewable energy in transport
- requires that biofuels produced in new installations emit at least 60% fewer greenhouse gases than fossil fuels
- introduces stronger incentives for the use of renewable electricity in transport
- establishes additional reporting obligations for the fuel providers and EU countries.

In 2016, the Danish Parliament adopted a law which sets up a blending obligation for advanced biofuels at 0.9%. This is above the indicative target of 0.5% set by the European Union.

Assessment

Over the last decade, Denmark has achieved an impressive growth in renewable energy, which accounted for around one-third of TPES and almost two-thirds of electricity generation in 2016. Denmark had the highest share of wind power in electricity generation among IEA countries in 2016. By 2020, the country is expected to meet about 40% of its final energy consumption from RE sources, exceeding its 30% RE target under the obligations.

This boom in renewable energy, particularly biomass and wind, has been driven by strong and broad political will at local and national levels, targeted support policies and community-based engagement. The current support policies were set up by the Energy Agreement of 2012 and adjusted several times since then. The cost of supporting RE through the public service obligation (PSO) has grown significantly since 2012. Nevertheless, when comparing the unit support levels (direct cost per megawatt-hour of supported electricity), Denmark ranks eighth-lowest among the EU countries, according to the Council of European Energy Regulators.

Denmark is to be commended in particular for organising a series of successful offshore wind tenders that have resulted in record-low prices based on an ever more refined approach for allocating support in an effective and efficient manner. The Danish tenders have many successful characteristics, which provide certainty to investors and drive the costs down, including guaranteed grid connection and electricity offtake, and one primary entry point (one-stop shop) for permitting and licensing.

In contrast to the remarkable growth in wind power generation, the situation in other sectors raises more questions. The use of renewable and alternative fuels in the transport sector is growing slowly. Without additional measures, Denmark will fail to meet its binding target of 10% RE in the transport sector by 2020, although the government is confident that additional measures will be adopted in time. In the heating sector, the key RE source so far has been biomass, which is combusted in CHP and heat-only plants, as well as in individual small boilers. While biomass combustion is important in replacing coal and other fossil fuels in thermal generation, its extensive use raises questions in public debate about sustainability, import dependence, security and affordability of biomass supply in the future, and the concern of "locking" investments in a biomass-based energy system.

Biogas projects have been developed throughout the country. Biogas has been upgraded to be used in the gas networks, but the cost efficiency of promoting biogas can be questioned, if pursued alone for the purpose of meeting a renewable energy target. Additional benefits, however, accrue where it is used for the treatment of agricultural waste (manure), which is typically the case in Denmark. Such benefits could be even higher, for example for plants designed with a "circular economy" perspective and capable of recycling nutrients into products replacing commercial fertilisers. From a climate perspective, the benefits of biogas can be seriously undermined if plant designs or operations allow significant methane leakage to occur. Future policy support should therefore only be granted to plants which can keep leakage at an insignificant level.

Many of the current RE support schemes will expire in the near future and new support mechanisms are being negotiated. The "Frozen Policies" scenario, modelled by the DEA, shows that in the absence of new measures, the growth of RE will stagnate and consumption of fossil fuels will increase after 2020, and the national target of at least 50% renewables by 2030 would not be achieved.

The 2017 Energy Commission report argues for phasing out renewable energy subsidies as cost and maturity of RE improve, and basing the new support on the principle of technology neutrality, taking into account the overall energy system. The IEA endorses the idea of using market-based, competitive mechanisms (such as tenders or auctions) to reduce prices for RE projects. Market-based support systems where suppliers see the market signals have proven to be highly efficient and have driven prices down, for example for offshore wind. However, to make competition between different renewable energy technologies fair and future-oriented, several issues should be taken into account:

- **Technological maturity**. It would be unfair to expect that nascent technologies can compete with mature ones. New, untested technologies would require additional support until they can be deployed on a large commercial scale. If Denmark had applied a strict technological neutrality principle in the past, the country – and the world – would not have seen the spectacular development of offshore wind plants that are witnessed today. Therefore, the IEA supports the introduction of a harmonised and competitive RE support scheme for mature technologies in parallel with separate targeted support for demonstration of non-commercial technologies on a smaller scale, in addition to research and development programmes to mature these technologies.
- The **relative value of technologies** for the future energy system, keeping in mind the benefit of having a diversified and dispatchable electricity mix if this is not rewarded by the market.
- **Economic, social and environmental externalities and benefits**, beyond the benefit of generating electricity at the least cost. For example, biogas technologies provide a sustainable solution to agricultural waste management (as explained above), while solar water heaters can add flexibility to district heating systems.

Recommendations

The government of Denmark should:

- ☐ When designing new support policies for renewable energy, take into account not only their cost-competitiveness, but also the degree of their technological maturity, their relative value for the future energy system as well as other economic, social and environmental impacts.
- ☐ For mature technologies, prioritise market-based competitive support schemes (such as tenders or auctions) to stimulate cost-efficiency, while for less mature technologies, design separate support frameworks for small-scale demonstration and through research, development and demonstration programmes.
- ☐ Further promote the use of sustainable liquid and gaseous biofuels, as well as electrification, in transport, with a view to at least meeting the EU 2020 RES-T (renewable energy sources for transport) target of 10%.

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9. Focus area 1: Integrating variable renewable energy

Key data

(2016 provisional)

Electricity from VRE: Wind 12.8 TWh (42.5% of total electricity generation), solar 0.7 TWh (2.5%).

Overview

Denmark is widely recognised as a world leader in variable renewable energy (VRE) integration. In 2016, 42.5% of electricity production came from a combination of on- and off-shore wind, while an additional 2.5% came from solar photovoltaics (PV). Denmark has demonstrated its ability to effectively integrate large shares of VRE while maintaining a highly reliable power system.

Denmark's ambitions, however, go much further. It has set a 2030 goal of having renewables cover at least 50% of total energy consumption, and a 2050 goal of becoming independent of fossil fuels. Meeting these goals will almost certainly necessitate a significant increase in the penetration of VRE generation in Denmark's power system, as well as a transformation of its energy system more broadly.

In particular, experiences in Denmark and in other jurisdictions suggest that wind and, to a lesser extent, solar PV will become the dominant renewable generating technologies. This is being driven in large part by pure economics. In Denmark, onshore wind is already the lowest-cost generating resource for new installations (DEA, 2016), while the cost of offshore wind and solar PV technologies continue to decline rapidly.

Therefore, the question for Denmark is not whether to continue to integrate large shares of VRE into its power system, but how.

Phases of VRE integration

While no two power systems are alike, it is possible to define some broad classifications based on the level of VRE penetration and their impact on operations. In particular, the IEA has identified four main phases of VRE integration (IEA, 2017a):

Phase One: VRE penetration levels are too low for the system operator to notice.

Phase Two: VRE penetration begins to have a noticeable impact on system operations.

Phase Three: Swings in supply and demand, driven by VRE penetrations, drive a need for increased flexibility.

Phase Four: VRE generation covers nearly 100% of generation at given times; system stability becomes a concern.

The IEA has also identified two additional phases that, while not yet seen in real-world experience, may at some point become relevant. They are:

Phase Five: VRE generation exceeds demand on a regular basis. At this stage, in the absence of additional outlets for consumption (e.g. increased demand, exports, or storage), large-scale curtailment could limit further deployment.

Phase Six: Seasonal variations in supply and demand lead to structural power deficits, and some form of long-term storage is necessary to maintain security of supply.

As defined, Demark fits most closely into phase four. It is also clear, however, that Denmark's power system transformation is not nearly complete, and that it may already be entering phase five.

In the context of this review, the IEA has identified five broad strategies for supporting the integration of VRE:

- system-friendly deployment of VRE
- maximising the flexibility of the non-VRE generating fleet
- leveraging demand-side flexibility
- increased electrification
- efficient utilisation of interconnectors.

System-friendly deployment of VRE

System-friendly deployment of VRE refers to the implementation of various methods for deployment that allow renewables to contribute to their own integration. "System-friendly", however, has a wide range of meanings. In this context, the IEA has identified four which are most relevant (IEA, 2016). They are:

- contribution to the provision of system services
- optimising the location of VRE plants
- optimising the generation profile
- integrated planning, monitoring and revision.

This section will examine each area in turn.

Contributing to the provision of system services

All power systems require the provision of services beyond just the delivery of energy. In Denmark, these so-called system or ancillary services are procured both through the grid code and through various kinds of market arrangements.

Historically, the provision of system services was limited to thermal generation. Technological advances, however, have made it possible for VRE and other technologies to play a more active role in this regard.

As a simple example, uncertainty over wind production can lead to an increase in the amount of required reserves. Improvements in forecasts of wind availability can therefore reduce the reserves requirement, if the market framework allows the wind operator to update the system operations accordingly.

Renewable resources are also becoming more controllable. This means VRE can respond to system conditions in real time, for example by electing to decrease output when market signals indicate that there is an overall excess of power, or by limiting output during normal operations in order to participate in the upward reserve market, therefore allowing for more efficient real-time dispatch.

Denmark has already done much to include VRE in its ancillary services procurement. In 2011 Energinet.dk released its ancillary services strategy, covering the period 2011-15 (Energinet.dk, 2011), and in 2015 a new strategy, Market Model 2.0 (Energinet.dk, 2015). As Market Model 2.0 builds on the 2011 strategy, it is worth detailing some relevant sections of the strategies.

In the 2011 strategy, Energinet.dk noted its own efforts to increase procurement from so-called “alternative suppliers”, including from wind and demand-side resources. The strategy is also notable for excluding the possibility of tying ancillary services requirements explicitly to increased VRE deployment. In particular, one of the guiding principles for the procurement of manually activated reserves is that the quantity of reserves procured will not be explicitly tied to the quantity of wind in the system. Put another way, wind should not be seen as a distinct resource in the power system that must be treated in a special way, but rather as part of the broader power mix.

That said, the strategy does not ignore the impact of increasing wind generation on system service needs, but, rather, Energinet.dk outlines two strategies for procuring system services. The first is to broaden the definition of ancillary service products to allow more resources (including VRE resources) to participate. The second strategy is to increase regional procurement of ancillary services.

Since first suggested in 2011, both of these strategies have made progress. The ancillary services markets now allow for a broader range of participating resources, and the four Nordic transmission system operators (TSOs) are developing a common market for automatic frequency restoration reserves (aFRR) (IEA, 2017b). Market Model 2.0 builds on these successes, though the details are still being developed.

One aspect of Market Model 2.0 that will certainly be critical is the continued development of regional ancillary services markets, and in particular the need for regional co-ordination on market rules and TSO activities. This will become increasingly important as new technologies may not have the same operating characteristics as existing technologies. For example, batteries can respond much more quickly to system conditions than more traditional technologies, but they can only provide system services for a limited duration and with a limited capacity, and must draw power from the grid (or an alternative power source) to recharge. Market rules should be designed to maximise the value of these technologies while also accommodating their differing constraints. This should be done in a consistent manner across all of relevant TSOs.

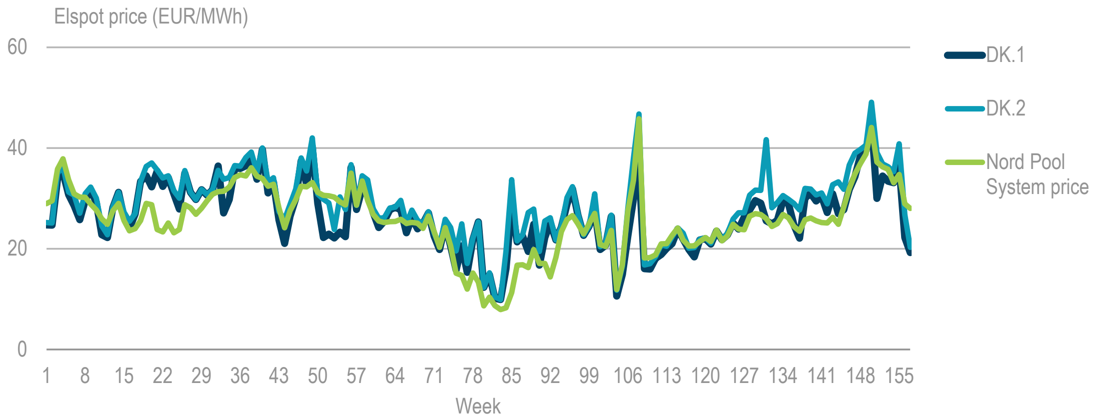
Optimising the location of VRE plants

There are two primary reasons why location matters when it comes to VRE deployment. First, VRE technologies such as wind and solar are weather-dependent. It is therefore intuitively obvious that these plants will perform better when deployed in places where the weather conditions are more favourable to their operations. Second, production from VRE plants in a given location tends to be auto-correlated. That is, when one VRE plant in a region is operating (e.g. an offshore wind turbine in the west of Denmark), it is likely that many other VRE plants in that same region are also operating. This can lead to a saturation effect, where the value of each additional VRE plant is diminished.

Ideally, generation owners should be encouraged to invest in particular locations by price signals, with the market providing the appropriate signals for where to invest and when to operate.

Denmark is divided into two price zones (one for the western grid and one for the eastern grid), and so the resolution of prices is limited. In addition, prices between the two zones are highly correlated: between 2014 and 2016, hourly prices in the two zones were equal 70% of the time. When prices do diverge, they tend to be higher in eastern Denmark, reflecting the fact that eastern Denmark's grid is more often constrained.

Figure 9.1 Weekly average elspot price for DK.1, DK.2, and the system average, 2014-16



Source: Nord Pool (www.nordpoolspot.com).

While market prices may offer investors sufficient signals to indicate in which of the two zones new generation could be built, they may not offer sufficient granularity to optimise the location of investment within each zone. An alternative is to include locational incentives in the renewables support scheme. The current subsidy scheme for onshore wind is being phased out, and it is not clear what, if any, scheme will replace it. Regardless, it is important that windmill owners are exposed to the local market price in order to optimise the location of deployment.

Even in the absence of an explicit subsidy, however, investment in particular locations can be encouraged through targeted tendering processes. Denmark already uses tendering schemes, in particular for some offshore wind farms. The development of offshore wind turbines outside the tendering process requires Denmark's "open-door" procedure, whereby windfarm developers may submit unsolicited bids to develop projects in a specific area. In theory, this process could also be used to support more optimal deployment of windfarms, by prioritising the approval of projects proposed in areas that are more optimal from a system perspective than those proposed in areas where the value of additional capacity is relatively lower. This would at a minimum require active collaboration with Energinet.dk to identify optimal locations for deployment, and transparency during the approval process so that investors can plan accordingly.

Optimising the generation profile

In addition to *where* renewable technologies are deployed, *how* they are deployed can also have a notable impact on their easy integration. Two factors are of primary importance: technology choice and direction of deployment. Ideally, both should be optimised to maximise the value of generation to the system.

Technology choice is particularly relevant in the case of wind turbines. The developer's incentive is to choose technologies that maximise profits. From a system perspective, however, it may be the case that a different technological configuration is more optimal. For example, using larger blades for a given nameplate capacity eases integration by reducing the variability of electricity production (IEA, 2016).

In the case of Denmark, the current subsidy scheme offers a higher subsidy to developers who choose to use longer blades. As this subsidy is being phased out, this incentive is being removed. If a new subsidy scheme is introduced, it should ideally include a similar kind of adjustment to encourage investment in more system-friendly technologies. Alternatively, Denmark may need to find other methods to encourage such system-friendly investment decisions, for example through the introduction of a separate, more targeted incentive scheme, or through changes to the grid code.

The direction that VRE generators face once deployed can also make a large difference. Generation that participates in the wholesale market is already encouraged to some degree to maximise the value of production through their exposure to wholesale prices. As prices tend to follow net demand, producers seeking to maximise revenues will generally try to optimise their output to match the system's demand profile.

To the extent that the system value is reflected in the energy price, deployment decisions can be left to the market. However, there may be times when market signals do not fully reflect, or even conflict with, what is most valuable from a system perspective. In these cases, the market price should either be improved to fully reflect the system's value (for example through the introduction of an appropriately high tax on negative externalities), or alternative incentive mechanisms should be employed (for example, targeted incentive mechanisms).

The problem is more pronounced for distributed resources, which save the owner the full retail price when deployed and operating. In the case of Denmark, most of the retail price is made up of non-energy-related costs (in particular grid costs and taxes; see Chapter 5 on electricity). There is, therefore, a strong incentive to maximise self-consumption, so as to avoid as much of the fixed charge as possible.

From a system perspective, though, maximising output is usually not optimal. It is often better to orient solar panels in such a way as to maximise output closer to sunset, in order to lessen ramping requirements, even if that means less production overall. This usually means installing the panels in a westward-facing orientation, though it could also include more sophisticated installations where solar PV is installed in combination with demand response, energy efficiency measures, or storage in order to reduce consumption during the appropriate hours.

In any case, as penetrations increase, it becomes increasingly important that proper incentives be provided to encourage system-friendly deployment. Reforming the retail price may be the best option in this case, for example by separating fixed charges from energy charges, and by exposing consumers to real-time prices. Allowing distributed resources to participate in ancillary services markets can also stimulate more system-friendly deployment, by offering them a separate revenue stream.

Integrated planning, monitoring and revision

Integrated planning in vertically integrated environments means all system investments, including generation, transmission, and ideally demand-side measures, are co-ordinated. In restructured (that is, non-vertically integrated) market environments such as Denmark's. System planning is limited to the grid. There are still, however, many opportunities to take an integrated planning approach, a fact that Denmark has already to a large extent absorbed.

In a restructured environment, investment in generation can only be assumed. From the grid planner's perspective, therefore, it is critical to understand what is likely in the evolution of both demand and technology. This is becoming more challenging, in large part because demand and technology are becoming increasingly intertwined. This is addressed to some degree in Denmark by including generators in the integrated planning exercises.

For most OECD economies, the past few years have seen their energy demand stagnate or even decline. Increased electrification of other parts of the energy system, however, may result in increasing electricity demand. For example, increasing penetration of electric vehicles could lead both to an increase in overall electricity demand and to changes in demand patterns. Increased use of heat pumps for heating and cooling could also have a large impact.

Technology improvements – in particular the decline in their cost – could also have a large impact. Continued cost declines in solar PV and wind are expected, but the rate of these declines could change. More rapid declines will lead to more rapid deployment, while slower declines could result in less rapid deployment than is otherwise anticipated. Changes to storage costs could also have a large impact.

Denmark's integrated planning efforts already take into account potential demand scenarios and technological changes. It is therefore important that Denmark continues to think broadly about what is possible, and allows planning to remain flexible enough to respond to unexpected changes.

Maximising the flexibility of the non-VRE generating fleet

As a consequence of the rapid rise of wind capacity in Denmark's power system, only about half domestically produced electricity comes from non-VRE sources. This breaks down into three main technologies: coal (28.8% of generation, on average), biofuels and waste (17.9%), and natural gas (7.3%). Most of this generation is either flexible by nature or has been retrofitted to become more flexible.[1] The ability for the non-VRE fleet to balance Denmark's wind and solar generation is therefore relatively high.

The Danish Energy Agency (DEA) has taken stock of the variety of flexibility measures already used in the Danish power system, as well as the performance of non-VRE generation (DEA, 2015). The measures relevant in this context are:

- use of "must-run units", or generation required to operate in order to maintain system stability
- rapid response (i.e. high ramp rates)
- lower minimum output
- shorter start-up times
- improvements to the co-production of heat and power, to allow more flexibility in the combined heat and power (CHP) fleet.

"Must-run units" have traditionally included CHP plants, which are often required to produce heat regardless of whether the electricity produced in this process has any value to the system. However, as suggested in the fifth point above, most modern and refurbished CHP plants are able to produce heat without producing electricity, at least temporarily, increasing their overall flexibility.

On the other points, Denmark's generating fleet also demonstrate a relatively high level of flexibility. Ramp rates are around 4% per minute; minimum output levels range between 15% and 25%; and start-up times from ignition to 90% of baseload are less than three hours. In addition, plant owners have taken a number of steps to improve overall operating efficiency, which is important in order to minimise costs when running at partial load.

The relatively low share of natural gas-fired generation in the power mix obscures the fact that, in terms of installed capacity, natural gas still has approximately the same share as coal. Relatively low coal prices have driven the share of natural gas generation to historic lows – a fact that is expected to continue.

As noted in Chapter 5 on electricity, many natural gas-fired plants are still available because of a subsidy, but that subsidy will expire in 2019. In the absence of a new subsidy or alternative mechanism, the expectation is that much of the existing natural gas fleet will permanently close. In addition, it is possible that much of the coal fleet will also retire, due to a combination of economic incentives and business decisions.

The net impact would be a reduction in the quantity of flexible generating capacity available, when at the same time that the amount of VRE generation is expected to increase. While security of supply is not yet a concern, over the long term the net impact may result in too little flexibility relative to the need, especially in relatively grid-constrained eastern Denmark.

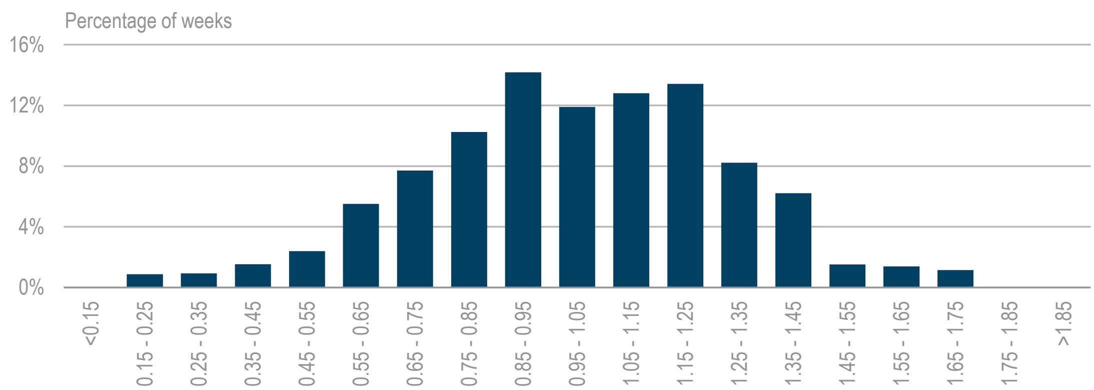
[1] In this context, flexibility refers to the ability for a power system or a generator to respond to variability or uncertainty over the quantity of demand and available supply.

Business decisions about whether to shut down natural gas- and coal-fired generation are outside Energinet.dk's control. The TSO does, however, have other tools at its disposal. For example, it has already deployed synchronous condensers at strategic locations in the grid. Looking forward, however, Energinet.dk will need to effectively balance reliance on this and other technical solutions (including, for example, storage, should it become more economically competitive), and procurement of ancillary and other services from market participants. This could include allowing new, non-traditional ancillary service providers to participate in the market, in particular that of electric vehicles.

Leveraging demand-side flexibility

Previous IEA research has noted that the correlation between VRE output and electricity demand in Denmark is relatively less favourable than in other countries analysed (IEA, 2016), in large part because of issues related to seasonality. As shown in Figure 9.2, in 2015 weekly VRE generation met between 90% and 110% of demand in only 27% of cases.

Figure 9.2 Range of weekly demand coverage factors (DCFs) in Denmark, 2015



Note: DCF analysis shows the correlation between VRE production and electricity demand.
Source: IEA (2016), *Next Generation Wind and Solar Power*.

To effectively integrate increasing shares of VRE, therefore, it will become more critical to leverage the full potential of demand-side flexibility.

Demand-side flexibility does not refer to a specific capability, but rather to a suite of solutions. These include, but are not limited to, targeted energy efficiency programmes; demand response; integration of distributed generation; and storage.

Energy efficiency programmes typically focus on reducing overall energy consumption. It can be equally important, however, to shape energy consumption profiles in order to align more closely to expected production patterns. Measures could include peak load reduction, or measures that shift or reshape consumption in order to, for example, reduce ramping requirements.

In the long run, active and passive demand response programmes will become more important.[2] Traditional demand response programmes have typically focused on reducing consumption during times of system stress or when it is more economical to do so. In environments with significant quantities of low- or zero-marginal cost generation (in particular wind and solar), however, there are likely to be periods when it would be more rational to increase consumption.

Exposing consumers to price signals is one way to encourage this kind of behaviour – for example by allowing them to take advantage of times when prices are negative. Consumers can only do so, however, if they have access to the appropriate information and tools. Denmark's DataHub, in combination with the smart meter roll-out and efforts to increase retail competition, is a prime example of the kind of tools being deployed to directly address this kind of opportunities. As noted in Chapter 1 on general energy policy, the development of the DataHub has already resulted in a number of digital pilot projects. Denmark's Digital Strategy 2016-2020 is another example of how the country is trying to address the digitalisation of the energy system in a strategic fashion.

These new tools are confronted with a few obstacles. Consumer demand is low, in part because of the relatively high tax on consumption. This reduces the scope for increased flexibility. In addition, as already noted, the high fixed component of the tariff also limits consumers' exposure to energy price fluctuations, diminishing the potential for economically driven demand response.

Increasing penetrations of distributed solar resources create both a challenge and an opportunity for increasing the system's flexibility. For example, as the penetration of distributed solar power increases, consumption patterns can change dramatically. If the solar resource is coincident with peak load, the need for peaking resources is reduced. When the sun sets, however, ramping needs can be quite significant.

From a system perspective, a more optimal solution is to co-ordinate the deployment of solar PV with demand response. In theory, retailers can offer packages that combine solar PV and demand response, but in practice they would only do so if there were proper incentives in place.

The incentives for distributed renewables deployment therefore matter a great deal, especially over the long run. Incentive programmes like net metering are relatively easy to create, but can lead to maximisation of deployment and production at the expense of system needs. This sort of market behaviour is unsustainable over the long run, and should be limited or avoided completely. As an alternative, introducing a fixed network capacity tariff, while at the same time reducing the kilowatt-hour tariff, is recommended.

Finally, as battery costs decline, the opportunity for using distributed storage to improve system flexibility increases. Deployment of storage in combination with solar PV is one obvious solution. Other solutions may also emerge, especially as smart meters are deployed in increasing numbers – for example, purchasing and reselling power from the grid. One obstacle to this sort of solution in Denmark, however, is the tax structure. Under the current tax policy, this sort of consumer behaviour would be taxed twice: first

[2] Active demand response refers to programmes that are dispatchable by the system operator, while passive demand response refers to solutions that respond to system or market conditions but that are outside the control of the system operator.

when the electricity is bought and stored, and then again when it is sold and repurchased. One option would be to remove the tax on stored electricity, though ideally this should only be done in cases where that power is resold – otherwise batteries could become a tool for tax avoidance. Ensuring that the proper incentives are in place will become increasingly important as the penetration of electric vehicles increases.

Increased electrification

As noted earlier in this chapter, Phase Five of VRE integration is characterised by periods of excess generation. The weather dependence of VRE generation means that there can be periods when supply exceeds demand. To prevent large-scale curtailment of VRE (and, by extension, limiting the economic potential of VRE), new outlets for this generation will need to be developed.

At present, excess VRE generation in Denmark is exported to neighbouring countries (see next section). Looking forward, however, as VRE penetrations in Denmark and elsewhere increase, the opportunities for economic exports may diminish. Therefore, it will become increasingly important to find additional uses for that excess generation domestically. In particular, this will involve increased electrification of energy demand, especially in the heating and transport sectors.

The need for electrification is already well understood in Denmark. The question, therefore, is primarily one of strategy and co-ordination. In particular, incentives will need to be aligned across the economy in order to drive investments in the proper direction.

Removing the PSO from the retail tariff is a good first step in this direction. As already noted in Chapter 1 on general energy policy, the phasing-out of the PSO is expected to lead to an increase in demand of 3.4 TWh by 2020, simply by making it more economical to consume more electricity.

Continuing to reduce the tax burden would do even more to increase electricity's competitiveness as a substitute for a more polluting form of energy. In addition, increased use of smart meters could allow for more targeted incentives based on particular types of consumption. More broadly, encouraging electrification will most likely require some kind of tariff reform. Ideally, tariffs should accurately reflect the value of consumption – encouraging increased consumption when prices are low thanks to high VRE generation, and reduced consumption when VRE supply is limited.

Similarly, more incentives could be provided to increase the deployment of electric vehicles. At the moment, these vehicles receive an incentive in the form of reduced registration taxes. This incentive is limited to two years, or 5 000 vehicles (whichever is reached first), after which the tax will be gradually increased.

From the perspective of increased electrification, keeping this incentive in place would help, while keeping an eye on the availability of VRE to satisfy such increased electricity demand. While the long-term goal is an increase in overall electricity demand, it is important that this increase come at a pace that is in line with increased deployment of VRE. If the increase in electricity demand outpaces VRE penetrations, excess demand will be met by other sources, in particular fossil generation.

From a policy-maker perspective, this sort of co-ordination issues can be difficult to manage. At a minimum, incentives for electrification should be reviewed regularly to ensure that they are in line with the broader power system transformation. Leveraging market-based solutions will also be important. Retailers, for example, could be encouraged to provide bundled products that include increased electrification along with electricity procured from VRE sources.

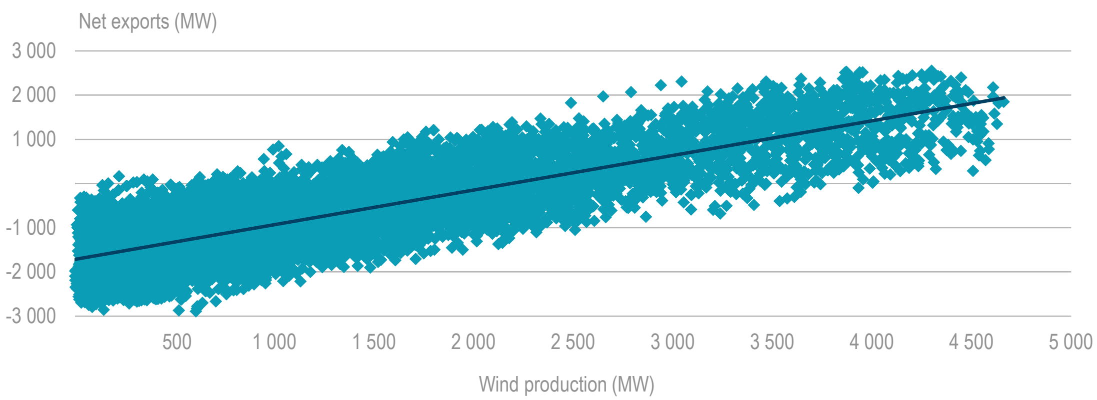
Efficient utilisation of interconnectors

Denmark regularly demonstrates the value of interconnectors in providing flexibility. In 2016, interconnectors balanced the variation in wind production (either by allowing for export of excess power, or allowing for imports when wind power is scarce) 78% of the time (Figure 9.3).

The significant levels of interconnector capacity, combined with Energinet.dk's effective management of the domestic power system, allow Denmark to effectively manage levels of wind generation that other systems would find difficult to support. As Figure 9.5 shows, there are periods when portions of the grid (in this case, Western Denmark) are operating without the support of any large-scale thermal power plants.

Denmark's effective use of its interconnectors is supported to a large degree by its close co-operation with the rest of the Nordic countries. This includes active collaboration between Energinet.dk and the other Nordic TSOs, and participation in the Nord Pool market, which gives Denmark access to the region's diverse generating fleet, in particular Norway's significant hydroelectric capacity.

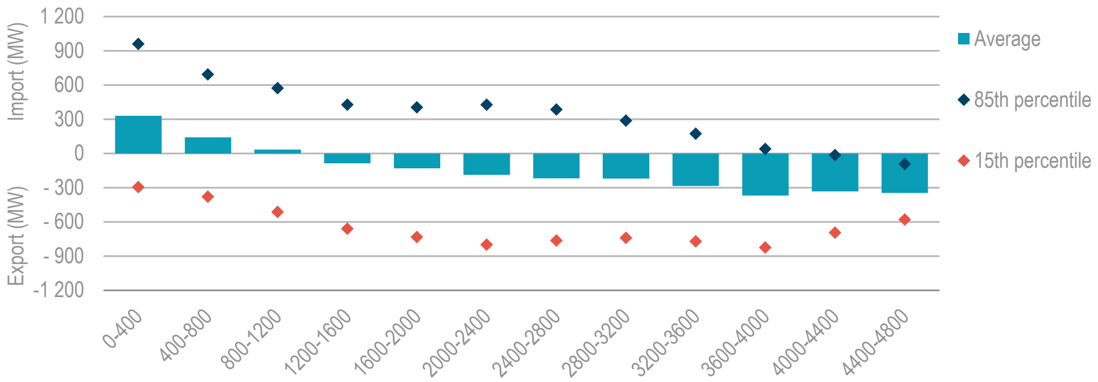
Figure 9.3 Net exports compared to wind production, 2016



Note: Based on the analysis originally done by DEA on data from 2014 (DEA, 2015). The correlation for 2014 was found to be 80%. It is important to note that this analysis is not meant to suggest Denmark would not have been able to balance these resources in all of these hours without the interconnectors. Rather, it shows that, during the relevant hours, the use of interconnectors was the most economical option.

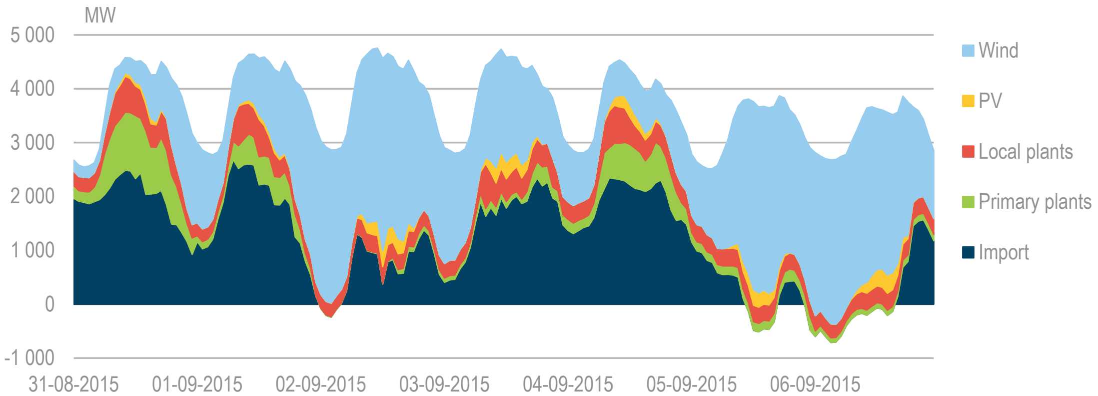
Source: Adapted from Energinet.dk (2017), *Market Data*, www.energinet.dk/EN/El/Engrosmarked/Udtraek-af-markedsdata/Sider/default.asp.

Figure 9.4 Interconnector flows and wind generation in Denmark



Source: IEA (2017c), *Status of Power System Transformation*.

Figure 9.5 Hourly dispatch 31 August to 6 September 2015 in Western Denmark (DK1)



Sources: IEA (2016), *Next Generation Wind and Solar Power*. Adapted from Energinet.dk (2015), *Market Data,* http://energinet.dk/EN/El/Engrosmarked/Udtraek-afmarkedsdata/Sider/default.aspx.

The Nordic TSOs are also in the process of establishing a common regional security co-ordinator (RSC), based in Copenhagen. This is a positive development, as it should significantly increase the ability for the participating TSOs to co-ordinate operations closer to real time. The full extent of the mandates of the Nordic RSC is still under discussion, and depends heavily on the outcome of EU discussions over the draft Clean Energy Package, which currently proposes expanding them into regional operating centres (ROCs). Energinet.dk and the other Nordic TSOs have indicated a preference for keeping operational control at the TSO level. As VRE penetrations increase, whether it is more efficient to keep control at the national level or move it to the regional level will become increasingly relevant.

Denmark is also well interconnected with Germany. The situation within Germany, however, demonstrates some of the limitations of relying on interconnectors to provide flexibility. While interconnection capacity to Germany is relatively high, transmission constraints within Germany limit the degree to which this interconnector can be used. In 2015, average net transfer capacity (NTC) between Germany and Western Denmark was 13% in the direction of Germany, and 54% in the direction of Denmark (DERA, 2016). Import capacity from Germany declined further in 2016, to just below 11% (Energinet.dk, 2016). While more interconnections between Denmark and Germany are planned, the continued deployment of wind power in Northern Germany implies that, if

Germany's internal grid constraints are not resolved, the value of increased interconnection will continue to be limited, unless those interconnections are built to regions with uncorrelated wind production patterns (DEA, 2015).

In the absence of increased grid reinforcements, non-transmission solutions can also be effective short-term solutions.

For example, Energinet.dk also closely collaborates with the German TSOs, in particular with TenneT. Energinet.dk's collaboration with TenneT in Germany on co-ordinated re-dispatch is a good example of how Denmark can work with neighbouring countries other than those in Nord Pool to improve co-ordination across borders. This collaboration has been supported by close contacts between the Danish and German ministries and their respective regulators. In July 2017, the Danish and German governments jointly announced an agreement to gradually increase interconnector capacity between the two countries, from a minimum of 400 MW to 1 100 MW in 2020 (EFKM, 2017).

Planned increases in interconnector capacity extend beyond just Germany. Taken as a whole, these will help to offset the expected decline in Denmark's domestic non-VRE generation. To fully leverage the resources of the region, however, Denmark and the rest of the Nord Pool countries will need to continue to improve their regional power market. Moving Nord Pool market operations closer to real time, for example, would allow market participants to update their expected performance with a higher degree of accuracy. Allowing interconnector capacity to be reserved in advance and shared would also increase their value towards flexibility, though this would have to be agreed to and co-ordinated at the EU level (Norden, 2016).

Assessment

Denmark, supported by a flexible domestic power system and high level of interconnection, has already done more than most countries to push the limits of VRE integration. As it transits to a power system where VRE generation often exceeds demand, however, and in particular as it looks to meet its long-term goal of becoming independent of fossil fuels, Denmark will have to continue to demonstrate leadership in this area. This will require increased innovation and co-ordination across the entire energy sector and across borders.

In practice, Denmark is already employing the strategies outlined above, albeit to varying degrees. To truly push the limits of VRE integration, the focus must be on improving how each strategy is implemented. Moreover, effectively integrating large shares of VRE into power systems requires the implementation of multiple strategies simultaneously. Often this requires co-ordination across multiple government agencies and with the inclusion of a range of market participants, and with TSOs and regulators in neighbouring countries.

As a first step, continued emphasis on encouraging the system-friendly deployment of VRE will become increasingly critical. Denmark already does much in this regard, including allowing so-called "alternative resources" to participate in ancillary services markets, encouraging investment in more system-friendly configurations of wind turbines, and using integrated planning methods. This provides Denmark with a good platform from which to build.

While it may be fair today to classify VRE and other non-traditional resources as "alternative", as the penetration of each increases, the alternative will eventually become the mainstream. Moreover, given that the pace of deployment can often exceed expectation, it makes sense to prepare for this eventuality early, to avoid having to address the implications of high VRE penetrations in real-time.

Energinet.dk's 2011 strategy on ancillary services and the Market Model 2.0 process are both good examples of how to respond to the uncertainty of VRE deployment. Each lays out a clear set of challenges and principles, and procedures for addressing them. Over time, however, these principles will need to become increasingly embedded into practice. Allowing new entrants into system services markets without undermining either the functioning of the markets or the stability of the system implies developing rules that are clearly and transparently defined, that minimise or avoid discrimination based on technology, and that ensure complete accountability on the part of the market participants. Given the regional nature of the Nordic power system, it also requires strengthening co-operation among all relevant Nordic institutions, in particular the TSOs. The establishment of the Nordic regional security co-ordinator (RSC) is a good next step, but thought should also be given to how the co-ordinator may evolve over time.

Denmark's relatively limited geography means there is only so much it can do to optimise the location of deployment over the long run. Still, much can be done to encourage optimisation of deployment in the near term. Providing specific location-based incentives, for example through the tendering process, is one example. Denmark could also consider increasing the number of price zones, so as to provide higher resolution market signals to investors.

The fact that Denmark's wind support scheme includes an incentive for system-friendly technology choices is commendable. As the support scheme is phased out, Denmark should consider how to continue to provide this incentive to investors – either in a new support scheme, should one be developed, or through more targeted methods. Denmark should also expand these incentives to cover all renewable technology types.

Similarly and somewhat related, Denmark should continue to utilise integrated planning methodologies. These planning exercises will become more challenging as rising VRE penetrations increase uncertainty over future system operations. Denmark should continue to expand the scope and depth of its analysis, and it should encourage continued and increased planning co-ordination among all relevant TSOs.

One of Denmark's strengths is the relative flexibility of its other-than-VRE generating fleet. Maintaining this flexibility may be difficult, however, given the economic uncertainty that much of this fleet faces. Already, much or all of Denmark's natural gas generation seems likely to be retired once the capacity subsidy is removed, and the future of the coal fleet is also in question. Looking forward, Denmark may need to support the development of market-based incentives for investment in flexible generation and demand-side response, or other forms of flexibility. This may be complemented by increased flexibility elsewhere in the power system, in particular through increasing the share of new resources in the ancillary services markets, and increased demand-side flexibility.

Given the fact that Denmark's VRE portfolio will never be optimal from a demand perspective, making demand more flexible will become an increasingly important option. Denmark's digitalisation strategy and deployment of tools such as the DataHub are good supporting steps, but more can be done, including tariff reform, and supporting innovation in the retail sector.

Similarly, increased electrification will be critical to aiding integration, especially as the number of periods when renewables generation exceeds domestic demand increases. Including all energy sectors in the integrated resource planning exercises may be a good step in improving co-ordination among sectors. Denmark should also consider developing targets for electrification, at least in the currently very oil-dependent transport sector, so that investors can begin to schedule their investments to meet expectations for rising demand.

Finally, Denmark's interconnectors are already being effectively used to economically balance the large shares of domestic VRE. Their value will almost certainly increase over time, but to remain fully effective, increased co-ordination across borders will become more critical. In particular, Denmark will need to continue to think beyond the Nordic region, while at the same time continuing to support improvements in the Nord Pool market. The EU's Clean Energy Package will also be an important component to cross-border power system co-operation. Given Denmark's ambitions, it should seek to influence that process in such a way as to maximise the value of collaboration at an EU level in support of domestic VRE integration goals.

Recommendations

The government of Denmark should:

- Support Energinet.dk in its efforts to prioritise the procurement of ancillary services and other relevant system services through market mechanisms, and encourage it to utilise other technological solutions only when there is a clear economic or reliability benefit.
- Continue to improve the incentives for the system-friendly characteristics of variable renewables deployed.
- Work to encourage more demand-side flexibility and the deployment of distributed generation and storage in a system-friendly, non-market distorting fashion.

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10. Focus area 2: The heating sector

Key data

(2015-16)

Heat consumption* (2015): 5.8 Mtoe (residential 65%, industry including process heat 24%, commercial and public services excluding agriculture 17%)

Household net heat demand (2015):** 3.7 Mtoe (district heating 43%, renewables mainly solid biofuels 31%, natural gas 16%, oil 6%, electricity 4%)

District heat production (2016 provisional): 3.2 Mtoe (biofuels and waste 57%, natural gas 19%, coal 19%, solar 3%, oil 1%)

*Heat is here defined as final energy consumption other than electricity.

**Energy for space and water heating in households.

Source: Danish Ministry of Energy, "Utilities and climate, presentation during the review visit.

Overview of heat consumption

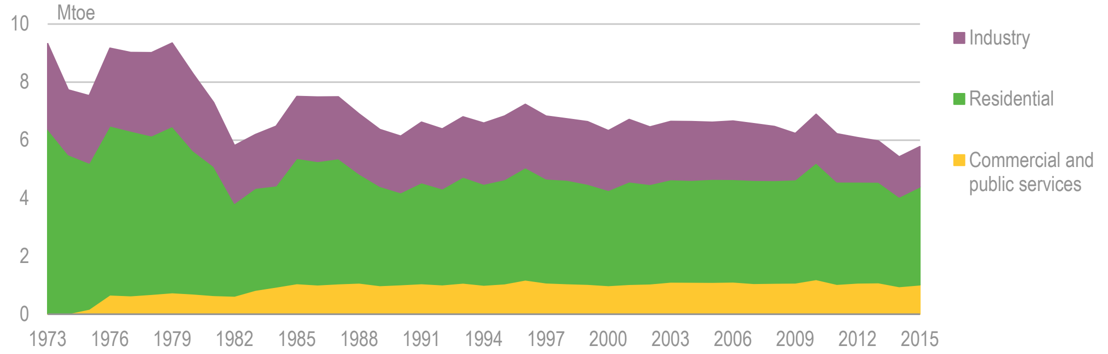
The government adopted in 2012 a long-term energy strategy in which the heating sector will play a key role in meeting the ambition in the Danish Energy Agreement to have a fossil fuel-independent energy system in 2050. Policy and regulations have been introduced to support the shift towards renewable heating, both in collective and individual heating solutions.

Total heat consumption (excluding electric heating and agriculture) was 5.8 Mtoe in 2015, which accounted for 43% of total final energy consumption (TFC). Households consumed 3.7 million tonnes of oil-equivalent (Mtoe) heat, over half the total heat consumption (Figure 10.1).

Heat consumption in industry, including process heat and space heating (excluding electric heating), totalled 1.4 Mtoe, mainly from fossil fuels. Natural gas accounted for 47% of total industrial heat, oil for 29% and coal for 8%. Commercial and public services (excluding the agriculture sector) consumed 1.0 Mtoe of heat. Both residential and commercial buildings are dominated by district heating, while industry buildings rely more on fossil fuels for heating (see Figure 10.2).

Among residential and commercial buildings, one-family houses accounted for 58% of total heat consumption in buildings, multi-family houses for 20% and non-residential buildings for 22% in 2015. While multi-family and non-residential buildings are dominated by district heating (DH), one-family houses use a mix of individual and collective heating, in which household biomass boilers account for the largest share (Patronen et al., 2017).

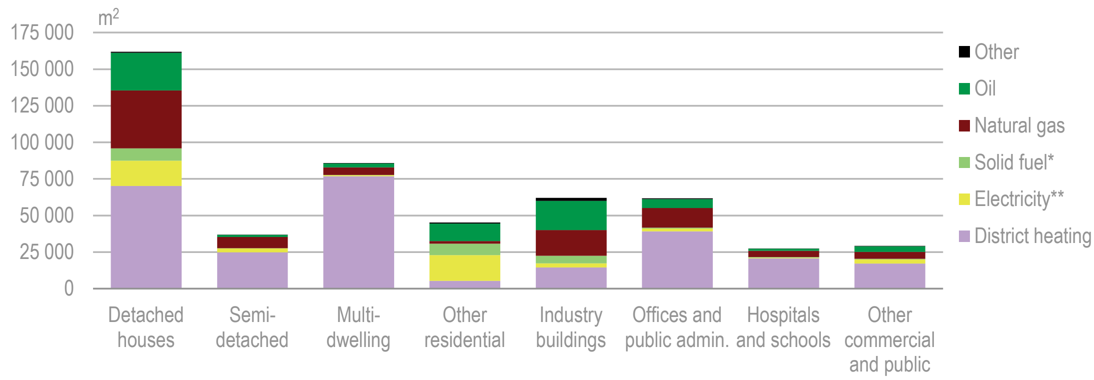
Figure 10.1 Heat consumption in TFC by sector, 1973-2015



Notes: Chart shows non-electricity final energy consumption excluding consumption in transport, agriculture/forestry, fishing and non-energy consumption. Electricity used for heating is not included. Gas used for cooking is included.

Source: IEA (2017), *World Energy Balances* 2017, www.iea.org/statistics/.

Figure 10.2 Building area heated by different fuels by building type, 2016



*Mainly solid biofuels.

**Electricity includes both electrical boilers and electricity used in heat pumps.

Source: Statbank Denmark (2017), "Subjects - Business sectors, Construction, Buildings", www.statbank.dk.

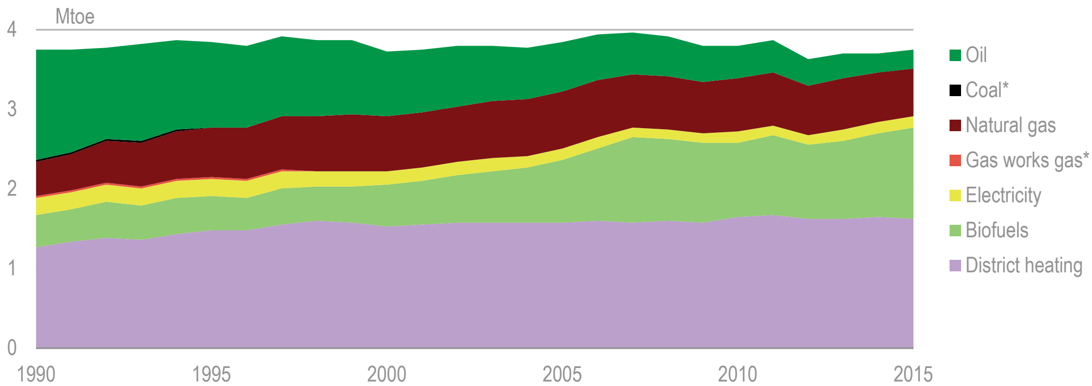
Construction of houses, industrial and commercial buildings peaked in the 1960-70s, a period when one-third of the total building stock was built (Statbank Denmark, 2017). These buildings have lower energy standards and a higher share of oil heating (around 15%) than buildings from the last decade, in which DH and electricity (including heat pumps) have increased as heat sources, while oil has fallen to around 1% or 2%. The large volume of buildings with lower energy standards implies a potential for improving energy efficiency further, and heat demand is projected to decline by 8% from 2015 to 2030. In this projection, DH is set to decline by 9% while the use of heat pumps is estimated to more than double (Ministry of Energy, Utilities and Climate, 2017).

Heat consumption in the residential sector

Net heat demand in the residential sector (including electric heating) was 3.7 Mtoe in 2015 (see Figure 10.3). District heating (DH) is the largest source of household heat supply, accounting for almost half of total heat consumption, followed by household biomass boilers, individual gas heating and small shares of individual oil boilers, direct electric heating and individual heat pumps.

Energy efficiency improvements have reduced energy intensity in space heating in buildings, which has compensated for a growing housing stock, and total heat demand has been rather stable for several decades. However, the heat supply has shifted from large shares of fossil fuels towards biofuels. Over the decade from 2005-15, oil consumption in residential heating declined by 62% and natural gas declined by 16%, while biofuels increased by 38%. DH has increased slightly by 3% over the same period.

Figure 10.3 Net heat consumption by fuel in the residential sector, 1990-2015



* Negligible.

Source: Danish Ministry of Energy, presentation at IDR meeting 2017.

Policy and regulation for heating in buildings

The Danish Energy Agreement of 2012 contains several initiatives to reduce heating based on fossil fuels in buildings and to promote renewable alternatives. Since 2013, oil-fired and gas-fired boilers may not be installed in new buildings, unless it is deemed the only valid option. Furthermore, from 2016, oil-fired boilers may not be installed in existing buildings with access to district heating or in natural gas networks. The government further granted DKK 42 million during 2012-15 to support the transition towards renewable heating systems in existing buildings (Energistyrelsen, 2012).

Other support policies for improving energy efficiency in buildings are listed in Chapter 7 on energy efficiency. The main focus for the remaining part of this chapter will be on district heating, and the integration of heat and electricity systems.

District heating

DH accounted for 18% of total final consumption in Denmark in 2015, the largest share of all IEA member countries. DH supply has changed significantly over the four decades since its introduction in Denmark, and most of it now comes from renewable sources. Regulation of the sector is undergoing changes as well, intended to make Denmark's DH systems more efficient.

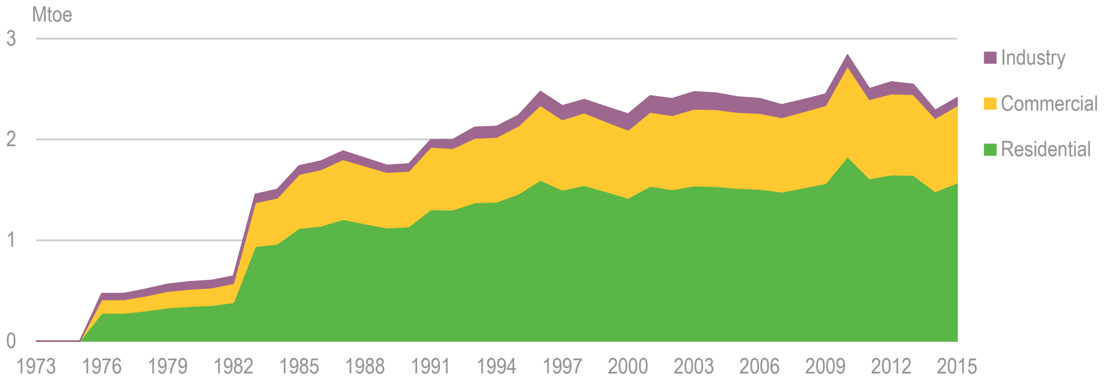
Supply and demand

Consumption

In 2015, total DH consumption was 2.4 Mtoe, the same as ten years earlier. Demand for heat depends on the outdoor temperature, and it peaked in the cold winter of 2010. Overall, consumption has been relatively stable over the last two decades, but demand per end-user will likely decline thanks to stricter energy efficiency requirements for new buildings and energy efficiency measures in existing buildings. DH companies are also required to promote energy savings (see Box 10.1).

The residential sector accounted for nearly two-thirds of total DH demand in 2015 (see Figure 10.4). Around 60% of households are connected to DH networks, and DH accounts for nearly half their net heat demand. Commercial buildings account for almost one-third of DH consumption, and a minor share of DH is used in industries.

Figure 10.4 DH consumption by sector, 1973-2015



Note: Includes all heat produced by main activity producer CHP and heat plants, as well as heat sold by autoproducer CHP and heat plants to third parties.

Source: IEA (2017), *World Energy Balances* 2017, www.iea.org/statistics/.

Production

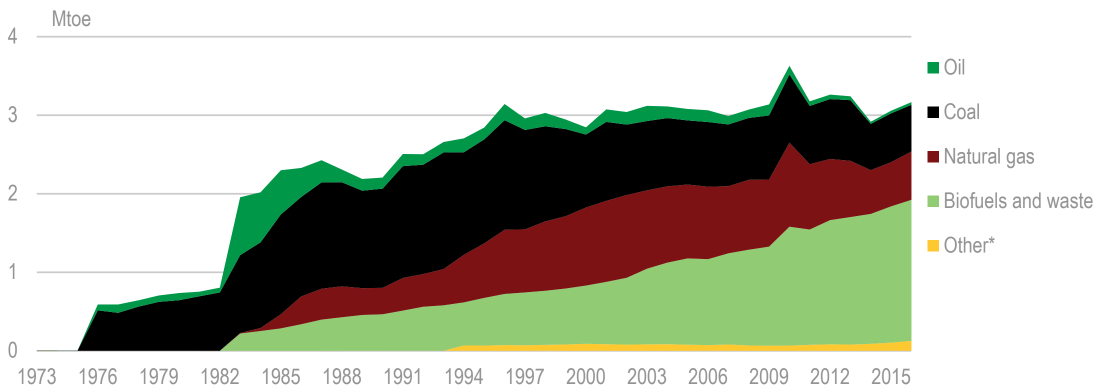
During the 1920s and 1930s, a collective DH system was developed on the basis of waste heat from local electricity production. From here on, DH from combined heat and power (CHP) plants expanded in the larger Danish cities and, by the 1970s, around 30% of all homes were heated by DH systems. Initially, DH production was based on coal and oil in large CHP plants. Natural gas CHP production increased in the 1980-90s, mainly at decentralised plants in more remote regions, and supplied up to 35% of total DH production in 2002. Since the early 1980s, however, biofuels use has grown to become the largest energy source for DH, driven by a favourable environmental tax regime (see Figure 10.5). Solid biomass has replaced coal in many large CHP plants as well as in new heat and CHP plants. Conversion of existing coal-fired CHP to biomass is expected to continue (see Chapter 4 on coal). However, coal and natural gas each still accounted for 19% of total DH generation in 2016.

Biofuels together with municipal waste incineration account for 57% of total DH generation in 2016 and the trend has been steadily increasing. Solid biofuels containing roughly equal shares of wood pellets, woodchips and straw, accounted for 35% of total supply. While woodchips and straw are domestically available, wood pellets are largely imported. The Baltic region and the Russian Federation account for roughly two-thirds of Denmark's wood pellet imports (Energistyrelsen, 2016). These imports have increased rapidly in recent decades, and account for over one-third of total supply of biofuels and waste in Denmark (see Figure 10.6).

Sustainability criteria have been introduced for the use of wood pellets and wood chips for electricity and district heating in a voluntary industry-level agreement, which will be fully implemented in 2019. The agreement has been drawn up by the Danish Energy

Association and the Danish District Heating Association, and contains sustainability criteria on carbon emissions reductions, biodiversity and forest conditions.

Figure 10.5 Fuel consumption in DH generation, 1973-2016



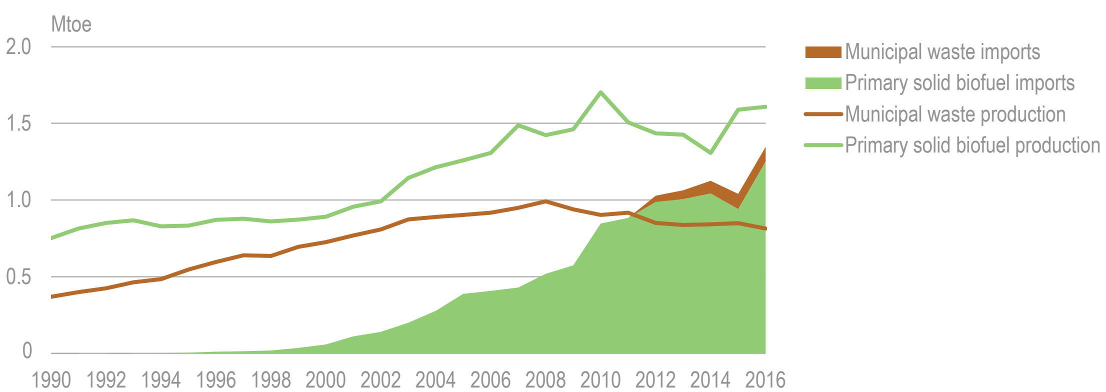
**Other* includes solar, electricity (direct and in heat pumps) and industrial surplus heat.

Notes: Includes all heat produced by main activity producer, CHP and heat plants, as well as heat sold by autoproducer CHP and heat plants to third parties. 2016 data are provisional.

Source: IEA (2017), *World Energy Balances* 2017, www.iea.org/statistics/.

Waste incineration is well developed in Denmark, and municipal waste accounts for 20% of total DH generation. In 2015, Danish waste-to-energy plants incinerated 3.6 million tonnes (Mt) of waste, of which around 10% was imported, e.g. from the United Kingdom (DA, 2017). Incineration accounts for over half the municipal waste treated in Denmark, which together with Sweden incinerates most waste per capita in the European Union (OECD, 2017). The European Commission, however, states in its Strategy for a Circular Economy that such high rates of incineration are inconsistent with more ambitious recycling targets (EC, 2017).

Figure 10.6 Production and imports of solid biofuels and waste, 1990-2016



Note: 2016 data are estimates.

Source: IEA (2017), *World Energy Balances* 2017, www.iea.org/statistics/.

Solar heating has grown rapidly in recent years as a result of the tax regime on fossil fuels and energy efficiency requirements for the DH sector, which both make solar heating an attractive option for DH producers (see Box 10.1). Denmark has become a world leader in large solar heating systems connected to DH. In 2016, the total installed area of solar collectors connected to DH networks was 1.3 million m^2, an increase of 58% over the previous year (see Figure 10.7). Since solar heat is produced mainly in the summer when heat demand is low, many DH systems use large thermal storages to shift the supply to periods of higher demand (see further section on CHP and heat storage below).

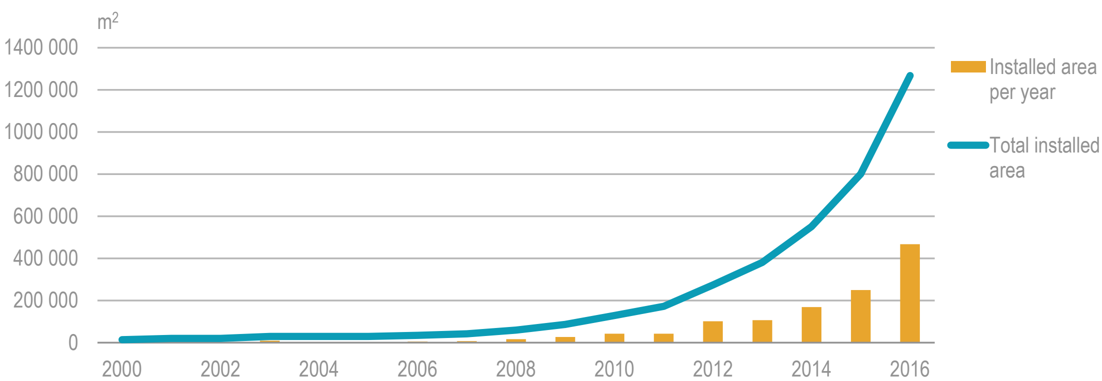
Box 10.1 Energy efficiency obligation scheme for energy companies

As part of Denmark's energy efficiency ambitions, energy companies working on production and distribution of electricity, gas or district heating participate in an energy efficiency obligation scheme (see also Chapter 7 on energy efficiency). The scheme requires the DH sector as a whole to achieve energy savings towards a target of 0.1 Mtoe (4.1 petajoules) in 2016-20. The process is administered by the Danish DH association, *Dansk Fjernvarme*, and communicated to DH companies that are members of the association.

DH producers are required to document and check the quality of energy savings, and annually report to the Danish DH association, which in turn reports to the Danish Energy Agency and the Danish Energy Regulatory Authority. Energy savings can only be certified if the DH company has been actively involved, through direct investments or through providing tools or advice to customers. Heat produced from solar energy is also allowed to be counted as energy savings, which has led to a rapid increase of solar heating in Danish DH networks.

Sources: ENS (2016) "Aftale af 16 december 2016 om Energiselskabernes energispareindsats" [Agreement 16/12/16 on Energy Companies' Energy Savings]; DF (2017), "Energispareforpligtelsen" [Energy Saving Commitment]; Patronen et al. (2017), "Nordic heating and cooling".

Figure 10.7 Installed area of solar heat collectors, 2000-16



Source: DF (2016a), "Stort fald i planlagte solvarme-anlæg" [Large drop in planned solar heating plants], Kolding.

DH production from large heat pumps has so far been small in Denmark because of high taxes on electricity. Industrial surplus heat also accounts for only a minor share of total DH production, partly for the same reason, as low-temperature surplus heat requires heat pumps to reach temperatures that are useful in a DH network. There is also a tax on industrial surplus heat, which was introduced to avoid overconsumption of energy in industrial processes, as energy and carbon taxes paid by industries are much lower than taxes paid by DH companies. Industries selling surplus heat pay in tax up to 33% of the total value of the heat (Skat.dk, 2017). However, there are exceptions that can lower the tax rate; the surplus heat tax is considered to be lower for the business using industrial heat, than the high electricity tax.

New industries, such as data centres, will increase available surplus heat in Denmark (Gronholt-Pedersen, 2017). Both Apple and Facebook are planning to set up new data centres, attracted by access to a reliable power system with high shares of green electricity, as well as a cool climate and available DH networks to offset surplus heat.

Combined heat and power

CHP accounts for two-thirds of total DH production in Denmark. This includes all coal plants and a majority of the natural gas plants. The share of CHP has fallen from over 80% a decade earlier, as a result of low electricity prices making CHP production less profitable. This has led to a development with more heat-only production, based on renewables such as biomass and solar heating. The government projects CHP to continue to be affected by the increasing volumes of wind and solar power, and current policies aim to promote CHP through regulation and subsidies. In the national regulation requirements for the heating sector, heat production units in general shall be established as CHP plants (the so-called CHP requirement).

Since 2004, decentralised natural gas CHP plants are supported through a subsidy mechanism called *Grundbeløbet* ("the basic amount"), which guarantees a minimum level of revenue from electricity sales (DE, 2016). When the electricity price falls, the subsidy increases to compensate for lower revenue. This subsidy was introduced to encourage the use of the available generating capacity held by natural gas CHP plants, which can be used to balance higher shares of variable wind power generation. However, the subsidy will be phased out at the end of 2018. From 2019, only CHP plants using biofuels may receive subsidies through the premium tariff granted to renewable electricity generation as a variable bonus on top of the market price.

Market and regulation

Market structure

The Danish DH market is fragmented in six large central DH areas, accounting for over half the total DH supply, plus around 400 small and medium-sized systems. Despite increased consolidation in recent years, there are around 600 DH suppliers with different ownership structures such as consumer-owned co-operatives, municipality-owned companies and joint-stock companies (Patronen et al., 2017).

In large DH systems, heat producers sell heat to a DH transmission company that owns and operates the large transmission pipelines. The DH transmission company supplies DH distribution companies that in turn sell to the end-consumer. Distribution companies are typically owned by municipalities or co-operatives. Some large transmission and distribution companies also produce heat. In small-scale systems, the producer often owns the distribution network and sells heat directly to the consumer.

Institutions and regulation

Denmark passed its first heating supply law in 1979. The law contained regulations regarding the form and content of heat planning in the country, which is largely managed at municipal level. Municipalities are responsible for preparing and updating heat plans and approving heat projects, and the City Council takes the final decision on expansion of heat supply in the municipality.

DH production and network companies are considered natural monopolies and are subject to regulation, which is set in the **Heat Supply Act** (HSA). The HSA regulates "heat-only" producing plants larger than 250 kilowatts (kW) installed heat capacity, and CHP plants with heating output below 25 megawatts (MW). Larger CHP plants are regulated by the Electricity Law, which governs the development and structuring of the electricity sector, but their heat production is subject to regulation under the Act (Patronen et al., 2017).

Companies are regulated as non-profit undertakings, where the consumer price should cover the costs related to heat generation. The HSA states which costs may be included in heating prices, which are regulated by the Danish Energy Regulatory Authority (DERA). Consumer prices can still vary according to production costs. Any complaints regarding DH prices are handled by the DERA and the Energy Supply Complaint Board. The price regulation stands out in a comparison of Nordic countries with more market-based systems (see Box 10.2).

Local heat supply authorities currently have the mandate to secure a high share of connection to district heating and natural gas networks. Hence, the municipality may introduce mandatory connection requirements for buildings in a given area. For existing buildings, the requirement is mandatory nine years after the decision was taken. The government is considering gradually removing these municipal provisions in order to enhance competition between individual and collective heat suppliers. There is, however, a lock-in effect from the costs of connection to DH networks and the cost of installing alternative heating technologies, e.g. the investment in a household heat pump. High investment costs tend to discourage customers from changing from the current system, even if the alternative may provide economic gains in the long term. Price differences between different heating alternatives must therefore be significantly large to overcome the lock-in effect, which limits market competition.

When establishing or extending DH supply, the choice of fuel is regulated on the basis of the available infrastructure of the area. In the case of CHP generation, nearly all fuel types can be chosen, but for heat-only production, the fuel is restricted. In areas with available natural gas supply, this must be used for heat production in non-CHP plants. If the DH facility is in an area without natural gas supply, biofuels (solid biofuels or biogases) and waste are allowed (DEA, 2015).

Prices and taxes

The consumption of DH is not taxed specifically, but a value-added tax (VAT) is added to the consumer bill. The fuel consumption in DH production, on the other hand, is subject to energy and carbon taxes, as well as sulphur and nitrogen oxide (NO_X) taxes. Tax differentiations are applied to encourage the use of renewable energy sources, such as biomass. Fossil fuels are heavily taxed, while renewable fuels are exempt from energy and carbon taxes. Biomass combustion is subject only to the NO_X taxation (Patronen et al., 2017). The use of industrial surplus heat is subject to a specific tax, as mentioned above.

DH prices vary significantly across systems, from around DKK 5 000 annually per household[1] to almost DKK 25 000 (DF, 2016b). Prices can vary according to fuel cost, taxes and depreciation cost, but large variations are found also within each production technology and fuel type. The cheapest DH is produced from biofuels in heat-only boilers and heat and power plants (see Figure 10.8).

[1]. Based on a 130 square meter standard house, with an annual heat consumption of 18.1 MWh.

Box 10.2 DH regulation in Nordic countries other than Denmark

DH is important in most Nordic countries, and the regulatory models differ. Prices are not regulated in Sweden or Finland, while Norway uses an alternative heating cost model.

Sweden has a market-based system with unregulated DH prices since the deregulation of its energy markets in 1996. Customers can change from DH to other heat sources, which create competition with mainly heat pumps. Instead of price regulation, DH companies and consumer groups (housing associations) participate in *Prisdialogen* (the price dialogue), a business collaboration to improve transparency and customer's market power.

To further increase competition on the market, "third-party access" (TPA) has been proposed and assessed by the government at several occasions, and a regulated TPA model was introduced in 2014. Heat producers are granted access to DH networks under certain conditions, regulated by the Swedish Energy Market Inspectorate. Network owners can dismiss TPA only if it is deemed to impose a risk to the business. TPA has practical limitations, however, and has so far not led to a major increase in competition.

Open access to DH networks to benefit from available surplus heat is tried by *Fortum Värme*, which has opened up its DH network in Stockholm for e.g. server halls and supermarkets with large cooling equipment that generates surplus heat.

Finland has also unregulated DH prices, but the DH companies are not allowed to abuse their dominant market position. The competition authority controls that prices are on equal terms for all customers and reflect the costs. As in Sweden, there is generally no obligation to connect to DH networks, and customers can change to other heating sources as they wish. Finland has no regulated TPA and access to DH networks needs to be negotiated with the network owner.

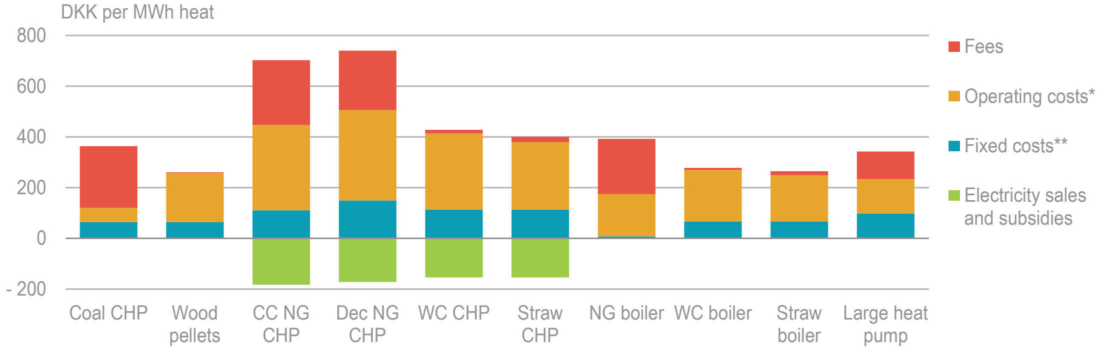
Finland uses a system of voluntary energy efficiency requirements, similar to that in Denmark. It includes the energy, industry, service and residential sectors, and covers both production and consumption of energy. A successful first period 2008-16 led to a 14 TWh reduction in annual energy consumption, and the system was extended with a new period 2017-25.

Norway uses much less DH than other Nordic countries, because of its vast access to cheap and clean hydropower, but the DH market is growing rapidly, supplying mainly the service sector. Municipal waste is the largest fuel and a landfill ban from 2009 is a major driver of DH development. DH operators are required to apply for a concession to supply DH in an area and, if granted, the municipality can decide to introduce mandatory connection for all new buildings in the area, as in Denmark.

In concession areas with mandatory connection requirements, DH prices are regulated on the basis of the alternative cost of heating, which for Norway means electricity. DH prices are therefore capped by the consumer electricity price, including taxes. This regulation ensures that DH customers are protected from unfair prices compared to households that are not connected to a DH network. However, it can cause an unstable business environment for DH companies with sudden changes in prices.

Source: Patronen et al. (2017), "Nordic heating and cooling".

Figure 10.8 DH cost breakdown per type of production, 2016



*_Operational costs_ include cost for fuel, operations and maintenance.

**_Fixed costs_ include depreciation of plant per MWh heat produced.

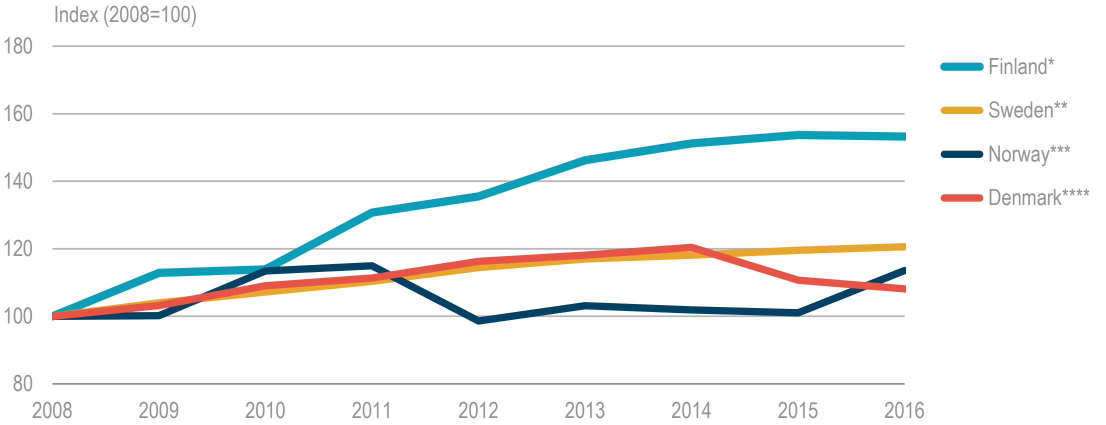
Note: CC = combined cycle, NG = natural gas, WC = wood chips, Dec = decentralised plant.

Source: DF (2016b), "Fjernvarmeprisen 2016" [District heating prices 2016], Kolding.

Biofuels clearly benefit from the tax exemptions, whereas energy and CO_2 taxes on fossil fuels make coal- and natural gas-based heat generation more expensive. Electricity used in large heat pumps would likely be the cheapest source of heat generation, were it not for high taxes on electricity consumption. DH and individual natural gas heating are similar in price, while individual oil heating is more expensive (DF, 2016b).

Prices have fallen slightly for most production types over recent years, but the average DH price has declined since 2014. This development stands out in a Nordic comparison, where DH prices in Sweden, Finland and Norway have been stable or increased (see Figure 10.9).

Figure 10.9 DH price development for customers in Nordic countries, 2008-16



*Different price series for 2007-10 (detached house 20 MWh/year) and for 2011-16 (detached house 18 MWh/year).

**Average DH cost per square metre in a 1 000 m^2 apartment building.

***Average price of total DH delivered to all end-consumers. Prices are correlated to changes in the electricity price.

****Weighted average DH price for a standard house (18.1 MWh/year).

Notes: This is a comparison of average DH prices for a typical customer, which is defined differently in the different countries. It does not take into account local price variations, differences in taxes or the DH price competitiveness compared to other heat sources. Nonetheless, the comparison shows the overall trend in the Nordic DH markets.

Sources: DF (2016b), "Fjernvarmeprisen 2016" [District Heating Prices 2016], Kolding; SSB (2017), "Fjernvarme og fjernkjøling" [District Heating and District Cooling]; NilsHolgersson (2017), "Rapporthistorik" [Report History]; Statistics Finland (2017), "Price of District Heating by Type of Consumer".

From 2008 to 2016, DH prices increased by over 10% in Norway, by around 20% in Sweden and by around 50% in Finland, while Danish DH prices increased by around 8% after falling by around 10% from 2014 to 2016. The price fall in the last two years can be explained mainly by falling natural gas prices, which led to a price drop in heat from natural gas by 20% to 30% in 2014-16. Natural gas is a more common fuel in Denmark than in the other Nordic DH systems, and before this recent price drop, average DH prices in Denmark and Sweden developed very similarly. After the Grundbeløbet subsidy is removed in 2019, the DH price is estimated to increase for customers connected to decentralised natural gas CHP plants (DE, 2016).

New economic regulation and framework for investments

In previous studies of the DH sector in Denmark (e.g. Larsen, 2015[2]), large potential cost savings have been estimated. The studies argue that a cost-recovery regulation hinders energy efficiency development in the supply sector, and suggests a new regulatory regime based on cost of production and a maximum profit. In 2016, a broad political coalition decided on a target to achieve DKK 0.5 billion in cost savings in the DH sector by 2020. Costs are to be saved through consolidation of the many small suppliers into larger entities, and by introducing a benchmarking system to evaluate and improve the efficiency of the companies.

Following the decided target for efficiency improvements, the government launched a new energy supply strategy in September 2016, setting up new directions for regulation in energy supply sectors, including DH (EFK, 2016). The current cost-recovery regulation, whereby companies only are allowed to cover their costs and a return on invested capital, will change into a new “incentive-based” economic regulation. In the new regulation, DERA will allow the DH company to create a surplus that can be used for DH activities, if the company can produce heat at costs below its income cap. For the following regulation period, the income cap can be reduced by the previous surplus, to pass on the efficiency gain to consumers. DH companies are thus stimulated to continuously improve efficiency to lower their costs.

Cost calculations will be standardised through a benchmarking system, where DH companies report operational costs, depreciation and revenue over the calendar year. Benchmarking enables income to be regulated on the basis of business standards rather than each company’s own estimated costs. Furthermore, the new regulation will remove the possibility for DH producers to temporarily increase prices to finance new investments. Temporary cost increases have been used as a free loan from the consumers to cover investment costs, and DH producers will now have to fund investments through regular bank loans, equity capital or retained earnings.

Over time, the new regulatory regime will encourage a market-based development of the sector, in which producers can invest according to their own best interests and consumers are allowed to choose the cheapest source of heating. The aim is to gradually phase out regulatory restrictions on companies’ choice of production (fuel and technology) and the use of mandatory connection to district heating.

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[2] ”Moderniseret regulering i fjernvarmesektoren” (Modernised Regulation in the District Heating Sector), https://ens.dk/sites/ens.dk/files/Forsyning/11._rapport_om_moderniseret_regulering_af_fjernvarmesektoren_tvaerministeriel_arbejdsgruppe.pdf.

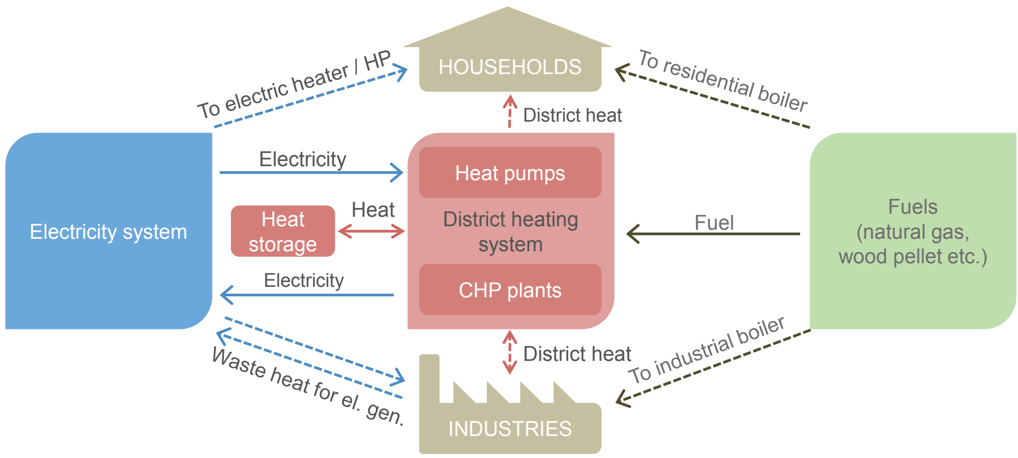
Integration of heat and electricity systems

Heat and electricity systems are integrated in several ways, e.g. when DH producers use CHP plants to generate both electricity and heat, and when DH producers use electric boilers or heat pumps that consume electricity (see illustration in Figure 10.10). Heat can be stored more easily than electricity, and this is used by CHP producers. Buildings also have the capacity of storing heat short term, which can be utilised if aggregated over many consumers.

Industries also have a role to play in energy systems integration, both as consumers and as potential producers of heat and electricity. Industrial surplus heat can feed into a DH system, or it can be used for power generation in an Organic Rankine Cycle (using a different liquid/vapour medium with a lower boiling point than water).

Flexibility in DH production and consumption can create synergies to the energy system as a whole, but it requires system-wide policies that allow efficient sector coupling.

Figure 10.10 Illustration of the integration of heat and electricity systems



The role of heat storage

Short-term heat storage is a common feature in Danish DH systems. It allows CHP producers to balance supply and demand for heat and electricity. CHP generation with large heat storage offers a low-cost opportunity to shift production to times when electricity demand is high and, correspondingly, the producer can use stored heat instead of running the plant when electricity supply is high.

Heat is typically stored in large insulated steel containers with water, where hot water rises to the top part and colder water towards the bottom. Separation of hot and cold water enables efficient loading and unloading of hot water from the storage. Short-term heat storage has typically a capacity corresponding to around eight hours of heat production at full load in the heating plant (IEA/NER, 2016). Some Danish DH systems, e.g. in connection with solar heaters, are equipped with larger seasonal storages. These can be underground storages in dams, aquifers, boreholes or caverns, e.g. old oil storage caverns. Seasonal storage may require heat pumps to increase the temperature of the stored water before use in DH systems.

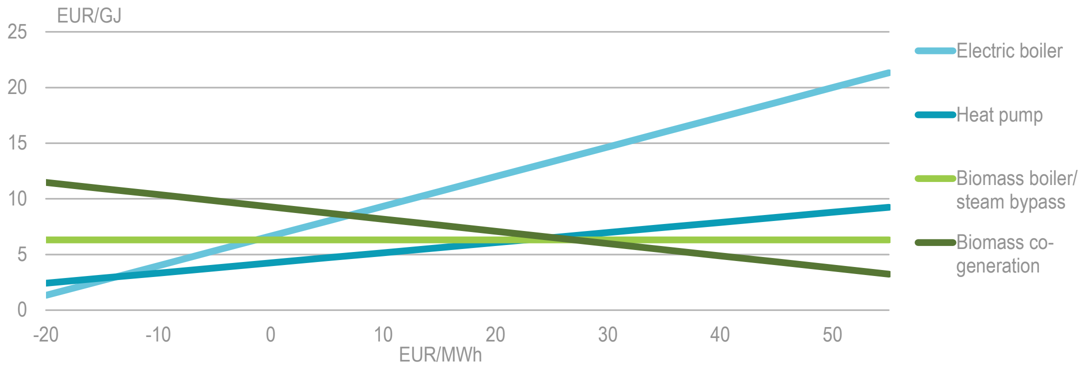
CHP plants contribute to electricity security of supply. Especially natural gas CHP plants with short start-up times and flexible operation provide useful capacity to balance variable wind power. This capacity is promoted in Denmark through the *Grundbeløbet* subsidy, which will be removed in 2019, and a regulatory focus on promotion of combined heat and power.

The role of electricity taxation

High electricity taxes provide little incentive to use electricity in heat generation. The taxes were introduced to encourage energy savings, as electricity is a high-quality energy source that can be transformed into other kinds of energy with low losses. However, large growth in subsidised wind power generation has led to increased power capacity with low operating cost and declining electricity prices. On cold and windy winter days, electricity prices can fall into negative, while DH producers are running their plants at full capacity, providing additional electricity generating capacity.

The short-term marginal cost of heat production from different heat sources depends on the electricity price. Electricity prices in the Nordic system of around EUR 20/MWh and lower would benefit heat pumps, whereas higher prices make biomass CHP plants more profitable (see Figure 10.11). However, different taxation schemes change this situation.

Figure 10.11 Marginal heat production cost by technology and by electricity price



Source: IEA/NER (2016), *Nordic Energy Technology Perspectives 2016*.

The issue of low and occasional negative electricity prices has gathered attention in Denmark and led to calls for increased use of heat pumps and electric boilers integrated in DH generation. The government set up a heat pump taskforce in 2015, which helped district heating plants implement heat pump solutions. Furthermore, in 2015, investment in heat pumps for district heating was encouraged through grants totalling DKK 26.7 million for ten projects (Patronen et al., 2017). In 2017-18 another DKK 53 million will be granted as investment subsidy for heat pumps in district heating. So far, however, heat pumps account for a very small share of DH generation.

Individual vs. collective use of heat pumps

Heat pumps are used also in individual heating systems. They are an attractive technology option for buildings not connected to DH or natural gas networks. Compared to the use of DH, however, heat pumps account for a very small share of household heating in Denmark (see Figure 10.11). From a perspective of integrating the electricity and heat systems, there are economic and efficiency trade-offs between using heat pumps in individual heating systems vs. in DH production.

Heat demand peaks during the coldest winter days. If many households have individual heat pumps as the primary heat source, peak heat demand will cause spikes also in electricity demand, not correlated with the available electricity generation. Heat pumps are more easily controlled and integrated in the energy system when connected to DH production. With many buildings connected to a DH system that uses both CHP and heat pumps, heat production can be planned so that CHP is used more in times of low wind power generation and heat pumps are used during windy days when electricity is cheap. New technology can, however, enable a similar flexibility to be achieved also for individual heat pumps. Smart meters and control systems can utilise the inherent storage capacity of buildings and automatically adjust consumption to price signals. To have significant effect on the overall system, an aggregator is required to connect and change a consumption behaviour in many buildings simultaneously.

From an economic perspective, the capital cost of connecting new houses to a DH system could be higher than the investment cost of an individual heat pump. The utilisation rate of a household heat pump will also likely be higher than for heat pumps connected to a DH system, where it will be used as a complement to other production. The optimal combination of DH using heat pumps and individual heating alternatives thus depends on prices and taxes for different heat sources and energy technologies.

The future role for DH and CHP

Continuing energy efficiency improvements and a likely warmer climate will lead to declining heat demand in buildings, which negatively affects DH companies whose business depends on selling heat. Energy markets are also changing towards increasing decentralisation and variability in production. The business response can be to develop new business models and offer comfortable indoor climate as a service, rather than selling kilowatt-hours of heat. In this model, energy efficiency improvements in buildings are not necessarily a loss for the heat supplier. The changing market conditions also enhance the need for further integration of heat and electricity systems. This can be helped by new technology that enables aggregation and improved control of energy consumption, which ideally would benefit both companies and individual consumers.

Assessment

District heating strongly contributes to Denmark’s energy transition, and the shift towards a mix of sustainable energy sources should be further supported. DH is the most important heating source in the residential and commercial sectors, providing almost half the total heat supply in buildings. Total DH demand has remained stable over the last two decades, whereas the DH production mix has shifted from being largely based on fossil fuels to a clear dominance of biomass and municipal waste. This shift forms an important part of the energy transition in Denmark, and needs to continue if the country is to meet its ambitious energy and environmental targets.

The rapid increase in biomass-based DH has made Denmark a large importer of wood pellets. As the conversion of existing coal-fired CHP plants continues, import diversity needs to be considered to guarantee security of supply. Furthermore, Denmark has a very high share of waste incineration and waste available as a fuel could become more restricted in the future, which puts further strain on the security of fuel supply. Denmark should assess the future for biofuels and municipal waste as fuels, in the light of sustainability requirements on biofuels and EU policy on waste treatment, and should further utilise domestically available renewable energy sources and industrial surplus heat.

Solar heating has increased rapidly in recent years, partly as a result of the energy efficiency obligation scheme, and can continue to grow if the regulatory support remains in place. However, solar heat still accounts for only a minor share of total heat production and is available mostly during the summer months when demand for heat is low. Denmark should assess the potential for further growth in solar heating compared to other alternatives, in terms of cost and energy efficiency. If the assessment identifies a significant untapped potential for solar heating, increased use of seasonal thermal storage should be encouraged so as to shift the supply to periods of higher demand.

The share of CHP is declining in Denmark and the trend is likely to continue with low electricity prices and the removal of the *Grundbeløbet* subsidy of natural gas CHP. The effects of this removal on consumer prices and on the total DH production should be monitored to ensure that DH is produced and used in an efficient way. Giving up subsidies for natural gas can contribute to the transition towards renewable energy in DH production, but alternatives to increasing the use of imported biomass as a source could be needed and this biomass should in any case be from sustainable forestry.

The district heating market is a natural monopoly, and the regulatory challenge is to promote improved efficiency while maintaining a good business environment. Denmark's DH market consists of a large number of heat producers and distributors, and prices vary considerably across networks. Price variations partly reflect the different levels of production costs, but also differences in operational efficiency between systems. Analyses have indicated a potential for significant productivity gains in the sector, and a new regulatory framework aims at tapping into that potential. Both production and network companies are monopolies that today are regulated as non-profit undertakings, with little incentive to improve efficiency. In the suggested new regulatory framework, benchmarks and standardised accounting principles will be introduced to support a regulation of revenue, including continuing efficiency requirements.

Further opening up DH networks for third-party access and removing restrictions in choices of fuel and technology in heat production can increase market competition and utilisation of industrial surplus heat. With new data centres being established in Denmark, the potential for using industrial surplus heat increases, and regulations and policy should support this development.

By enabling customers to change between DH and individual heating solutions, competition is increased between DH and other heat supply technologies. Improving market competition can be a way to optimise the use of individual vs. collective heating solutions, where a number of trade-offs exist that are otherwise hard to assess. The government is considering removing the DH and gas network connection mandate as a way to increase competition between individual, and collective, heat supply. If it decides to do so, it should take into account the need for a 'critical mass' in smaller DH systems for them to remain economically viable.

Other Nordic countries have chosen less regulated models based on competition between DH and other heating technologies. How competitive an unregulated heat market is depends on how strong the lock-in effects are for customers in the market. A price comparison shows prices increasing more in the less regulated markets of Sweden and Finland in recent years, which could indicate that free competition on the DH market does not always bring overall lower prices. However, the price trend is partly explained by a relatively large drop in fuel prices in Denmark, from falling natural gas prices.

Taxes and regulations need to be aligned to support further integration of heat and electricity systems and achieve potential synergies. The boom in biomass combustion and a slow uptake of other sustainable technologies, particularly heat pumps, have been driven by distorted price signals with zero taxation for biomass and high electricity taxes. In order to support security of supply in the heat sector and facilitate the transition of the DH sector towards the 2050 objectives, it is necessary to provide adequate, non-distorted conditions for more flexible and diverse DH systems, which would use heat pumps, industrial surplus heat, solar water heaters, geothermal energy and thermal storage. To achieve this, taxation of electricity in heat generation and use of surplus heat in DH should be reconsidered.

Taxation and possibly other measures should be adjusted to optimise the use of DH and individual heating options. In DH systems, it makes sense to use sustainable biomass in existing CHP plants in the short and medium term in order to replace coal, oil and gas. On the other hand, fossil fuels in individual boilers and very small DH networks can be replaced directly by more advanced heating technologies, such as heat pumps, without converting fossil-fired boilers into biomass use.

Denmark's world-leading deployment of variable wind power and large utilisation of CHP plants with heat storage capacity in DH systems form ideal conditions for efficient integration of heat and electricity systems. Taxation should be adjusted to improve integration between the electricity and heat systems, so that CHP producers with heat storage can utilise times of excess power in the system and contribute to balancing the power and heat systems. If taxes and regulations are well aligned, DH suppliers will be able to respond to electricity price signals and utilise the optimal mix of heat production and storage to compensate for fluctuations in power generation. Policy should support the utilisation of new technology that can further improve sector coupling. A more system-wide approach to energy policy is required to avoid conflicts between support in heat and electricity generation.

Recommendations

The government of Denmark should:

- ☐ Given the magnitude of the transition towards renewable energy systems, provide adequate incentives for economically feasible investments in the short term:
  - > In DH systems, by continuing to support the switching of fossil fuel-fired plants to sustainable biomass and other sustainable options, while acknowledging that the role of biomass and waste in DH will have to be reconsidered in the long term.
  - > In individual heating systems and very small DH systems, by encouraging a faster phasing-out of fossil-fired heating and a transition to heat pumps and other sustainable heating technologies.
- ☐ Introduce a new regulatory regime for DH markets and support improved efficiency and long-term competitiveness in DH systems through:

- > Introducing a regulatory benchmark, including standardised accounting principles, to increase efficiency and promote further co-operation among DH companies, improve quality and maintain competitive consumer prices.
- > Considering further measures to increase competition on the DH market, such as promoting increased third-party access to increase the utilisation of industrial surplus heat and allowing customers to change heat supplier.

☐ Enhance the integration between the heat and electricity sectors and remove restrictions on the choice of non-fossil heat production technology to diversify across heat sources, by:

- > Adjusting energy tax levels to enable efficient integration of heat and electricity systems, and align policy on a system-wide approach.
- > Considering the need to remove regulatory barriers and to adapt the infrastructure to integrate different heat sources, e.g. concerning temperature requirements, to enable companies to take investment decisions on the basis of the long-term socio-economic value of technology options for supply, demand-side efficiency and storage.

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11. Energy technology research, development and demonstration

Key data

(2016)

Government energy RD&D spending: DKK 738 million (EUR 99 million)

Share of GDP: 0.039% (IEA median*: 0.024%)

RD&D per capita: DKK 129

Exchange rate: DKK 1 = USD 0.149 = EUR 0.134

* Median of 17 IEA member countries for which 2016 data are available.

Overview

Energy technology research, development and demonstration (RD&D) in Denmark is aligned with the energy and climate policies, and supports the country's low-carbon objectives. Denmark had one of the highest levels of public funding as a ratio of GDP among IEA member countries, until public funding was halved in 2016 and 2017. In line with the Danish energy objectives, nearly half the funding was allocated to renewable energy projects. Considerable public spending on energy RD&D has brought about significant socio-economic benefits, including a shift towards a low-carbon energy mix, increased energy efficiency, job creation, and increasing exports of energy technology.

Strategies

Denmark does not have a dedicated strategy for energy RD&D. Each of the major state-funded energy research programmes (see below section on programmes) has its own strategy for allocating public funding. The Danish electricity and gas system operator, Energinet.dk, also has its own three-year RD&D strategy (Box 10.1).These strategies are broadly aligned with the energy policy objectives laid down in the national Energy Agreement adopted by political majority in 2012. The strategies prioritise the areas that can help Denmark achieve its long-term objective to become a low-carbon economy, such as renewable energy, smart grids and energy efficiency.

While government-funded RD&D programmes set the overall strategic directions, the government does not interfere in the process of selecting and prioritising specific technologies and projects. The programmes' managing boards issue calls for proposals in relatively broad areas and assess and select "winning" projects on the basis of their quality; therefore, projects targeting various technologies can compete with each other.

In exceptional cases, public funding can be earmarked to specific technologies via a special financial act.

Overall research priorities in Denmark are outlined in the catalogue *Forsk2025* (Research2025), which updated the previous catalogue Research2020 (*Forsk2020*) in 2017. The *Forsk2025* was prepared by the Danish Agency for Science and Higher Education with input from businesses, organisations, ministries, research institutions and various other stakeholders, which have links to RD&D, and with limited involvement from the political level. The purpose of the catalogue is to instil knowledge, inspiration and prioritisation for political decision making on allocation of strategic research funding. The catalogue is not a strategy *per se*, but it provides a consolidated overview of the most important research areas for the future as seen by different stakeholders.

The Energy Agreement of 2012 highlights the need to maintain a high level of RD&D in energy technology to support continued efficiency improvements in the use of energy and to promote cost-effective renewable energy technologies that also have a commercial and export potential.

In the framework of preparing a new energy agreement for the period beyond 2020, the recommendations of the national Energy Commission include (see Chapter 1, Box 1.1):

- A national strategy must set the course and ensure co-ordinated efforts.
- Energy research funding must be increased to DKK 0.8-1 billion per year from 2020 onwards and the continuity of efforts must be safeguarded.
- Priority must be given to original demonstration projects and test platforms.

The commission concludes that Denmark's position as an energy technology front-runner must be strengthened.

Exports of energy technology

A key topic in Denmark is about exporting energy technology and the relationship between exports and the government-funded energy RD&D. Exports of Danish energy technology set a record in 2014 at DKK 74.4 billion (EUR 10 billion), or 12% of total Danish goods exports. By 2015, Denmark's exports of energy technology dropped by 3.9% to DKK 71.4 billion, amounting to 11.1% of total Danish exports. Exports of "green energy" technology (renewables and efficiency-related) worth DKK 40.9 billion represented 57.4% of all energy technology exports in 2015, while "other energy" technologies (fossil fuels-related) accounted for DKK 30.4 billion or 42.6%. Germany is the largest market for Danish exports of energy technology (about 35%). The technologies where Denmark has competitive advantage include wind energy, district heating, energy efficiency, bioenergy, oil and gas, and smart grids and system integration (Energy Commission, 2017).

Public energy RD&D funding

Following the political agreement in 2008 to spend DKK 1 billion per year on energy RD&D from 2010 onwards, public energy RD&D spending was raised from DKK 761 million in 2009 to over DKK 1.3 billion in 2010, a 72% increase. In line with the national energy policy objectives, Denmark tripled the amount of funding allocated to energy efficiency, and also increased the funds for renewables by 51%.

However, since then, spending on energy RD&D has shown an overall decreasing trend (Figure 11.1). After the change in the government in June 2015, because of a shift in political priorities, the state budget adopted for 2016 resulted in a dramatic fall in public expenditure on energy RD&D: about half a billion krone in 2016, and slightly more in 2017.

The level of public funding on energy RD&D in 2016 was DKK 738 million, 44% less than the 2010 peak (see Figure 11.1). Renewables had the largest share, accounting for 47% of total energy RD&D funding, followed by energy efficiency, with 21%. The rest was spent on power and storage technologies and small shares for nuclear, fossil fuels, hydrogen and other technologies.

Box 11.1 Energinet.dk's RD&D strategy

The Danish electricity and gas transmission system operator, Energinet.dk, has its own three-year RD&D strategy that aims to catalyse solutions, which are to be market-ready in 2020-50. The strategy includes Energinet.dk's own RD&D activities (ForskIN) and a programme funded via external RD&D projects (ForskEL until 2017; when funding was transferred to the Energy Technology Development and Demonstration Programme, EUDP). ForskIN and ForskEL/EUDP are aligned to ensure cohesion and synergies, and are closely co-ordinated with other Danish energy research programmes, including ELForsk. The activities in ForskIN focus primarily on the development, demonstration and implementation of commercial solutions, while ForskEL/EUDP activities are more long-term, with a larger emphasis on applied research and development.

The initiatives in ForskIN include:

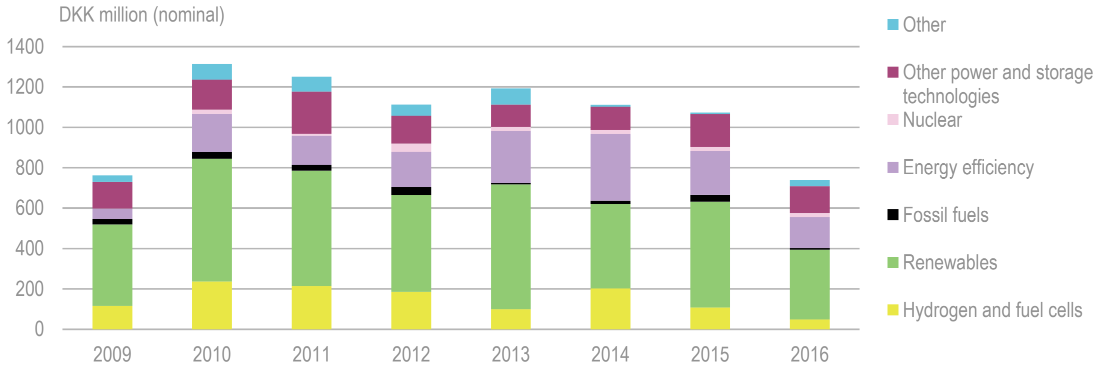
- quality of electricity and infrastructure
- flexibility and storage
- RE gases and infrastructure
- data security.

Energinet.dk 's participation in the ForskEL/EUDP programme includes :

- integration of RE generation technologies, which supports the commitment to an economically viable transition
- Energy storage and integration, which supports the commitment to a high level of security of supply
- market and society, which supports the commitment to a healthy investment climate.

Source: Energinet.dk (2015), "Strategy for Research, Development and Demonstration in Energinet.dk: Paving the way for the green transition".

Figure 11.1 Government energy RD&D spending by category, 2009-16

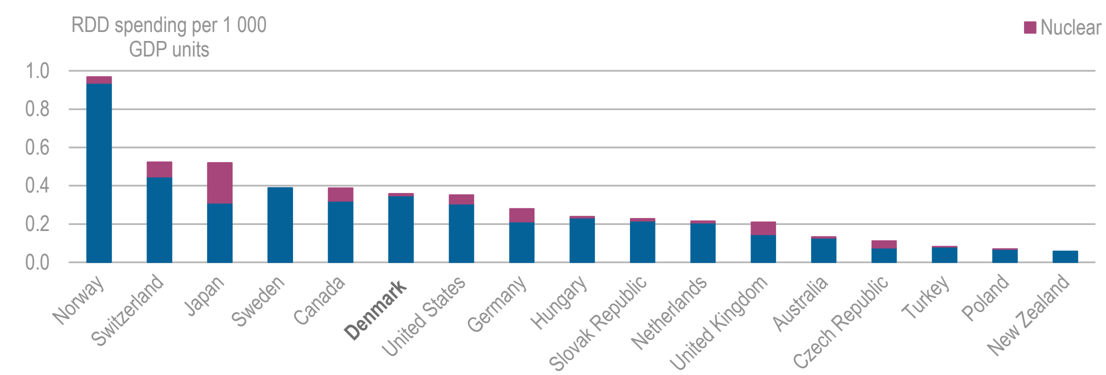


Source: IEA (2017), “IEA Energy Technology RD&D database, 2017”, www.iea.org/statistics/.

In the 2009-16 period, total public funding on energy RD&D amounted to DKK 8.6 billion. Renewable projects received the largest amount, nearly half (46.2%), followed by energy efficiency projects (17.7%), hydrogen and fuel cells (14.1%) and other power and storage technologies (13.4%). Smaller shares were set aside for research in fossil fuels, nuclear and other projects, which accounted for 2.3%, 1.7% and 4.2%, respectively.

Before the drop in funding in 2016-17, the Danish government’s spending on energy RD&D as a ratio of GDP was the fourth-highest among IEA countries in 2015, following Norway, Finland and Japan. The drop in funding changed Denmark’s ranking down among IEA members in 2016 (see Figure 11.2).

Figure 11.2 Government energy RD&D spending as a ratio of GDP in IEA member countries, 2016



Note: Data are estimated and not available for all IEA member countries at the time of publishing.
Source: IEA (2017), “IEA Energy Technology RD&D database, 2017”, www.iea.org/statistics/.

As part of Mission Innovation (see below section on international collaboration), Denmark has committed to increase its clean energy RD&D funding to DDK 580 million by 2020, which is twice the amount of the average funding of the Energy Technology Development and Demonstration Programme (EUDP) in the years 2015-16. This Mission Innovation funding would still be below the level of **total** public funding on energy RD&D in the early 2010s.

Energy RD&D programmes

Following the reforms of research programmes in 2014-17, the major energy-related RD&D programmes today are the Energy Technology Development and Demonstration Programme (**EUDP)**, **the Innovation Fund,** and **ELForsk.** They cover a broad range of the RD&D chain – from applied research to commercialisation (Table 11.1).

Table 11.1 Energy RD&D programmes in Denmark.

		Focus area				
	Funding, million DKK (year)	**Basic research**	**Applied research**	**Develop-ment**	**Demon-stration**	**Commer-cialisation**
The Free Research Council *(Det Fri Forskningsrad)*	*					
National Research Foundation (*Grundforskningfonden*)	*					
EUDP	180 (2016)					
ForskEL (merged with EUDP from 2017)	130 (2016)**					
ElForsk	25 (2016)**					
Innovation Fund Denmark	178 (2016)					
Horizon 2020 (EU-funded)	350 (2016)***					
Commercialisation Fund (*Markedsmodnings-fonden*)	58.5 (2016)					

* The total funding of the Free Research Council is DKK 1 000 million, and of the National Research Foundation is DKK 424.5 million (2015). However, there are currently no funds earmarked for the energy area.

** These schemes have been funded by the public service obligation (PSO), which is being phased out.

*** The figure is an estimate and reflects the funds obtained by Danish beneficiaries from the Horizon-2020 funds in the energy area.

In addition, the Commercialisation Fund supports the market penetration of new energy technologies. The Free Research Council and the National Research Foundation do not directly target the energy sector, but the basic research supported by these two institutions can have spill-over effects on energy technologies.

The ForskEL programme, initially funded by the public service obligation (PSO) was closed down in 2017 following the decision to phase out the PSO, and the funding was transferred to EUDP.

Danish energy R&D is also supported through the European Union's research programmes. Denmark's ambition is to have its energy sector awarded 2.5% of the budget for the European Union's major research programme Horizon 2020 in the period 2014-20.

The private sector is heavily involved in energy RD&D, both on its own terms and together with universities and other institutions. The three government-run RD&D programmes – **EUDP**, **the Innovation Fund** and **ELForsk** – mainly provide support to projects that are implemented in public-private partnerships. In most major technology areas, the industry creates partnerships and develops sectoral strategies.

Denmark has established a single website for all Danish RD&D funding programmes with a focus on energy and climate (www.energiforskning.dk). It lists the Danish programmes for which public funding is available, along with deadlines for applications and other relevant information, as well as information about some European and Danish energy research projects. This website is regularly updated by the programmes themselves.

Energy Technology Development and Demonstration Programme (EUDP)

The EUDP is an autonomous legal entity owned and managed by an independent board of directors appointed by the Danish Minister of Energy, Utilities and Climate. The secretariat for EUDP is based in the Danish Energy Agency (DEA). The legal provision for the programme is the Act on EUDP of 22 December 2010. This Act supports the policy objectives of security of supply, climate change mitigation and a cleaner environment, but also increased cost-effectiveness. It aims at making Denmark independent of fossil fuels, while promoting development of business potentials and fostering growth and employment.

Since 2017, EUDP also manages the funding of the former ForskEL RD&D programme, which was a PSO-funded programme that supported projects focusing on efficient green conversion of the energy system. The last completed call for applications of ForskEL was in 2015 (2016 pool); the 2017 call is managed by EUDP.

With a total annual funding of over DKK 300 million (EUR 40 million) in 2017,[1] EUDP supports private companies and universities that develop and demonstrate a broad range of technologies, including renewable energy, energy efficiency, fuel cells and hydrogen, integration of energy systems including storage, more efficient methods for recovery of oil and gas, and storage of CO_2.

The EUDP Secretariat publishes open calls for proposals approximately twice a year. Applicants are encouraged to display their own ideas and project proposals based on new technology and related business plans. Support is given in accordance with EU state aid rules. Foreign participants receive EUDP funding under the same conditions as Danish participants, but must be either a company or a university registered in Denmark. In exceptional cases, when there is a political will to provide direct support to a specific field of technology, earmarked funding is provided through the annual Financial Act. Funds are provided via dedicated calls but administered in the same way as other EUDP funds.

The EUDP strategies, which provide directions and principles of support, are reviewed and revised regularly. The current strategy for 2017-19 is based on the wish to invest in areas where there is a particularly good match between global demand for new energy

[1] Including EUDP funding of DKK 180 million and ForskEl funding of 130 million in 2017. In the previous years, the EUDP funding alone (without ForskEl) was around DKK 300 to 400 million.

technology and specific Danish strengths and business potentials. Therefore, the primary focus is on projects to develop, demonstrate and scale up technologies in Denmark with a view to being able to export them.

Innovation Fund Denmark

In 2014, the Technology Foundation (*Højteknologifonden*) and the Strategic Research Council (*Det Strategiske Forskningsråd*) were merged into a third fund, the ”*Innovationsfonden*” – Innovation Fund Denmark (IFD), which allocates funds to many R&D areas, not only energy. IFD administers the funds earmarked budget for “strategic” research, including two separate budget lines for energy-related R&D. In the 2017 state budget, no funding has been earmarked in advance to strategic R&D for 2018 and 2019, although, according to the Administration, such funds will likely be included in the future budgets. Innovation Fund Denmark may also allocate some additional money for projects which are not part of the strategic research.

In 2017, the Innovation Fund also administered the following thematic applications, among others: Energy (DKK 103 million); Environmental Technology (DKK 25 million) and Bioresources and Relations between Food, Health and Lifestyle (130 million).

ElForsk

ELForsk is an Energy R&D programme financed by PSO with an annual funding of DKK 25 million and administrated by the Danish Energy Association. It supports R&D with the primary focus on energy efficiency and on energy savings by industries, companies, households and municipal and commercial end-users. It funds projects within the target areas, which include buildings, ventilation, lighting, cooling, power and operational electronics, industrial processes and behaviour. The projects cover a wide range of the value chain from applied research to development and market introduction.

Carbon capture and storage (CCS)

The Geological Survey of Denmark and Greenland (GEUS) conducts research into possibilities for storing CO_2 in the Danish subsurface and in the North Sea. GEUS represents Denmark at international forums, such as CO_2GeoNet, and has participated in several international projects, mainly at European ones, including CASTOR (2003-06), GeoCapacity (2006-09), ECO_2 (2009-11), TOPS (2013-17), and NORDICCS (2011-15).

One of the projects headed by GEUS has laid the foundation for assessing the use of CCS as a tool to reduce CO_2 emissions for all of Europe. The results include the development of a standard for assessing the storage capacity of underground reservoirs, and a geological information system (GIS) database of large CO_2 sources and storage sites in 25 European countries.

GEUS activities include research on the possibility of enhancing oil recovery in the North Sea by injecting CO_2 into the oil reservoirs. This work uses advanced laboratory facilities in which the physical conditions of the North Sea reservoirs are reproduced.

Monitoring and evaluation

The government-funded RD&D programmes are regularly evaluated, and the various impacts of RD&D activities are assessed. The latest major evaluation was conducted in

2015 by independent consulting companies commissioned by the Danish Ministry of Energy, Utilities and Climate. It evaluated the three major energy research programmes at that time: EUDP, ForskEL and ELForsk (COWI et al., 2015). The evaluation showed that the programmes had many positive impacts, the most important ones being:

- a significant increase in Danish exports of green energy technology
- changes in the composition of Danish energy consumption: increased use of renewable energy (as discussed in Chapter 8)
- decoupling of industrial production growth from energy consumption (see Chapter 7 on energy efficiency).

This contributed to strengthening the green transition and creating a reduction in total CO_2 emissions. The programmes have also contributed to the creation of revenue and employment in Danish companies.

Most projects in the programmes (85%) have achieved their goals, according to project participants' own assessments. The programmes have been successful in reducing the risks for private participants and in stimulating private initiatives: 55% of participants estimated that their projects would not have been completed without the support; and 41% considered that, without support, the project would have been implemented but on a smaller scale, within a longer time frame and/or with weaker results.

International collaboration

Denmark participates in numerous international R&D bodies and platforms, where exchange of knowledge plays a key role: Mission Innovation, IEA Technology Collaboration Programmes (TCP), Clean Energy Ministerial, EU ERA-NET, SET-Plan, Horizon-2020, Nordic Energy Research, etc. Denmark also has bilateral collaboration projects and programmes (see Box 1.2 in Chapter 1 on general energy policy), e.g. the Sino-Danish Renewable Energy Centre.

Denmark has participated in Mission Innovation since its launch in November 2015 in Paris. Today, 22 countries and the European Union are participating in the initiative. Mission Innovation aims to strengthen and accelerate public and private global clean energy innovation. Each participating country will seek to double its governmental and/or state-directed clean energy R&D investment over five years. New investments would be focused on transformational clean energy technology innovations that can be scalable to varying economic and energy market conditions. The EUDP administers the bulk of the Mission Innovation funds, the remaining part being administered by the Innovation Fund.

Denmark has committed to increase its energy R&D funding, as part of Mission Innovation, to DDK 580 million by 2020 (twice the amount of the average funding of its EUDP programme in the years 2015-16). The focus areas emphasised in the Danish Mission Innovation Portfolio include: Industry and buildings; Vehicles and other transportation; Bio-based fuels and energy; Solar, wind and other renewables; Nuclear energy, Hydrogen and fuel cells, Cleaner fossil energy; CO_2 capture, utilisation and storage; Electricity grid; Energy storage; and Basic energy research. By mid-2017, Denmark had been on track with its funding target. It plans to co-host the Ninth Clean Energy Ministerial (CEM9) and the Third Mission Innovation Ministerial (MI3) in May 2018.

Danish companies and research institutions take part in 19 IEA Technology Collaboration Programmes (TCP) (formerly, Implementing Agreements) in the areas of energy end use, smart grids, renewable energy and fossil fuels:

- Energy Technology Systems Analysis (ETSAP TCP)
- Buildings and Communities (EBC TCP)
- District Heating and Cooling (DHC TCP)
- Energy Efficient End-Use Equipment (4E TCP)
- Energy Storage (ECES TCP)
- Heat Pumping Technologies (HPT TCP)
- Smart Grids (ISGAN TCP)
- Industrial Energy-Related Technology Systems (IETS TCP)
- Advanced Fuel Cells (AFC TCP)
- Advanced Motor Fuels (AMF TCP)
- Hybrid and Electric Vehicles (HEV TCP)
- Enhanced Oil Recovery (EOR TCP)
- Bioenergy (Bioenergy TCP)
- Hydrogen (Hydrogen TCP)
- Ocean Energy Systems (OES TCP)
- Photovoltaic Power Systems (PVPS TCP)
- Renewable Energy Technology Deployment (RETD TCP)
- Solar Heating and Cooling (SHC TCP)
- Wind Energy Systems (Wind TCP).

Danish research institutions and companies participate in EU's Horizon 2020 – the biggest EU research and innovation programme with nearly EUR 80 billion of funding available over seven years (2014 to 2020). Energy is one of the priority thematic areas with a focus on energy efficiency, low-carbon energy, and smart cities and communities.

Denmark takes part in the EU Strategic Energy Technology Plan (the SET Plan). As part of the SET Plan, Danish research institutes and companies can participate in the European Energy Research Alliance (EERA), the European Technology and Innovation Platforms (ETIP) and the SET-Plan Information System (SETIS).

Denmark is a member of Nordic Energy Research, an institution under the Nordic Council of Ministers aiming to promote and extend regional co-operation in energy RD&D and to contribute to addressing the following challenges:

- infrastructure that enables system solutions
- transportation fuels and the utilisation of biomass
- energy efficiency improvements in demand sectors
- decarbonisation of energy-intensive industry.

Assessment

Energy research, development and demonstration (RD&D) in Denmark is effectively aligned with the country's energy and climate objectives, including the transition to a low-carbon economy. In addition, energy RD&D contributes to maintaining the competitiveness of Danish energy industry and increasing the exports of energy technologies, in particular in areas where Denmark already has a competitive advantage, including in wind energy, district heating, energy efficiency, bioenergy, oil and gas, smart grids and system integration.

Denmark is to be praised for having established a single website for all Danish RD&D funding programmes with a focus on energy and climate (www.energiforskning.dk). This initiative can increase transparency and facilitate access to RD&D funding. It is important to ensure that this website is regularly updated. It is also positive that Denmark participates in the major international energy technology platforms and networks to maximise synergies and knowledge-sharing.

Until recently, Denmark was among the leading IEA countries in terms of public spending on energy RD&D per unit of GDP. Evaluations demonstrate that several national RD&D programmes have been very successful and have effectively contributed to energy efficiency improvements, renewable energy development, as well as to growing employment, increasing energy technology exports and creating revenues. The 2008 political decision to increase the energy RD&D spending to DKK 1 billion per year has therefore resulted in multiple socio-economic benefits for the country, and contributed to the global efforts to combat climate change.

The main challenge today is maintaining the adequate levels of financing to continue reaping the benefits of RD&D programmes. After peaking in 2010, Danish spending on energy RD&D has shown an overall decreasing trend, reaching a particularly dramatic drop in 2016 and 2017 because of other priorities for public spending. Although Denmark pledged to dedicate DKK 580 million to clean energy R&D in 2020 as a member of Mission Innovation, this amount would still be significantly lower than the energy RD&D spending in the early 2010s. Therefore, the government is encouraged to increase public funding for energy RD&D at least to the levels of 2010-12, or preferably to even higher levels because a timely and cost-effective transition to a low-carbon future requires support for clean energy technologies across all innovation stages.

Another challenge for RD&D stakeholders is the lack of multi-annual funding commitments. The allocation of funding takes place on a year-to-year basis. Stakeholders have therefore no visibility for available future funding, which can undermine some potentially promising RD&D initiatives.

In several Danish RD&D programmes, funding is administrated in accordance with the energy policy objectives laid down by the government. However, while each programme has its own strategy, there is no common country-level strategy for energy RD&D that would apply to all programmes. The IEA encourages the government to adopt such a strategy to ensure that public funding is directed primarily to the areas of strategic importance for the country, and to guarantee continuity of the energy RD&D policy, coverage of the overall RD&D chain, and synergies between various programmes.

Recommendations

The government of Denmark should:

- Develop a specific strategy and key priorities on energy research, development and demonstration to ensure it contributes to main energy policy objectives and helps solve energy challenges.
- Increase public funding for energy research, technology and innovation at least to the levels of 2010-12 and stimulate increases in private funding; facilitate the research community's efforts to look for EU funding.
- Consider more specific multi-annual funding commitments and options, both in light of the foreseen changes in the funding from the PSO and of the target of increasing the exports of energy-related technologies.

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ANNEX A: Organisation of the review

REVIEW CRITERIA

The Shared Goals, which were adopted by the International Energy Agency (IEA) Ministers at their 4 June 1993 meeting in Paris, provide the evaluation criteria for the in-depth reviews conducted by the IEA. The Shared Goals are presented in Annex C.

REVIEW TEAM

The IEA in-depth review team visited Denmark from 15 to 19 May 2017. The team met with government officials, energy suppliers, interest groups, and other organisations. This report was drafted on the basis of the review team's preliminary assessment of the country's energy policy and information on subsequent policy developments from the government and private-sector sources. The members of the team were:

IEA member countries

Ms. Bettina Lemström, Finland (team leader)

Dr. Markus Bareit, Switzerland

Mr. Tjalling de Vries, the Netherlands

Mr. Miroslav Marias, Slovak Republic

Mr. Pawel Pikus, Poland

Mr. Niels Ladefoged, European Commission

International Energy Agency

Mr. Aad van Bohemen

Ms. Elena Merle-Beral, consultant

Mr. Matthew Wittenstein

Mr. Miika Tommila

The team is grateful for the co-operation and assistance of the many people it met throughout the visit. Thanks to their kind hospitality, openness and willingness to share information, the visit was highly informative, productive and enjoyable. The team expresses its gratitude to Deputy Permanent Secretary Kristoffer Böttzauw and his staff at the Ministry of Energy, Utilities and Climate. In particular, the team thanks Mr. Claus Krog Ekman from Denmark's Permanent Representation to the OECD, and Ms. Birgitte Bay and Mr. Peter Beck Nellemann from the Ministry for the professionalism they displayed throughout the review process.

The report was drafted by Elena Merle-Beral (Executive summary and chapters 1, 6 to 8 and 11), Sean Calvert (chapter 2), Oskar Kvarnström (chapter 10), Miika Tommila

(chapters 3 and 4) and Matthew Wittenstein (chapters 5 and 9). Hwayun Lee and Oskar Kvarnström drafted the supply and demand sections of the report.

The report was prepared under the guidance of Aad van Bohemen, Head of Energy Policy and Security Division. Miika Tommila was the managing author. Helpful comments and updates were provided by the following IEA staff: Emanuele Bianco, Ute Collier, Carlos Fernandez Alvarez, Peter Fraser, Rebecca Gaghen, Marine Gorner, Christina Hood, Simon Mueller, Luis Munuera, Carrie Pottinger, Joe Ritchie, Keisuke Sadamori, Jesse Scott, Cecilia Tam and Laszlo Varro.

Oskar Kvarnström and Hwayun Lee prepared the figures and Bertrand Sadin prepared the maps. Roberta Quadrelli and Rémi Gigoux provided support on the statistics. Therese Walsh managed the editing process, and Astrid Dumond and Katie Russell managed the production process.

ORGANISATIONS VISITED

- Aalborg University
- Concito
- Confederation of Danish Industries
- Danish Climate Council
- Danish Competition and Consumer Authority
- Danish District Heating Association
- Danish Economic Councils
- Danish Energy Agency
- Danish Energy Association
- Danish Energy Regulatory Authority
- Danish Wind Industry Association
- De Frie Energiselskaber
- Ecological Council (NGO)
- Energinet.dk
- Greenpeace Denmark
- Ministry of Energy, Utilities and Climate
- Ministry of Finance
- Ministry of Taxation
- Oil Gas Denmark
- Roskilde University
- Technical University of Denmark
- University of Southern Denmark
- World-wide Fund for Nature

ANNEX B: Energy balances and key statistical data

Unit: Mtoe

SUPPLY		1973	1990	2000	2010	2013	2014	2015	2016E
TOTAL PRODUCTION		**0.43**	**10.08**	**27.73**	**23.35**	**16.63**	**16.00**	**15.95**	**14.93**
Coal		-	-	-	-	-	-	-	-
Peat		-	-	-	-	-	-	-	-
Oil		0.07	6.11	18.26	12.49	8.92	8.35	7.90	7.11
Natural gas		-	2.77	7.41	7.34	4.28	4.14	4.14	4.04
Biofuels and w aste[1]		0.35	1.14	1.69	2.82	2.39	2.30	2.60	2.56
Nuclear		-	-	-	-	-	-	-	-
Hydro		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wind		-	0.05	0.37	0.67	0.96	1.13	1.22	1.10
Geothermal		-	0.00	0.00	0.01	0.01	0.00	0.00	0.01
Solar/other[2]		-	0.00	0.01	0.02	0.07	0.08	0.09	0.11
TOTAL NET IMPORTS[3]		**19.00**	**7.12**	**-9.53**	**-4.94**	**0.75**	**0.46**	**0.63**	**0.92**
Coal	Exports	0.04	0.03	0.07	0.04	0.03	0.03	0.05	0.01
	Imports	1.91	6.25	3.86	2.68	2.77	2.56	1.52	1.59
	Net imports	1.87	6.22	3.78	2.64	2.74	2.53	1.47	1.58
Oil	Exports	2.85	5.82	18.40	13.25	13.49	12.61	13.53	12.83
	Imports	21.43	8.57	9.91	9.47	12.33	11.87	13.92	13.12
	Int'l marine and aviation bunkers	-1.42	-1.53	-2.06	-1.49	-1.45	-1.63	-1.64	-1.69
	Net imports	17.15	1.22	-10.55	-5.28	-2.61	-2.36	-1.25	-1.40
Natural Gas	Exports	-	0.93	2.88	3.16	1.97	1.87	1.97	1.90
	Imports	-	-	-	0.14	1.20	0.56	0.59	0.61
	Net imports	-	-0.93	-2.88	-3.02	-0.77	-1.31	-1.38	-1.29
Electricity	Exports	0.11	0.42	0.67	1.01	0.89	0.85	0.84	0.85
	Imports	0.09	1.03	0.72	0.91	0.99	1.09	1.35	1.29
	Net imports	-0.02	0.61	0.06	-0.10	0.09	0.25	0.51	0.44
TOTAL STOCK CHANGES		**-0.44**	**0.16**	**0.43**	**1.07**	**-0.23**	**-0.36**	**-0.49**	**0.69**
TOTAL SUPPLY (TPES)[4]		**18.99**	**17.36**	**18.63**	**19.48**	**17.15**	**16.11**	**16.10**	**16.54**
Coal		1.93	6.09	3.99	3.81	3.02	2.41	1.73	1.97
Peat		-	-	-	-	-	-	-	-
Oil		16.72	7.65	8.02	7.02	6.00	5.77	5.82	5.89
Natural gas		-	1.82	4.45	4.42	3.32	2.80	2.85	2.87
Biofuels and w aste[1]		0.35	1.14	1.75	3.63	3.69	3.67	3.88	4.15
Nuclear		-	-	-	-	-	-	-	-
Hydro		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wind		-	0.05	0.37	0.67	0.96	1.13	1.22	1.10
Geothermal		-	0.00	0.00	0.01	0.01	0.00	0.00	0.01
Solar/other[2]		-	0.01	0.01	0.02	0.07	0.09	0.09	0.11
Electricity trade[5]		-0.02	0.61	0.06	-0.10	0.09	0.25	0.51	0.44
Shares in TPES (%)									
Coal		*10.2*	*35.1*	*21.4*	*19.6*	*17.6*	*14.9*	*10.7*	*11.9*
Peat		-	-	-	-	-	-	-	
Oil		*88.1*	*44.1*	*43.0*	*36.0*	*35.0*	*35.8*	*36.1*	*35.6*
Natural gas		-	*10.5*	*23.9*	*22.7*	*19.3*	*17.4*	*17.7*	*17.4*
Biofuels and waste [1]		*1.9*	*6.6*	*9.4*	*18.6*	*21.5*	*22.8*	*24.1*	*25.1*
Nuclear		-	-	-	-	-	-	-	-
Hydro		*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Wind		-	*0.3*	*2.0*	*3.5*	*5.6*	*7.0*	*7.5*	*6.7*
Geothermal		-	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*
Solar/other [2]		-	*0.0*	*0.1*	*0.1*	*0.4*	*0.5*	*0.6*	*0.7*
Electricity trade [5]		*-0.1*	*3.5*	*0.3*	*-0.5*	*0.5*	*1.5*	*3.2*	*2.7*

0 is negligible, - is nil, .. is not available, x is not applicable. Please note: rounding may cause totals to differ from the sum of the elements.

Unit: Mtoe

DEMAND							
FINAL CONSUMPTION	**1973**	**1990**	**2000**	**2010**	**2013**	**2014**	**2015**
TFC	**15.31**	**13.17**	**14.23**	**14.96**	**13.50**	**12.86**	**13.31**
Coal	0.46	0.43	0.31	0.15	0.15	0.14	0.13
Peat	-	-	-	-	-	-	-
Oil	13.31	6.86	6.57	6.19	5.24	5.10	5.20
Natural gas	-	1.12	1.65	1.73	1.57	1.43	1.45
Biofuels and waste[1]	0.16	0.56	0.65	1.28	1.31	1.26	1.45
Geothermal	-	-	-	-	-	-	-
Solar/other[2]	-	0.00	0.01	0.01	0.01	0.01	0.01
Electricity	1.39	2.44	2.79	2.76	2.68	2.63	2.64
Heat	-	1.76	2.25	2.84	2.55	2.29	2.42
Shares in TFC (%)							
Coal	*3.0*	*3.3*	*2.2*	*1.0*	*1.1*	*1.1*	*1.0*
Peat	-	-	-	-	-	-	-
Oil	*86.9*	*52.0*	*46.2*	*41.4*	*38.8*	*39.7*	*39.1*
Natural gas	-	*8.5*	*11.6*	*11.6*	*11.6*	*11.1*	*10.9*
Biofuels and waste [1]	*1.1*	*4.3*	*4.6*	*8.5*	*9.7*	*9.8*	*10.9*
Geothermal	-	-	-	-	-	-	-
Solar/other [2]	-	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.1*
Electricity	*9.0*	*18.5*	*19.6*	*18.4*	*19.8*	*20.4*	*19.8*
Heat	-	*13.3*	*15.8*	*19.0*	*18.9*	*17.8*	*18.1*
TOTAL INDUSTRY[6]	**4.06**	**2.98**	**3.22**	**2.67**	**2.42**	**2.35**	**2.36**
Coal	0.23	0.33	0.27	0.11	0.10	0.11	0.11
Peat	-	-	-	-	-	-	-
Oil	3.38	1.21	1.05	0.81	0.69	0.64	0.65
Natural gas	-	0.54	0.78	0.71	0.67	0.68	0.65
Biofuels and waste[1]	0.06	0.11	0.11	0.20	0.14	0.13	0.16
Geothermal	-	-	-	-	-	-	-
Solar/other[2]	-	-	-	-	-	-	-
Electricity	0.40	0.72	0.86	0.73	0.72	0.71	0.72
Heat	-	0.07	0.16	0.11	0.10	0.08	0.08
Shares in total industry (%)							
Coal	*5.6*	*10.9*	*8.3*	*4.0*	*4.1*	*4.6*	*4.4*
Peat	-	-	-	-	-	-	-
Oil	*83.2*	*40.7*	*32.5*	*30.2*	*28.4*	*27.4*	*27.3*
Natural gas	-	*18.0*	*24.1*	*26.7*	*27.8*	*28.8*	*27.6*
Biofuels and waste [1]	*1.4*	*3.8*	*3.4*	*7.5*	*5.8*	*5.7*	*6.6*
Geothermal	-	-	-	-	-	-	-
Solar/other [2]	-	-	-	-	-	-	-
Electricity	*9.7*	*24.3*	*26.7*	*27.4*	*29.8*	*30.1*	*30.6*
Heat	-	*2.4*	*4.9*	*4.2*	*4.1*	*3.4*	*3.4*
TRANSPORT[4]	**2.70**	**3.45**	**4.03**	**4.36**	**3.97**	**4.00**	**4.07**
OTHER[7]	**8.55**	**6.75**	**6.98**	**7.93**	**7.12**	**6.52**	**6.88**
Coal	0.23	0.11	0.04	0.04	0.05	0.04	0.03
Peat	-	-	-	-	-	-	-
Oil	7.24	2.21	1.52	1.08	0.85	0.73	0.76
Natural gas	-	0.59	0.88	1.02	0.89	0.75	0.80
Biofuels and waste[1]	0.10	0.45	0.54	1.05	0.94	0.90	1.07
Geothermal	-	-	-	-	-	-	-
Solar/other[2]	-	0.00	0.01	0.01	0.01	0.01	0.01
Electricity	0.98	1.70	1.90	1.99	1.92	1.89	1.88
Heat	-	1.69	2.09	2.73	2.45	2.21	2.34
Shares in other (%)							
Coal	*2.7*	*1.6*	*0.6*	*0.6*	*0.7*	*0.5*	*0.4*
Peat	-	-	-	-	-	-	-
Oil	*84.7*	*32.8*	*21.8*	*13.6*	*11.9*	*11.2*	*11.0*
Natural gas	-	*8.7*	*12.5*	*12.9*	*12.6*	*11.5*	*11.6*
Biofuels and waste [1]	*1.2*	*6.7*	*7.7*	*13.3*	*13.2*	*13.8*	*15.5*
Geothermal	-	-	-	-	-	-	-
Solar/other [2]	-	-	*0.1*	*0.2*	*0.2*	*0.2*	*0.2*
Electricity	*11.5*	*25.2*	*27.2*	*25.1*	*27.0*	*28.9*	*27.4*
Heat	-	*25.0*	*30.0*	*34.4*	*34.4*	*33.9*	*33.9*

Unit: Mtoe

DEMAND								
ENERGY TRANSFORMATION AND LOSSES	**1973**	**1990**	**2000**	**2010**	**2013**	**2014**	**2015**	**2016E**
ELECTRICITY GENERATION[8]								
Input (Mtoe)	4.59	7.08	8.36	9.16	7.81	6.98	6.34	..
Output (Mtoe)	1.64	2.23	3.10	3.34	2.99	2.77	2.49	2.59
Output (TWh)	19.12	25.98	36.05	38.86	34.74	32.18	28.95	30.09
Output Shares (%)								
Coal	*35.8*	*90.7*	*46.2*	*43.8*	*41.1*	*34.4*	*24.5*	*28.8*
Peat	-	-	-	-	-	-	-	-
Oil	*64.1*	*3.4*	*12.3*	*2.0*	*1.0*	*1.0*	*1.1*	*1.0*
Natural gas	-	*2.7*	*24.3*	*20.3*	*9.8*	*6.5*	*6.3*	*7.3*
Biofuels and waste [1]	-	*0.8*	*5.1*	*13.7*	*14.5*	*15.6*	*17.1*	*17.9*
Nuclear	-	-	-	-	-	-	-	-
Hydro	*0.1*	*0.1*	*0.1*	*0.1*	-	-	*0.1*	*0.1*
Wind	-	*2.3*	*11.8*	*20.1*	*32.0*	*40.6*	*48.8*	*42.5*
Geothermal	-	-	-	-	-	-	-	-
Solar/other [2]	-	-	*0.1*	-	*1.5*	*1.9*	*2.1*	*2.5*
TOTAL LOSSES	**3.77**	**4.17**	**4.41**	**4.63**	**3.77**	**3.43**	**2.97**	**..**
of which:								
Electricity and heat generation[9]	2.94	2.65	2.41	2.19	1.59	1.30	0.82	..
Other transformation	0.57	0.11	0.09	0.29	0.20	0.25	0.24	..
Own use and transmission/distribution losses[10]	0.26	1.41	1.91	2.14	1.97	1.87	1.91	..
Statistical Differences	**-0.09**	**0.02**	**0.00**	**-0.11**	**-0.12**	**-0.18**	**-0.19**	**..**
INDICATORS	**1973**	**1990**	**2000**	**2010**	**2013**	**2014**	**2015**	**2016E**
GDP (billion 2010 USD)	167.75	229.13	298.22	322.00	330.09	335.62	341.01	345.40
Population (millions)	5.02	5.14	5.34	5.55	5.61	5.64	5.68	5.73
TPES/GDP (toe/1000 USD)[11]	0.11	0.08	0.06	0.06	0.05	0.05	0.05	0.05
Energy production/TPES	0.02	0.58	1.49	1.20	0.97	0.99	0.99	0.90
Per capita TPES (toe/capita)	3.78	3.38	3.49	3.51	3.05	2.85	2.83	2.89
Oil supply/GDP (toe/1000 USD)[11]	0.10	0.03	0.03	0.02	0.02	0.02	0.02	0.02
TFC/GDP (toe/1000 USD)[11]	0.09	0.06	0.05	0.05	0.04	0.04	0.04	..
Per capita TFC (toe/capita)	3.05	2.56	2.67	2.70	2.40	2.28	2.34	..
CO_2 emissions from fuel combustion ($MtCO_2$)[12]	56.2	51.0	50.8	47.2	38.6	34.4	32.0	..
CO_2 emissions from bunkers ($MtCO_2$)[12]	4.4	4.8	6.4	4.6	4.5	5.0	5.0	..
GROWTH RATES (% per year)	**73-90**	**90-00**	**00-10**	**10-12**	**12-13**	**13-14**	**14-15**	**15-16**
TPES	-0.5	0.7	0.4	-5.8	-0.8	-6.1	-0.1	2.7
Coal	7.0	-4.1	-0.5	-19.5	22.2	-20.1	-28.3	14.3
Peat	-	-	-	-	-	-	-	-
Oil	-4.5	0.5	-1.3	-5.3	-4.7	-3.9	0.9	1.3
Natural gas	-	9.4	-0.1	-11.2	-4.8	-15.4	1.7	0.5
Biofuels and waste[1]	7.1	4.4	7.6	0.5	0.7	-0.4	5.7	6.8
Nuclear	-	-	-	-	-	-	-	-
Hydro	-	4.1	-4.0	-	-50.0	-	100.0	-
Wind	-	21.3	6.3	14.6	8.4	17.6	8.0	-9.5
Geothermal	-	-	17.5	18.3	-14.3	-33.3	-25.0	266.7
Solar/other[2]	-	9.1	5.2	30.4	117.6	17.6	5.7	23.9
TFC	-0.9	0.8	0.5	-4.4	-1.2	-4.7	3.5	..
Electricity consumption	3.4	1.4	-0.1	-1.4	-0.3	-1.8	0.5	..
Energy production	20.5	10.7	-1.7	-10.4	-11.3	-3.8	-0.3	-6.4
Net oil imports	-14.4	..	..	..	..	..	..	..
GDP	1.9	2.7	0.8	0.8	0.9	1.7	1.6	1.3
TPES/GDP	-2.3	-1.9	-0.3	-6.5	-1.9	-7.5	-1.7	1.4
TFC/GDP	-2.7	-1.9	-0.3	-5.2	-2.2	-6.4	1.8	..

0 is negligible, - is nil, .. is not available, x is not applicable. Please note: rounding may cause totals to differ from the sum of the elements.

Footnotes to energy balances and key statistical data

1. Biofuels and waste comprises solid biofuels, liquid biofuels, biogases and municipal waste. Data are often based on partial surveys and may not be comparable between countries.
2. Solar/other includes solar photovoltaics, solar thermal and ambient heat used in heat pumps.
3. In addition to coal, oil, natural gas and electricity, total net imports also include biofuels and waste and trade of heat.
4. Excludes international marine bunkers and international aviation bunkers.
5. Total supply of electricity represents net trade. A negative number in the share of TPES indicates that exports are greater than imports.
6. Industry includes non-energy use.
7. Other includes residential, commercial and public services, agriculture/forestry, fishing and other non-specified.
8. Inputs to electricity generation include inputs to electricity, CHP and heat plants. Output refers only to electricity generation.
9. Losses arising in the production of electricity and heat at main activity producer utilities and autoproducers. For non-fossil-fuel electricity generation, theoretical losses are shown based on plant efficiencies of approximately 33% for solar thermal and 100% for hydro, wind and solar photovoltaic.
10. Data on "losses" for forecast years often include large statistical differences covering differences between expected supply and demand and mostly do not reflect real expectations on transformation gains and losses.
11. Toe per thousand US dollars at 2010 prices and exchange rates.
12. "CO_2 emissions from fuel combustion" have been estimated using the IPCC Tier I Sectoral Approach from the *2006 IPCC Guidelines.* In accordance with the IPCC methodology, emissions from international marine and aviation bunkers are not included in national totals.

ANNEX C: International Energy Agency "Shared Goals"

The member countries* of the International Energy Agency (IEA) seek to create conditions in which the energy sectors of their economies can make the fullest possible contribution to sustainable economic development and to the well-being of their people and of the environment. In formulating energy policies, the establishment of free and open markets is a fundamental point of departure, though energy security and environmental protection need to be given particular emphasis by governments. IEA countries recognise the significance of increasing global interdependence in energy. They therefore seek to promote the effective operation of international energy markets and encourage dialogue with all participants. In order to secure their objectives, member countries therefore aim to create a policy framework consistent with the following goals:

1. Diversity, efficiency and flexibility within the energy sector are basic conditions for longer-term energy security: the fuels used within and across sectors and the sources of those fuels should be as diverse as practicable. Non-fossil fuels, particularly nuclear and hydro power, make a substantial contribution to the energy supply diversity of IEA countries as a group.

2. Energy systems should have **the ability to respond promptly and flexibly to energy emergencies.** In some cases this requires collective mechanisms and action: IEA countries co-operate through the Agency in responding jointly to oil supply emergencies.

3. The environmentally sustainable provision and use of energy are central to the achievement of these shared goals. Decision-makers should seek to minimise the adverse environmental impacts of energy activities, just as environmental decisions should take account of the energy consequences. Government interventions should respect the Polluter Pays Principle where practicable.

4. More environmentally acceptable energy sources need to be encouraged and developed. Clean and efficient use of fossil fuels is essential. The development of economic non-fossil sources is also a priority. A number of IEA member countries wish to retain and improve the nuclear option for the future, at the highest available safety standards, because nuclear energy does not emit carbon dioxide. Renewable sources will also have an increasingly important contribution to make.

5. Improved energy efficiency can promote both environmental protection and energy security in a cost-effective manner. There are significant opportunities for greater energy efficiency at all stages of the energy cycle from production to consumption. Strong efforts by governments and all energy users are needed to realise these opportunities.

6. Continued **research, development and market deployment of new and improved energy technologies** make a critical contribution to achieving the objectives outlined above. Energy technology policies should complement broader energy policies. International co-operation in the development and dissemination of energy technologies, including industry participation and co-operation with non-member countries, should be encouraged.

7. Undistorted energy prices enable markets to work efficiently. Energy prices should not be held artificially below the costs of supply to promote social or industrial goals. To the extent necessary and practicable, the environmental costs of energy production and use should be reflected in prices.

8. Free and open trade and a secure framework for investment contribute to efficient energy markets and energy security. Distortions to energy trade and investment should be avoided.

9. Co-operation among all energy market participants helps to improve information and understanding, and encourages the development of efficient, environmentally acceptable and flexible energy systems and markets worldwide. These are needed to help promote the investment, trade and confidence necessary to achieve global energy security and environmental objectives.

(The Shared Goals were adopted by IEA Ministers at the meeting of 4 June 1993 Paris, France.)

* Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Luxembourg, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom, the United States.

ANNEX D: Glossary and list of abbreviations

In this report, abbreviations and acronyms are substituted for a number of terms used within the International Energy Agency. While these terms generally have been written out on first mention, this glossary provides a quick and central reference for the abbreviations used.

Acronyms and abbreviations

ACER	Agency for the Cooperation of Energy Regulators
AEA	annual emissions allocations
CHP	combined heat and power
DEA	Danish Energy Agency
DERA	Danish Energy Regulatory Authority
DF	Dansk Fjernvarme
DH	district heating
DKK	Danish krone
DUC	Danish Underground Consortium
EC	European Commission
EERA	European Energy Research Alliance
EOR	enhanced oil recovery
EPA	Environmental Protection Agency
ESOS	Energy Savings Obligation Scheme
ETS	Emissions Trading Scheme
EU	European Union
FIP	feed-in premium
HHI	Herfindahl-Hirschman Index
HSA	Heat Supply Act
IFD	Innovation Fund Denmark
LULUCF	land use, land-use change and forestry
M&E	monitoring and evaluation
NEEAP	National Energy Efficiency Action Plan
NEMO	nominated electricity market operator

ANNEXES

NESO	national emergency strategy organisation
NTC	net transfer capacity
OTC	over-the-counter
PCI	project of common interest
PSO	public service obligation
RD&D	research, development and demonstration
ROC	regional operating centre
RSC	regional security coordinator
SME	small and medium-size enterprises
TCP	Technology Collaboration Programmes
TFC	total final consumption
TOU	time-of-use
TPA	third-party access
TPES	total primary energy supply
TSO	transmission system operator
TYNDP	Ten-Year Network Development Plan
UNFCCC	United Nations Framework Convention on Climate Change
VAT	value-added tax
VRE	variable renewable energy
WACC	weighted average cost of capital

Units of measure

bcm	billion cubic metres
b/d	barrels per day
cm/h	cubic metres per hour
EJ	exajoules
GWh	gigawatt-hours
kb/d	thousand barrels per day
km^2	square kilometres

kWh	kilowatt-hours
kWh/m^2	kilowatt-hours per square metre
kWh/t	kilowatt-hours per tonne
mb	million barrels
mcm	million cubic metres
m/s	metres per second
Mt	million tonnes
MtCO_2-eq	million tonnes of carbon dioxide-equivalent
Mtoe	million tonnes of oil-equivalent
MWh	megawatt-hours
PJ	petajoules
toe	tonnes of oil-equivalent
TWh	terawatt-hour
W	watt


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Denmark has a long tradition of setting ambitious national energy targets. In 2030, renewables should cover at least half of the country's total energy consumption. By 2050, Denmark aims to be a low-carbon society independent of fossil fuels. The country is moving convincingly to meet these world-leading targets.

The International Energy Agency's latest review of Denmark's energy policies focuses on two interrelated issues: how to integrate increasing volumes of variable renewable energy in the power system beyond its current share of 45%, and how to decarbonise the heating sector.

Electricity generation in Denmark has changed fundamentally over the past two decades. Coal generation has been vastly eroded, and the bulk of power generation now comes from wind and bioenergy. Supported by a flexible domestic power system and a high level of interconnection, Denmark is now widely recognised as a global leader in integrating variable renewable energy while at the same time maintaining a highly reliable and secure electrical-power grid.

The heating sector is also critical for Denmark's low-carbon ambitions. Denmark's large-scale use of combined heat and power plants with heat storage capacity, and the increasing deployment of wind power offer great potential for efficient integration of heat and electricity systems. However, policies and regulations need to be aligned to realise that potential. Finding the right levels of energy taxation is particularly important.

Denmark has successfully decoupled its economic growth from greenhouse gas emissions, thanks to a combination of energy efficiency improvements, and fuel switching to renewables. As in all countries, more needs to be done to limit emissions from transport.

ENERGY POLICIES OF IEA COUNTRIES

Denmark

2017 Review