ENERGY TRANSITION

IN DENMARK

Adam Jones (211163250)
York University
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Submitted to Prof. Mark Winfield.

Introduction

This research began as an attempt to understand the methods that Denmark has employed to utilize energy storage technologies in its transition to an energy system based on renewable resources. In much of the developed world, energy systems are segmented into electricity, heat and transport. Each system is mostly self-contained and optimized for internal efficiency and energy storage systems are being employed within these systems for very specific purposes.

Research showed that the Danish energy system is not as segmented as that of most developed nations due to the widespread use of district heating (DH) systems featuring combined heat and power (CHP) plants. The dominance of these systems has led to a focus on their use as bridges between renewable electricity generation and heating requirements. DH systems can act as thermal, or heating storage for intermittent resources.

The high share of CHP plants in electricity generation means that, to a large extent, the heating storage systems are already in place, though some work needs to be done to increase the storage capacity. Many of these systems are fuelled by biomass and biogas, the increased use of which is a component in the energy transition. Initiatives are also in place to increase the use of electricity from wind turbines in DH systems, coinciding with increased investment in wind farms.

There is some capacity for gas storage in two large subterranean caverns, 1075m^3, equivalent to 12,948 GWh. In their *Snapshot of the Danish Energy Transition* (2015), Agora Energiewende translates the statements of Energinet.dk regarding the future use of the gas grid in "linking the power, heat and transport sectors,"[1] but presently this is at the RD&D stage.

[1] Stephanie Ropenus and Jacobsen, H.K., *Snapshot of the Danish Energy Transition.* (Berlin: Agora Energiewende & Kongens Lyngby, Denmark: DTU Management Engineering, 2015), 26.

Addressing emissions from the transport sector is a significant problem faced by Denmark and the government projections for 2035 do not suggest major progress will have been made by that time. Government transport policy has a similar focus on merging with the electricity sector but only in the long-term. The use of electric vehicles (EVs) as mobile and decentralized electricity storage requires significant investments in electricity infrastructure.

Political Organization

Denmark is a constitutional monarchy, governed by a parliamentary democracy. Its legislature, the Folketing, is comprised of 179 members – 175 from mainland Denmark plus 2 each from the Faroe Islands and Greenland. The government is made up of fifteen members of parliament who are selected to join the High Court of the Realm (also known as the cabinet) based on proportional representation.[2]

Each ministry of the government is responsible for a sector of Danish society. Responsibility for climate change mitigation and adaptation is assigned to the Ministry of Energy, Utilities and Climate, though other ministries are involved in the long-term climate strategy including the Ministry of the Environment, Ministry of Transport, Building and Housing, Ministry of Education, and Ministry of Employment.[3]

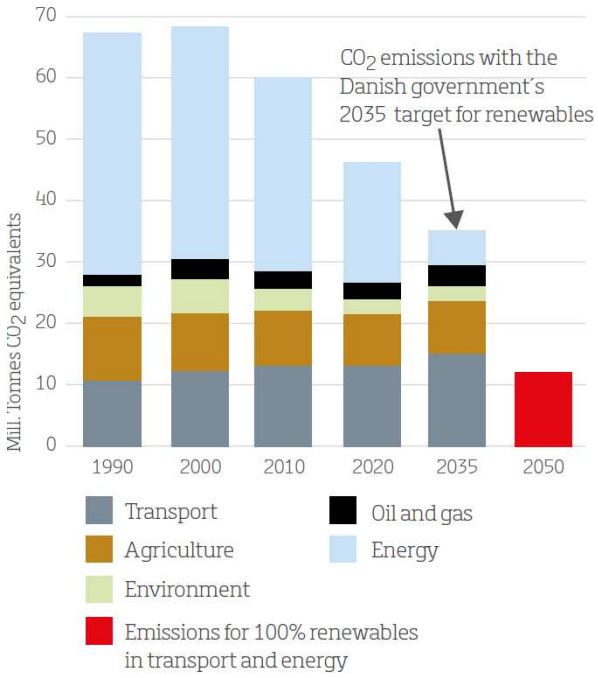
Climate Goals

The country's short-term greenhouse gas (GHG) emissions reduction target is 40% of 1990 levels by 2020, which will require the reduction of approximately 4 million tonnes of

[2] Denmark Constitution. Section 59, 1. 1953. (Grl, Lov nr. 169 af 5.6.1953)
[3] Danish Government, *The Danish Climate Policy Plan.* (Copenhagen: Danish Ministry of Climate and Energy, 2013), 11,13.

carbon dioxide equivalent (CO2-e) annually compared to the business-as-usual scenario.[4] This target is in line with the long-term targets of the European Union of 80%–95% of 1990 levels by 2050.[5]

Figure 1: Danish CO2 Emissions 1990-2050



Greenhouse Gas Emissions

In 2013 Denmark's total GHG emissions were 56,754,000 tonnes CO_2-e.[6] Of this, energy production accounts for 41.002 million tonnes (Mt); industrial processes and product use accounts for 2.126 Mt; agriculture, 9.958 Mt; land use and forestry, 2.370 Mt; and waste, 1.298 Mt. Aarhus University's Danish Centre for Environment and Energy reports domestic transportation emissions at 11,415,427 tonnes of CO_2-e.[7] International air transport accounts for 2.5 Mt and sea transport for 1.916 Mt CO_2-e.[8]

Denmark's Sixth National Communication and First Biennial Report (2012) states that by the end of 2011, the country had reduced emissions below its 2013 commitment.[9] The report states that the country is expected to meet its 2020 targets.

To achieve the targets shown in Figure 1[10], will require dramatic reductions in all sectors, most significant in energy and transport. To achieve this the Danish government has produced

[4] *The Danish Climate Policy Plan*, 10.
[5] *Ibid.*, 10.
[6] Winther, M. *Danish emission inventories for road transport and other mobile sources.* (Aarhus University, DCE – Danish Centre for Environment and Energy, 2015), 17.
[7] Ibid., 8, 9.
[8] Ibid., 17.
[9] Danish Ministry of Climate, Energy and Building. *Denmark's Sixth National Communication and First Biennial Report.* (Copenhagen: Ministry of Climate, Energy and Building, 2013), 35, 36.
[10] *The Danish Climate Policy Plan*, 15.

several plans and strategies to reform these sectors to increase the share of renewable energy and reduce reliance on fossil fuels. These include the Climate Policy Plan, Energy Strategy 2050, Green Energy – The Road to a Danish Energy System Without Fossil Fuels, A Greener Transport System in Denmark, Our Future Energy, among others.

The Danish Climate Plan indicates that international policy at the EU level, such as more stringent emissions standards for cars and a "well-functioning European emission trading system" (ETS), have great potential to reduce domestic emissions.[11] While the ETS will address emissions in several sectors, it does not cover all emissions. As part of their obligations in the EU, Denmark is required to reduce these non-ETS emissions by 20% of 2005 levels by 2020.[12]

Policy Approaches

Denmark has been developing alternative energy systems for a significant period of time and the most recent examples of energy transition policies represent the continuation of plans begun in the 1970s, most significantly district heating systems. In the intervening years institutions and agencies have been created to carry out policies related to environmental issues, climate change, and the energy transition.

This report describes numerous substantive policy instruments implemented by the Danish government in several areas to direct the transition to a fossil fuel-free energy system. Substantive instruments, as described by Winfield, are policy instruments that involved direct action on the part of the government to encourage or discourage behaviour on the part of the governed.[13] The energy transition has been directed through regulations, tariffs, and tax changes,

[11] *Ibid.*, 11.
[12] *Ibid.*, 14.
[13] Mark Winfield, *Implementing Environmental Policy in Canada* (Toronto: York University, 2014), 2.

each intended to favour the development of an energy system based on renewable energy resources.

Procedural instruments are those which focus on modifying the decision-making process in the government.[14] Denmark has implemented a small number of procedural policy instruments in recent years to ensure that government decision-making is directed toward the energy transition. New planning regimes and intergovernmental partnerships in particular have helped to direct public investment.

Denmark's Energy System

Ministry of Energy, Climate and Utilities

The Ministry of Energy, Climate and Utilities oversees the energy sectors. Under its purview are the Danish Energy Agency (DEA) and the Danish Energy Regulatory Authority (DERA), both of which are involved in the management of the national energy systems.

The DEA is responsible for national and international agreements related to energy production, consumption and supply in addition to leading the country's efforts to reduce GHG emissions. It is also tasked with ensuring that public utilities – including energy, water, waste and telecommunications – are operated economically.[15]

DERA is an independent body in charge of regulating the markets for electricity, natural gas and heating with the purpose of securing well-functioning energy sectors. The authority's responsibility is to ensure reasonable conditions for producers and consumers, efficient energy infrastructure, and the best possible regulatory frameworks. DERA regulates and approves the

[14] Ibid., 12.
[15] Danish Energy Agency, *About the Danish Energy Agency.* (Web)

mechanisms by which prices of energy products are determined, monitors the wholesale and retail markets, and ensures transparency for end-users.[16]

Ministry of Transport, Building and Housing

While the electricity, gas and heating sectors require significant intervention to reduce GHG emissions, the systems for which they provide energy – transportation, housing and buildings – constitute significant sources of GHG emissions and consumers of energy. The Ministry of Transport, Building and Housing has administrative and parliamentary responsibility over all forms of transportation (rail, road, water, air, public transit) and publicly owned buildings.[17] Policies related to the transition away from fossil fuels in the transport sector are carried out by this ministry. Despite the name, this ministry is not responsible for policies relating to climate mitigation and adaptation in the building and housing sector, rather it is responsible only for publicly owned buildings and properties.

Agencies within this ministry include the Danish Building & Property Agency, Danish Transport and Construction Agency, Rail Net Denmark, as well as several others with specific authority over regional projects and systems such as the Copenhagen Metro and CPH City & Port Development, which has a mandate to operate the ports in Copenhagen and develop related properties.[18] These agencies have been given responsibilities related to the country's climate change targets as it relates to their core tasks, for example the electrification of railways is managed by Rail Net Denmark.

[16] Danish Energy Regulatory Authority, *Profile.* (Web).
[17] Ministry of Transport, Building and Housing, *The Ministry.* (Web).
[18] Ministry of Transport, Building and Housing, *Overview of Institutions.* (Web).

Electric

The electricity system is operated as a market, regulated by the Electricity Supply Act (1999), with the goal of ensuring security of supply, economic delivery of electricity, environmentally sustainable energy use, and consumer protection.[19] The supply market is segmented into two areas, East and West, which are each components of the regional Nord Pool Spot market, which itself is a component of the Nordic ELBAS intra-day market between the Nordic countries, Germany and Estonia.

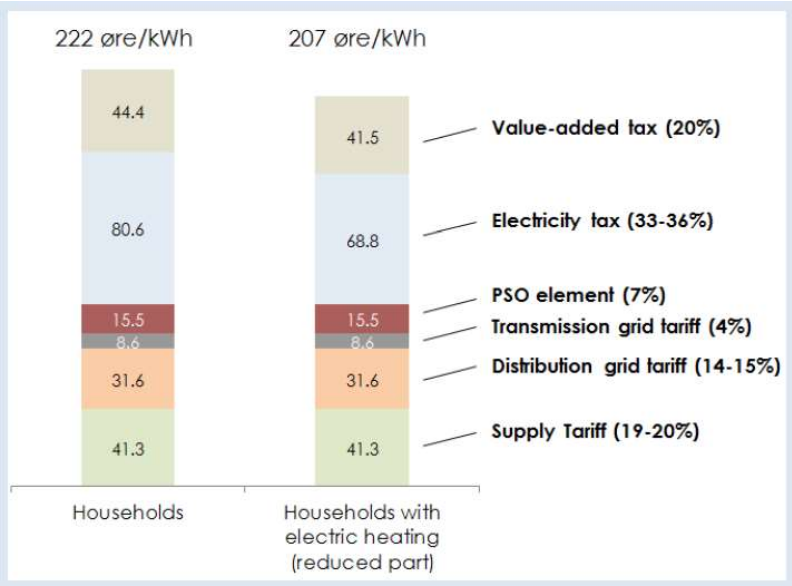
The retail market is separated into a free market with commercial prices and a regulated market for residential rates.[20] The regulated market, however, is being phased out and customers are being transferred to market price suppliers with the aim of increasing overall efficiency and economic delivery of electricity.[21] Commercial prices in the free market are determined on a contractual basis and can be influenced by the customer preference for variable or fixed prices, duration of the contract, green product component, among other options.[22]

Retail rates for electricity include several tariffs that are determined by DERA. These include; a supply tariff that is directed to production costs, a distribution grid tariff that pays for access to the distribution network, a transmission grid tariff that pays for access to the transmission network, a Public Service Obligation (PSO) that supports renewable and decentralized generation, electricity taxes that differ based on end-user, and a value-added tax of

[19] Danish Energy Agency, *Electricity Supply*. (Web)
[20] Lena Kitzing, et al., *The residential electricity sector in Denmark: A description of current conditions.* (Copenhagen: Technical University of Denmark, 2016), 15.
[21] Ibid., 17.
[22] Ibid., 17.

25% on top of all other tariffs.[23] DERA sets the distribution tariffs *ex ante*, based on forecasts, and each DSO has a regulated revenue cap which is approved annually, also by DERA.[24]

Figure 2: Electricity Taxes, 2012[25]



The PSO is particularly interesting in that its purpose is to support the development of renewable energy technologies. The fee is applied to all electricity consumers and funds are directed toward enhancing the cost-effectiveness of renewable energy investments.[26] The funds are administered by Energinet.dk.[27] The PSO has been used to support RD&D as well as grid connection costs of renewable energy. It represents a significant revenue for reinvestment – almost DKK 4.7 billion in 2012 when the fee was DKK 0.155/kWh.[28]

Residential customers in Denmark paid the highest price for electricity in Europe in 2015, an equivalent of over EU0.35/kWh.[29] Only 20% of the final price represents the cost of supply –

[23] Kitzing, et al., *The residential electricity sector in Denmark,* 14.
[24] IEA and OECD, *Energy Policies of IEA Countries: Denmark 2011*. (Paris: OECD Publishing, 2012), 101.
[25] Kitzing, et al., *The residential electricity sector in Denmark,* 14.
[26] Ibid., 22.
[27] Energinet.dk, *Subsidies for Renewable Energy.* (Web, last updated 30 October 2013).
[28] Danish Ministry of Climate, Energy and Building, *Energy Policy Report 2013*, (Copenhagen: Report by the Ministry of Climate, Energy and Building to the Danish Parliament on Danish Energy Policy, 24 April 2013,), 12.
[29] Kitzing, et al., *The residential electricity sector in Denmark,* 13.

the supply tariff – while the remainder of the price is dominated by the electricity tax (33-36%) and value-added tax (20%).[30]

The transmission system is owned and operated exclusively by Energenit.dk, an independent public enterprise which also co-owns interconnections to Norway, Sweden and Germany.[31] The distribution system is managed by approximately 75 DSOs.[32] Two companies are responsible for majority of the system; DONG Energy, which provides generation, distribution and retail sales of electricity, and Vattenfall, a Swedish state-owned company.[33] In addition there are more than 50 retail suppliers who sell electricity to consumers.[34]

Production Profile

In 2014, the generating capacity of Denmark's domestic electricity system was 13,657 MW[35] with a net generation of 30,615 GWh.[36] Official statements from Energinet.dk for 2015 show a decrease in net generation to 27,704 GWh which was comprised of 9,493 GWh from central power stations, 3,454 GWh from CHP plants and the remainder from renewable energy systems.[37] Figure 3 shows the generation profile and total consumption from 1990 through 2015 and forecast into 2025. This graph reveals the growth of alternative generation systems with CHP beginning in the mid-1990s, wind increasing rapidly in the mid-2000s, and solar only starting to make a noticeable contribution at the present day. The forecast shows an expected increase in all three of these generation technologies with a correlated decrease in central power plants, the remainder of which will include large hydropower plants and biomass/biogas plants.

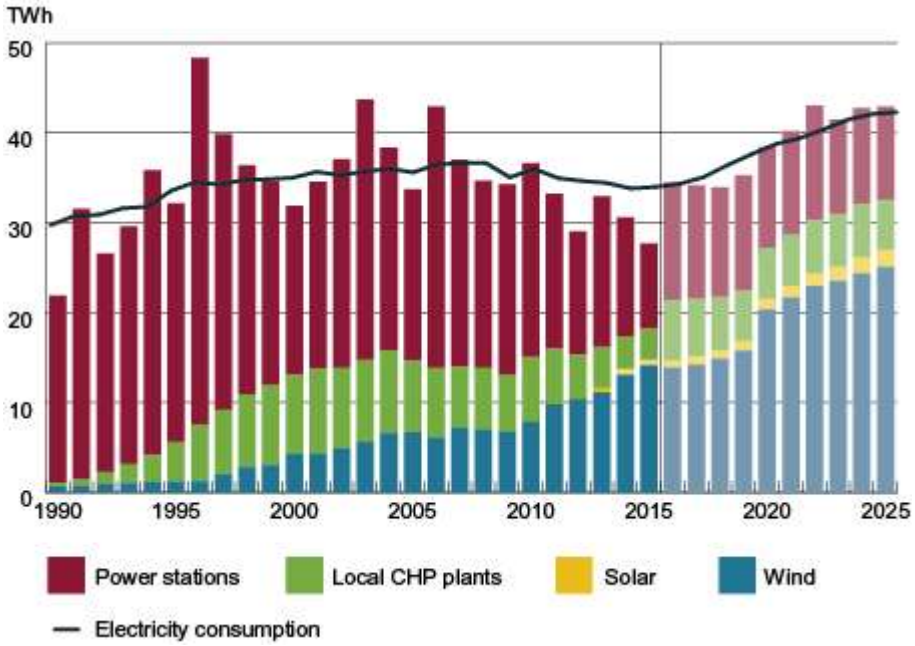
[30] Kitzing, et al., *The residential electricity sector in Denmark,* 14.
[31] IEA and OECD, *Energy Policies of IEA Countries: Denmark 2011*, 19.
[32] Kitzing, et al., *The residential electricity sector in Denmark,* 9.
[33] IEA and OECD, *Energy Policies of IEA Countries: Denmark 2011*, 99.
[34] Kitzing, et al., *The residential electricity sector in Denmark,* 6.
[35] Danish Energy Agency, *Key figures – Denmark - 2014.* (Web).
[36] Energinet.dk, "Electricity Generation," *Environmental Reporting.* (Web, last updated 7 September 2016).
[37] Ibid.

Fuels consumed in 2015 for the generation of electricity in central and CHP plants include coal (3,007,171 tonnes), oil (76,165 tonnes), and natural gas (561,862,000 Nm^3), which altogether produced 9,159GWh of electricity. Two other fuel sources, biofuels (2,861,667 tonnes) and waste (3,275,243 tonnes) produced 3,789 GWh of electricity.[38] In addition to biofuels and waste, both considered renewable resources, significant electricity production came from renewable energy systems.

The renewable energy profile of Denmark is dominated by wind turbines, both on- and off-shore. Wind capacity for 2015 was 5,085 MW, with these resources having generated 14,133 GWh of power.[39] Off-shore turbines showed a decrease in generation in 2015 due to faults in cables to two major wind farms. The country's total installed solar capacity was 783.3 MW, with generation surpassing 600 GWh. In 2015, a subsidy program was initiated to support the construction of 400kW solar PV plants that increased solar capacity by 30% and production by 1%, the effects of which have not yet been reported.[40] Biomass electricity plants generated 2,530 GWh by consuming 38.98 Petajoules (PJ) of wood and straw waste.[41] Biogas, mainly produced from liquid manure and organic waste, generated 468 GWh of electricity in 2015.[42] Many of the Biomass and Biogas plants are integrated into CHP plants, delivering heat and electricity. In the same year, 31 hydropower plants generated 19GWh.[43]

[38] Energinet.dk, "Key figures from last years," *Environmental Reporting.* (Web, last updated 7 September 2016).
[39] Energinet.dk, "Wind Power," *Environmental Reporting.* (Web, last updated 7 September 2016).
[40] Energinet.dk, "Solar Power," *Environmental Reporting.* (Web, last updated 7 September 2016).
[41] Energinet.dk, "Biomass," *Environmental Reporting.* (Web, last updated 7 September 2016).
[42] Energinet.dk, "Biogas," *Environmental Reporting.* (Web, last updated 7 September 2016).
[43] Energinet.dk, "Other RE," *Environmental Reporting.* (Web, last updated 7 September 2016).

Figure 3: Danish Electricity Generation and Consumption 1990-2025.[44]

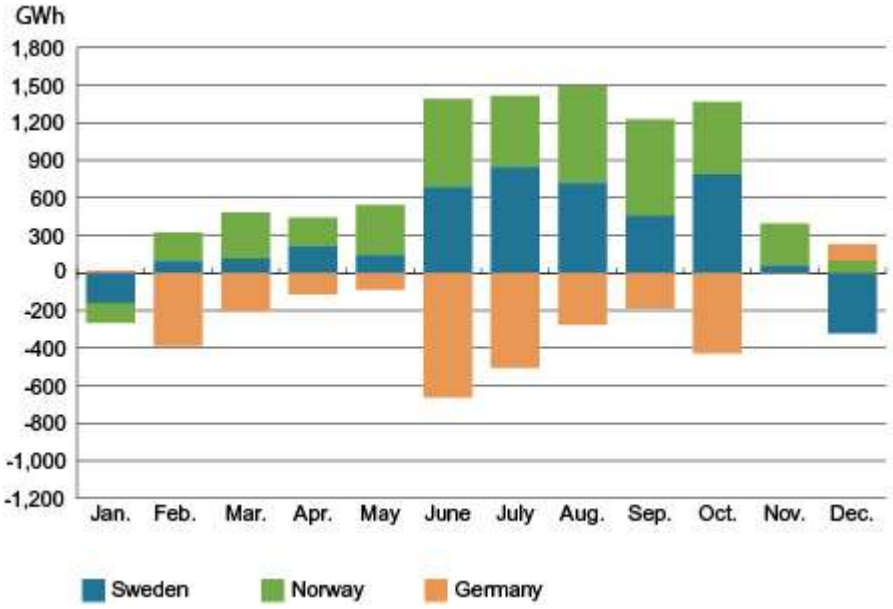


Import & Export

According to Energinet.dk, total electricity consumption in 2015 was 33.6TWh including transmission losses, an increase of 0.4% from 2014.[45] The gap between total generation (27.7 TWh) and total consumption (33.6 TWh) of 5,912 GWh was made up with imports from Sweden (net import 3,649 GWh), Norway (net import 4,954 GWh), and Germany (net export 2,691 GWh).[46] These values represent the annual balance between Denmark and the three countries, Figure 4, below, shows the monthly import/export balances.

[44] Energinet.dk, "Imports and exports," *Environmental Reporting.* (Web, last updated 7 September 2016).
[45] Energinet.dk, "Consumption in Denmark," *Environmental Reporting.* (Web, last updated 7 September 2016).
[46] Energinet.dk, "Imports and exports," *Environmental Reporting.* (Web, last updated 7 September 2016).

Figure 4: Monthly Electricity Import & Export for 2015[47]



Emissions from Electricity Generation

The DEA reports that in 2014, CO_2 emissions attributable the energy sector amount to 7.3 tonnes per capita (population 5.7 million) for a total of 41,610,000 tonnes.[48] For electricity generation, the same report puts CO_2 emissions at 401 grams per kilowatt hour (g/kWh) of electricity sold. Based on Energinet.dk's report of electricity production 30,615 GWh[49] for 2014, this calculates to 12,276,615 tonnes attributable directly to electricity generation.

The use of CHP plants couples the generation of electricity with the production of heat which significantly increases the efficiency of their operation compared to remote centralized power plants. Energinet.dk reports that for 2015, total greenhouse gas emissions from CHP generation were 9,843,000 tonnes of CO2-e.[50]

[47] Ibid.
[48] DEA, *Key figures – Denmark - 2014.*
[49] Energinet.dk, "Electricity Generation," *Environmental Reporting.* (Web, last updated 7 September 2016).
[50] Energinet.dk, "Greenhouse Gases," *Environmental Reporting.* (Web, last updated 7 September 2016).

Policy Measures

As mentioned previously, the most significant mechanism by which the electrical system is being changed is through the Public Service Obligations (PSO); compulsory tariffs on electricity the revenues from which are "allocated in support of environment-friendly power generation, security of supply and energy-related research and development."[51] PSOs secure financing for renewable energy projects beyond cyclical government initiatives and represent a significant revenue for reinvestment – almost DKK 4.7 billion in 2012 when the fee was DKK 0.155/kWh.[1] In the second quarter of 2016, the PSO tariff was DKK 0.247/kWh.[52]

Beginning with the *Energy Agreement of 22 March 2012,* there has been broad political support for an "ambitious green transition plan that focuses on energy savings throughout society, and promotion of renewable energy through more wind turbines, more biogas and more biomass."[53] This agreement has enabled the government to plan around 2,900 MW of new wind power capacity, support the conversion of CHP plants from coal to biomass, develop a comprehensive strategy for the roll-out of smart meters, invest in EV and hydrogen infrastructure.[54] Other renewable technologies are supported by the agreement including "EUR 3.3 mill. … for wave power as well as a pool of EUR 4.7 mill. to promote new renewable technologies for heating, e.g. geothermal energy and large heat pumps."[55]

[51] IEA and OECD, *Energy Policies of IEA Countries: Denmark 2011*, 101.
[52] Energinet.dk, "Electricity Generation," *Environmental Reporting.* (Web, last updated 27 May 2016).
[53] *The Danish Climate Policy Plan*, 37.
[54] Danish Ministry of Climate, Energy and Building. *DK Energy Agreement, March 22 2012*.
[55] *The Danish Climate Policy Plan*, 37.

Gas & Heating

In addition to operating the electricity transmission grid, Energinet.dk is also the gas transmission grid operator. Energinet.dk owns and operates the gas transmission network, gas storage systems and the gas exchange. The transmission grid consists of 860km of pipelines and several regulation and metering stations.[56]

Additionally, Energinet.dk owns the country's only two subterranean gas storage facilities; Lille Torup has the capacity to store 440 million cubic metres of natural gas, enough to produce approximately 5,300 GWh of electricity[57], and Stenlille is capable of storing 575 million cubic metres.[58] The company reports that in 2014 it transported 4.47 billion Nm^3 (normal cubic metres) of natural gas with transport-associated emissions of 3,426 tonnes of CO2-e.[59]

There are only four gas distribution companies; DONG Gas Distribution, HMN Naturgas, NGF Nature Energy Distribution, and Aalborg Kommune, Gasforsyningen.[60] Retail customers purchase gas through suppliers who in turn purchase from distributors.

Like the electricity market, the gas market has been liberalized with the purpose of enabling consumers to select any supplier and increase the efficiency of supply from domestic and foreign producers. In July 2013, Gaspoint Nordic was opened as the first gas exchange marketplace for Denmark. This acts as a physical exchange market through which suppliers can

[56] Energinet.dk, "Environmental key figures for gas," *Climate and Environment.* (Web, last updated 30 April 2016).
[57] Energinet.dk, "Maintenance of the Lille Torup gas-storage facility," *Gas.* (Web, last updated 19 December 2014).
[58] Danske Bank, "Sale of DONG Storage to Energinet.dk for DKK 2.25 billion," *News.* (Web, 11 November 2014.)
[59] Energinet.dk, "Environmental key figures for gas," *Climate and Environment.* (Web, last updated 30 April 2016).
[60] Gasmarketed, *How to become a gas supplier in Denmark.* (Web, last updated 20 November 2015.)

purchase day-ahead, month-ahead, and other "gas products" to sell to consumers.[61] Large consumers are entitled to join the market directly.

Emissions

The operation of the gas grid generates climate impacts and ghg emissions from transportation losses and other system processes. Energinet.dk reports that the operation of Denmark's grid consumed 24,022 MWh of natural gas in meter/regulation boilers for the purposes of heating gas for distribution in 2014, emissions from which totalled 4,939 tonnes of CO2-e.[62]

District Heating

The Ministry of Energy, Utilities and Climate also regulates the supply of heat and electricity through DH systems served by CHP plants. The nature of these systems lead them to be classified as local monopolies; both the production plant and heat pipe system are owned by one company which sells directly to the consumer, who is unable to select another service provider. For this reason, these companies do not operate on a profit model but are compensated based on the costs of operation, with end-user prices determined by "the law of 'the sum of necessary costs'."[63]

Denmark has approximately 670 CHP plants sited in industrial and municipal locations.[64] The DEA states that more than 60% of consumers receive heat from CHP plants, approximately 1.7 million houses and buildings.[65] These systems utilize a variety of fuels; coal, natural gas, biomass and biogas. Energinet.dk reports that the total thermal generation for 2015 based on

[61] Gaspoint Nordic, *Company Description.* (Web.)
[62] Energinet.dk, "Environmental key figures for gas," *Climate and Environment.* (Web, last updated 30 April 2016).
[63] Danish Ministry of Energy, Utilities and Climate. "Electricity, district heating and gas supply," *Facts.* (Web, last updated 21 February 2012).
[64] Danish Energy Agency, *Combined Heat and Power.* (Copenhagen: Danish Energy Agency, n.d.), 2.
[65] Ibid., 2.

renewable fuels, ie. Biomass and biogas, was 3,789 GWh while non-renewable fuels accounted for 9,159 GWh.[66]

The emissions from district heating systems are accounted for under the sources of generation – CHP plants fuelled by coal will have higher emissions than those fuelled by natural gas which in turn have higher emissions than those powered by renewable energies. For 2015, Energinet.dk reported 9,678,013 tonnes of CO2 from electricity and CHP generation.[67] Additional emissions included SO_2 (2,533 tonnes), NO_x (9,049 tonnes), CH4 – Methane (4,330 tonnes), CO (6,166 tonnes) and small amounts of N_20, unburnt hydrocarbons, and particulates.[68]

Responses

The DEA has acknowledged the role of thermal storage in district heating systems as a major component of the future energy system. *Regulation and planning of district heating in Denmark* (2015) states that CHP based on renewable energy, with large heating storage in the form of hot water tanks, "allows CHP plants to decrease their production when there is plenty of electricity in the system, e.g. when it is very windy."[69] When there is greater electricity demand, the plants can increase their production without associated losses of thermal energy. "When the heat production is higher than the excess heat demand, the heating is simply stored. Conversely, when the heat production is lower than the demand, heat energy from the storage can be used."[70]

Supporting this aim, the DEA has set up a framework for partnership with Local Government Denmark to share information and guides on energy planning and "a number of

[66] Energinet.dk, "Key figures from last years," *Environmental Reporting.* (Web, last updated 7 September 2016).
[67] Ibid.
[68] Ibid.
[69] Danish Energy Agency, *Regulation and planning of district heating in Denmark,* (Copenhagen: Danish Energy Agency, 2015), 5.
[70] Ibid., 5.

subsidy schemes to promote renewable energy and heating supply [that are] subject to municipal heat-planning."[71]

To achieve its goal of phasing out oil and coal for heating by 2030 and having "heating supply … 100% covered by renewable energy by 2035,"[72] the government has made changes to regulations regarding individual heating systems to encourage the transition to electricity-based heating. First, a ban on oil and gas heating systems in new buildings was instituted in 2013.[73] Subsequently, a ban on the installation of oil-fired boilers in existing buildings began in 2015.[74] Supported by the *Energy Agreement*, between 2012 and 2015, "a pool of EUR 5.6 mill. has been earmarked to bolster the conversion from oil- and gas-fired boilers in existing buildings to renewable energy."[75]

Between 2012 and 2015, DKK 35 million was secured under the *Energy Agreement* (2012) to support research into conversion of district heating over to renewable energy. The funds were assigned to "analyses of financial framework conditions and the establishment of demonstration projects which, in addition to large heat pumps, could include other renewable technologies with a view to utilising the capacity of the district heating system as storage for increasing amounts of wind turbine power."[76]

To encourage the use of electricity from renewable sources, the Finance Act was amended in 2013 to reduce the tax on electricity-based heating.[77] This change in the electric heating tariff is not clearly explained in any English documents but seems to be an exemption

[71] *The Danish Climate Policy Plan*, 36.
[72] *Ibid.*, 20.
[73] Danish Government. *Our Future Energy.* (Copenhagen: Danish Ministry of Climate, Energy and Buildings, 2011), 13.
[74] Ibid., 13.
[75] *The Danish Climate Policy Plan*, 37.
[76] *Energy Policy Report 2013*, 13.
[77] *Ibid.*, 9.

from a small portion of the electricity tariff for renewable-source electricity used for heating as shown in Figure 2 above.

Further reducing the environmental impact of heating are "standards [that] have been set for maximum energy consumption in buildings..."[78] which ensure that heat is not wasted through poorly insulated buildings and electricity through poorly maintained or inefficient utility systems.

Transport

According to the Ministry of Transport, in 2010 there were 73,574 km of roads and 2,667 km of railway in Denmark.[79] The same report states that there were 2.1 million private cars, the use of which represented 60% or more of the total kilometres travelled by Danes.[80]

Emissions

Aarhus University's Danish Centre for Environment and Energy calculated the greenhouse gas emissions from road transport, including passenger vehicles, light and heavy duty vehicles, and mopeds and motorcycles in 2013. The emissions of GHGs are as follows; CO_2 (11,021,000 tonnes), CH_4 (481 tonnes), and N_20 (379 tonnes).[81] Based on the IPCC *Fourth Assessment Report* global warming potentials, one tonne of CH_4 is equivalent to 25 tonnes CO_2 and one tonne of N_2O to 298 tonnes CO_2.[82] This puts the total at 11,145,967 tonnes of CO_2-e.

Additional transport sources of emissions include industry vehicles, domestic aviation, railways, shipping (within national boundaries), agricultural and forestry vehicles, and fishing as

[78] *The Danish Climate Policy Plan*, 36.
[79] Ministry of Transport. *The Danish Transport System – Facts and Figures*. (Copenhagen: Ministry of Transport, 2012), 6.
[80] Ibid., 25, 26.
[81] Winther, *Danish emission inventories*, 8.
[82] Environment and Climate Change Canada, "Global Warming Potentials," *GHG Emissions Quantification Guidance.* (Web, last updated 17 April 2015.)

well as other smaller sources. Emissions from these sources is reported at 393,300 tonnes of CO_2, 402 tonnes of CH_4 and 175 tonnes of N_20.[83] This calculates to 455,500 tonnes CO_2-e.

Total combined transport emissions for 2013 amount to 11,601,467 tonnes CO_2-e.

Policy Measures

There are two dominant policy strategies for reducing these emissions which both have the capacity to act as mobile and distributed energy storage systems; incentives for the purchase of electric vehicles and investments in research, development and demonstration (RD&D) of battery technologies and hydrogen fuel-cells for heavy transport. Both of these strategies have been recommended by Sorknaes as long-term projects which require investments in electricity infrastructure to become viable.[84] The *Climate Policy Plan*'s forecasts show results to be expected after 2035, as shown in Figure 1.

Energy Strategy 2050, published in 2013, recognizes that a transport sector based on renewable energy will require investments in electricity infrastructure, more trade with other countries, a well functioning market and "storage facilities for electricity and heating".[85] Funded through the PSOs, RD&D is being undertaken to develop EV infrastructure and hydrogen fuel technologies. Both streams of research are being pursued with the intention of electrifying the transportation system; directly with batteries or indirectly through electrolysis.

Between the years of 2013 and 2015, a pool of DKK 70 million was established to fund the development of transport electrification. These funds have been split to support the transition of various technologies for different subsectors of transport with DKK 40 million dedicated to

[83] Winther, *Danish emission inventories*, 9.
[84] Sorknaes, Peter, et al. *Facilitating energy storage to allow high penetration of intermittent renewable energy: Overview of current status and future development scenarios of the electricity system in Denmark – allowing of large quantities of wind power.* (Munich, Germany: Store Project, 2013), 38.
[85] Danish Government. *Energy Strategy 2050 – from coal, oil and gas to green energy.* (Copenhagen: Danish Ministry of Climate and Energy, 2011), 51.

EV charging stations, DKK 20 million going to gas for heavy transport, and the remaining DKK 10 million allotted to hydrogen RD&D.[86]

Beginning in the mid-2000s, the government began to give incentives and subsidies toward the purchase of energy-efficient cars. In 2008, an "electric car pilot scheme" was initiated to increase consumer experience with EVs and support development of technology.[87] *The Danish Climate Plan* (2013) announced a pool of EUR 9.3 million for the development of infrastructure for EVs and hydrogen and gas for heavy transport.[88] The *Plan* states that this was to take place alongside "minimum requirements for biofuels, and the technological development of cars to comply with stricter CO2-EU regulations."[89] In 2013, the government "extended the tax-exemption period for electric and hydrogen cars to the end of 2015."[90] This exemption represents a significant subsidy in that the luxury taxes for personal vehicles amount to 150-180% of the unit price. However, these exemptions appear not to have been renewed after 2015. News reports suggest that the growth in purchases of electric vehicles has made it too expensive for the government to continue the exemption.[91]

Electrification of the train network has already begun with **"**15 new electric trains for inter-regional transport."[92] Several tracks have already been electrified, starting with "EUR 86.7 mill. earmarked in … the 2013 budget for electrification of the track between Køge and Næstved."[93]

[86] *Energy Policy Report 2013*, 14.
[87] *The Danish Climate Policy Plan*, 40.
[88] *Ibid.*, 40.
[89] *Ibid.,* 21.
[90] *Ibid.,* 40.
[91] Peter Levring, "Teslas hit by 180% Danish Tax on Cars as Green Goals Ditched," *Bloomberg News.* (Web, last updated 30 September 2015).
[92] *The Danish Climate Policy Plan*, 40.
[93] *Ibid.*, 40.

Conclusions

Denmark's energy transition has been formulated to build upon strengths in the existing systems while extensive planning being is undertaken to ensure that the future energy system is 100% renewable, stable and reliable.

The broad strategy for the reduction of greenhouse gas emissions is to reform the use of energy and direct all sectors, as much as possible, toward the consumption of renewable energy, predominately wind and bio-fuels. The resulting system will require applications of various types of energy storage to ensure grid stability but at present, Danish energy policy has a focus on thermal storage in district heating systems.

Because of the predominance of district heating and the use of CHP plants in Denmark, initiatives have been undertaken to require oil and gas-based systems to be replaced with electric systems at their end of life. This policy enables district heating systems to store wind energy as heating energy.

Further research will be required to clarify the specific, long-term RD&D streams which focus on electrical energy storage to balance the electrical grid.

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