IEA HPP Annex 42: Heat Pumps in Smart Grids

Task 1 (i):

Market Overview

Denmark

September 2014

Report compiled by:

Danish Technological Institute

DANISH TECHNOLOGICAL INSTITUTE

Contents

List of figures & tables

1. Executive Summary

In March 2012, one of the world's most ambitious energy plans and agreements "Vores Energi" (in English "Our Energy") was reached by a broad majority in the Danish Parliament bringing Denmark a good step closer to the target of 100% renewables in heating by 2035 and 100% renewable energy in the energy and transport sector by 2050.

Essentially, this means that everything that uses fossil fuels today has to be replaced by another technology that either already exists, does not exist today, or exists in a form that is very expensive or limited. Electric vehicles, for example, exist today, but they have a limited range, especially in the colder Nordic countries during winter.

Wind power is planned to account for 50% of the electricity mix already by 2020. Wind power is volatile and energy storage is still expensive. Large investments in the electricity transmission grid are required with new connections to Germany, Sweden, and maybe the UK. Smart Grid solutions are planned to mitigate some of these investments, but the first thorough analyses and reports conclude that there is no real economic incentive for the average household to invest in Smart Grid solutions. Even worse, scenarios for Smart Grid in Denmark are very, very far from reaching the predicted potential from just a few years back.

Heat pumps are planned to convey much of the electrification and phase out of fossil fuels for heating. However, they are simply too expensive and cannot compete with the much cheaper gas condensing boilers.

District heating is also planned to phase out a substantial amount of fossil fuels. However, bio fuels might prove to be a scarce resource, and waste incineration plants are already importing other scarce sustainable sources, aka "waste" from abroad.

As the consumption of fossil fuel drops, state revenue on coal, oil and gas will also drop as energy goods are among the most taxed resources in the world. To counter this, a "supply security tax" has been discussed, but it has been postponed and left on the shelf for now, as the opposition grew too big. Nevertheless, recent political measures and discussions have created a sense of insecurity in the general public as to what to expect or which energy related investments are feasible.

2. Overview of the Danish Energy Sector

2.1. Overview of main challenges in Denmark

A massive investment in the transmission grid is necessary to accommodate rising shares of wind power in the electricity mix and therefore Energinet.dk is planning 308 km of 400 kV overhead lines and 238 km of 400 kV cables, totalling DDK 6.1 billion (€ 0.82 billion), not including a planned upgrade of a Danish/Swedish cable connection. The long term development of the 132/150 kV grid is planned to include 250 km of new cables and cable laying of 2600 km of existing overhead line, totalling DKK 12.3 billion (€ 1.65 billion).

Smart Grid can reduce the costs related to implementing more wind power and reduce the overall investment costs related to the planned upgrade of the distribution net that is necessary to accommodate more heat pumps and EV's. How much the costs can be reduced is hard to quantize, as predictions made just a few years back have not been fulfilled, and scenarios for Smart Grid in Denmark are very much far from reaching the predicted potential from just a few years back. Smart Grid appliances are not very common today, and the question is whether they ever will be. A recent report[1] published by The Danish Ministry of Climate, Energy and Building estimates that the average household could save DKK 40 a year (€ 5.37) by implementing Smart Grid solutions in the future.

Furthermore, the electricity cost itself constitutes only a relatively smaller fraction (18 %) of the kWh-cost, even considering the before mentioned reduction of environmental fees. Effectively, this does not promote the demand side flexibility as a significant value proposition to the end-customer.

The Danish Energy Agency estimates that gas supplies from the North Sea will decline between 2018 and 2042. Based on the current knowledge of reserves, natural gas supplies are likely to be exhausted in 2040.

Waste accounts for a substantial amount of the primary energy supply for district heating plants. A recent article pointed out that 10 out of 27[2] incineration plants are importing waste from other countries in that increased recycling among other things creates waste shortages in Denmark. Critics argue that it is an adverse trend. In 2012, the Danish Environmental Protection Agency registered an import of 107000 metric ton waste.

Recent political measures and discussions have created a sense of insecurity as to what to expect or which energy related investments are feasible.

[1] Danish Ministry of Climate, Energy and Building "Smart Grid Strategy - The intelligent energy system of the future"2013

[2] http://ing.dk/artikel/affaldsmangel-oeger-import-136812, August 28th 2014

2.2. Danish electricity generation

Danish electricity generation is predominately a mix of both coal, wind power and waste fuelled CHP plants. Overall, the share of wind power, biomass and waste in the electricity mix is on the rise, while fossil fuels such as coal, oil, and gas is declining as shown in Figure 1 and Figure 2.

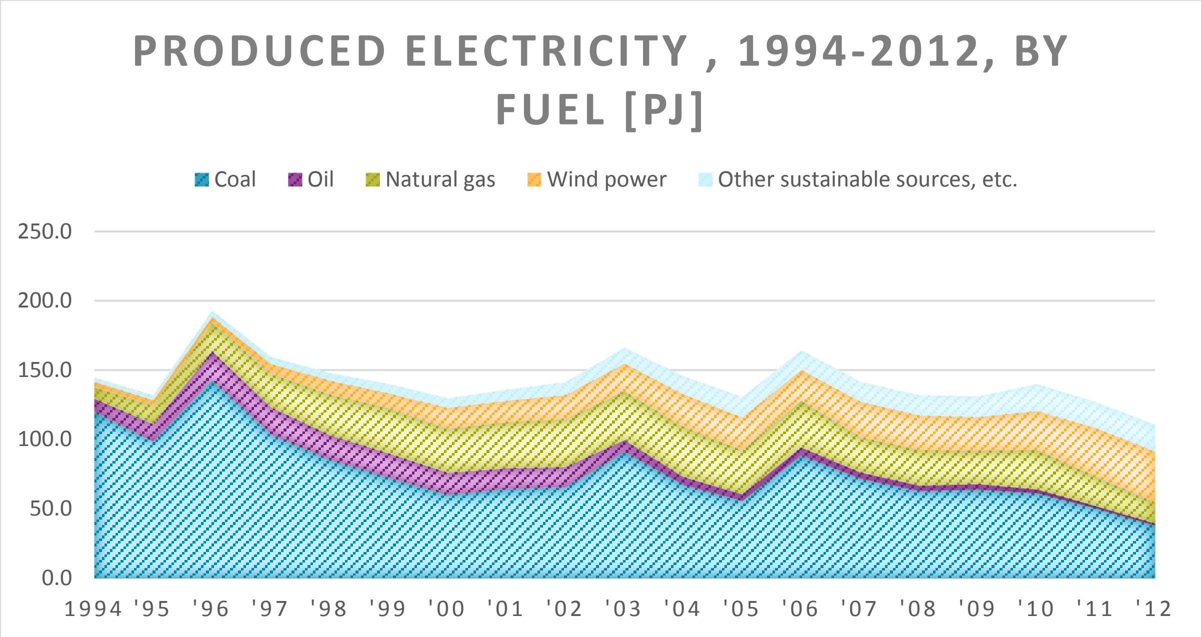

Figure 1 Produced electricity , 1994-2012, by fuel [PJ] Source(s) Danish Energy Agency, Energy Statistics 2012.

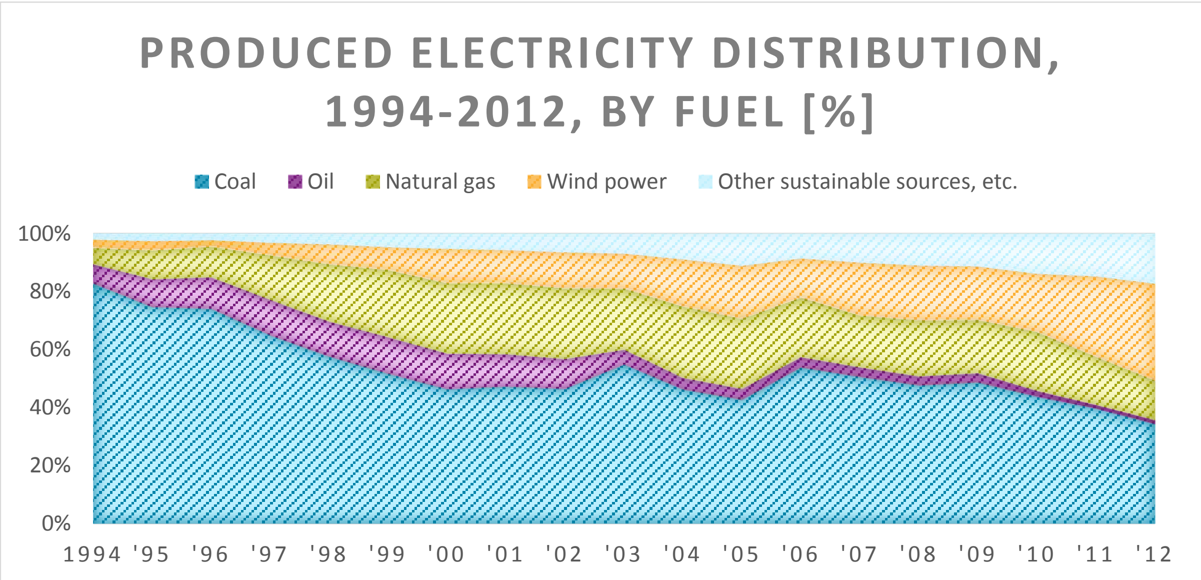

Figure 2 Produced electricity distribution, 1994-2012, by fuel [%]. Source(s) Danish Energy Agency, Energy Statistics 2012.

The information in Figure 1 could easily be interpreted as that the Danish electricity *consumption* being very fluctuating and even rapidly declining in recent years. However, this is not the case in that the electricity generation is closely correlated to price trends on the Nordic electricity exchange, Nord Pool. Years with more precipitation in Norway and Sweden, predominately hydro powered electricity generation, result in lower price trends on Nord Pool and in turn a lower Danish net export.

Figure 3 shows the net electricity export, and the observant reader will notice an inverse correlation with Figure 1. In 2012, the net import of electricity reached 18.8 PJ compared to a total production of 111 PJ.

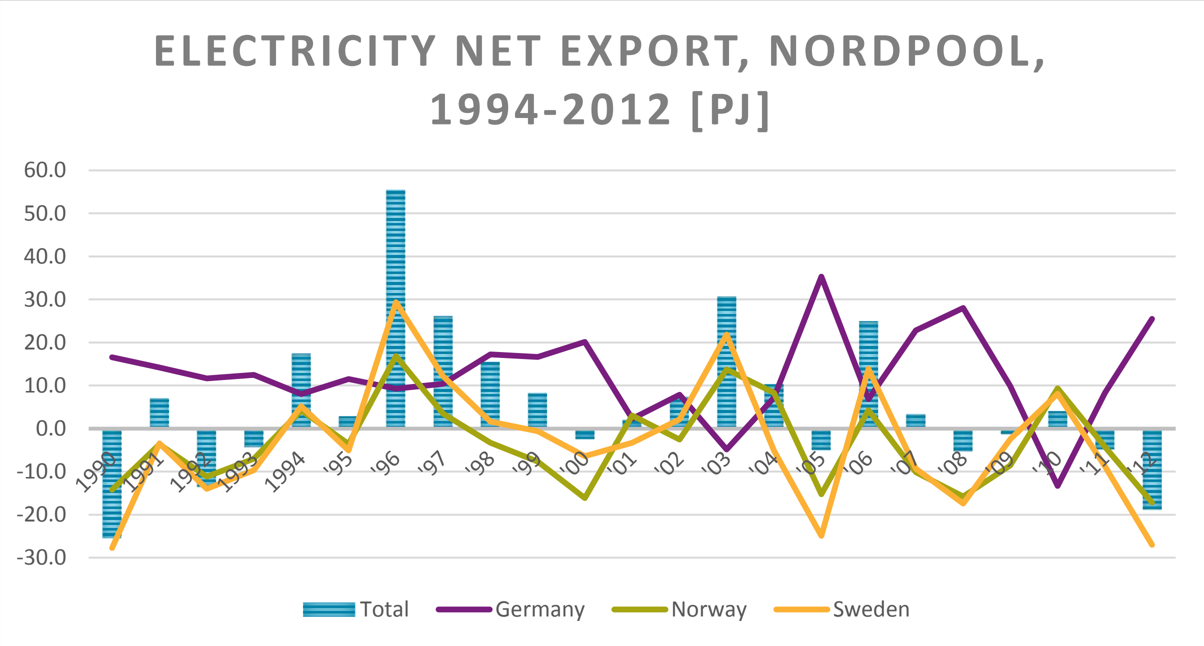

Figure 3 Electricity net export, Nordpool, 1994-2012 [PJ]. Source(s) Danish Energy Agency, Energy Statistics 2012.

This inverse relationship between the net import of electricity and the total production indicates a relatively stable electricity consumption. This is indeed the case as shown in Figure 4. Notice that even though the electricity consumption has remained relatively constant in the past many years (1994-2012), the GDP has risen nearly 35 %, which denotes a declining energy intensity or higher energy efficiency in the use of generated electricity.

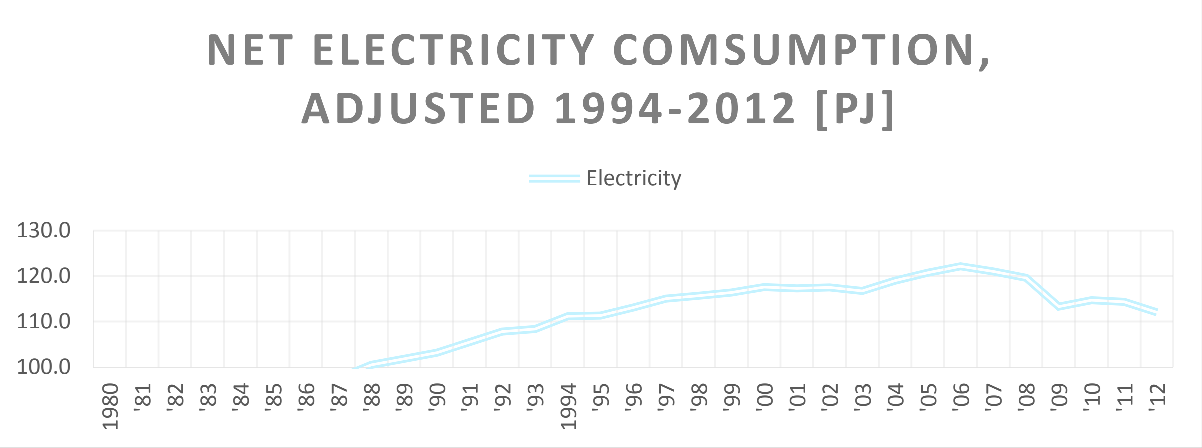

Figure 4 NET Electricity consumption, adjusted '94-'12 [PJ]. Source(s) Danish Energy Agency, Energy Statistics 2012.

Thus, the Danish electricity generation is not only meant to satisfy a national demand, but it is also actively used for trade on the Nordic electricity exchange, Nord Pool.

Renewables in the electricity mix have been rising constantly in recent years (Figure 2) and wind power accounted for 29.8 % of the Danish electricity supply in 2012. According to the 2012 Energy Agreement, which will be discussed more thoroughly later, the share of renewable energy in the electricity generation is planned to reach approx.70 % by 2020, hereof 50 % from wind power. This is a significant development, which demands new requirements from the electricity transmission grid to effectively integrate the fluctuating electricity from primarily wind power. However, if planned and timed right, the use of heat pumps and the coalition between peaking wind power and heat demand in winter could mitigate the new requirements and demands of the future electricity mix.

In relation to the mentioned 2012 Energy Agreement, The Danish Energy Agency has forecasted a baseline scenario to 2035 by energy production, energy consumption and energy-related greenhouse gas emissions. It addresses only briefly the forecasts for the electricity generation separately, as shown in Figure 5. The figure shows a process of implementing the steps already adopted, but without additional means. The scenarios are not predictions, but descriptions of the development, which under a number of assumptions may occur by 2035, if new initiatives or instruments are not to be implemented, hypothetically assumed. The mentioned “other sources” in Figure 5 mainly pertain to electricity produced at CHP plants fuelled by biofuels or waste.

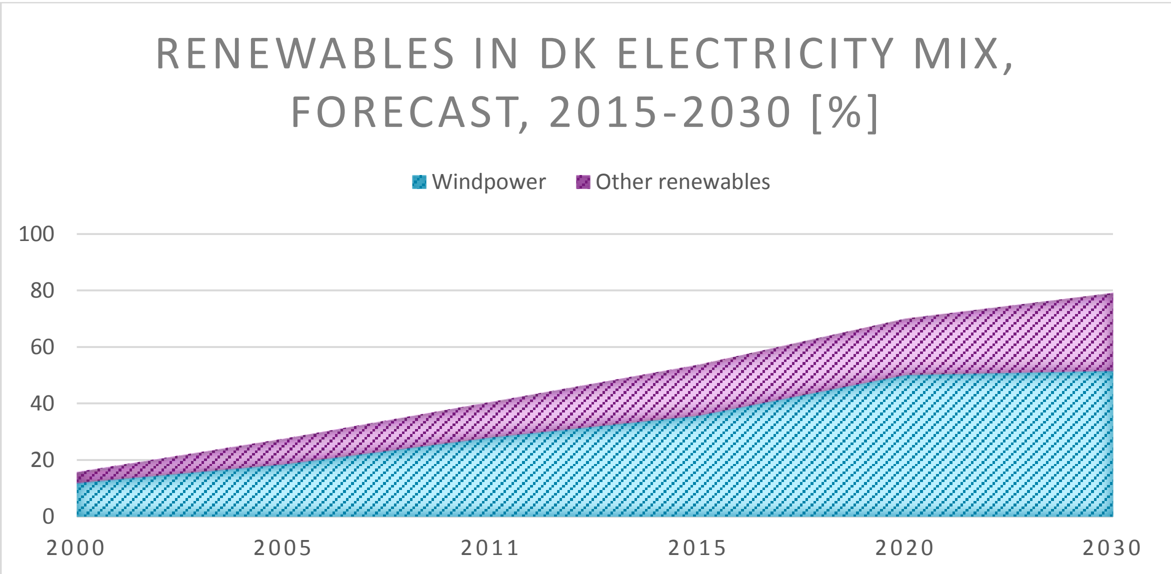

Figure 5 Renewables in DK electricity mix, forecast, 2015-2030 [%]. Source(s) Danish Energy Agency, Danmarks Energifremskrivning 2012 [Danish Energy Outlook 2012], p. 4.

In relation to the electricity consumption, a moderate rise in all major sectors consuming electricity is expected in coming years, as seen in Figure 6. From 2014 to 2035, the overall electricity consumption is expected to rise from 113.1 PJ to 127.7 PJ or 12.9 %. For the household sector, this rise is not due to a higher energy demand, quite the contrary. The energy demand in this sector is expected to fall, even though e.g. heat pumps are expected to replace oil furnaces. Thus, the expected rise in electricity demand is mainly due to the phase out of fossil fuels.

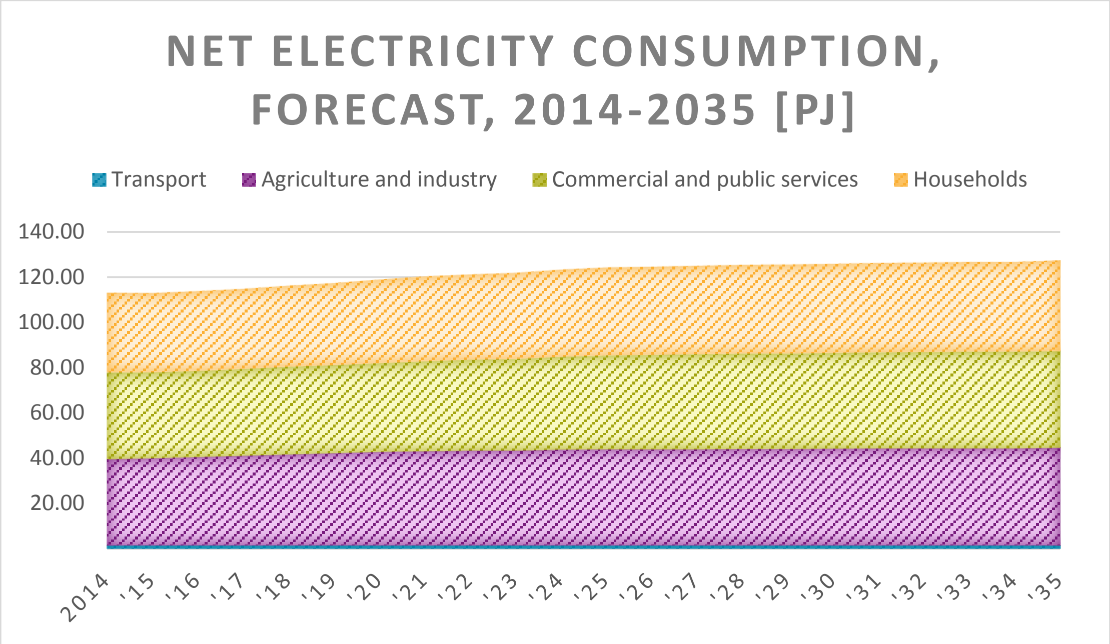

Figure 6 NET Electricity consumption, forecast, 2014-2035 [PJ]. Source(s) Danish Energy Agency, Danmarks Energifremskrivning 2012 [Danish Energy Outlook 2012], p. 14

In short, the Danish electricity generation is trending towards renewable sources as of today constitute more than half. Moreover, the foreign trade is quite substantial and dependent among other factors on Nord Pool price trends, which in turn are influenced by the precipitation in Norway and Sweden.

From the perspective of implementing electrically driven heat pumps on a larger scale for domestic heating, it is worth looking into electricity generation capacity. Figure 7 shows the Danish electricity generating capacity. Again, the before mentioned trends can easily be seen, namely, that wind power accounts for a larger and larger capacity, while the capacity from large-scale units remain relatively constant or have a slight declining trend.

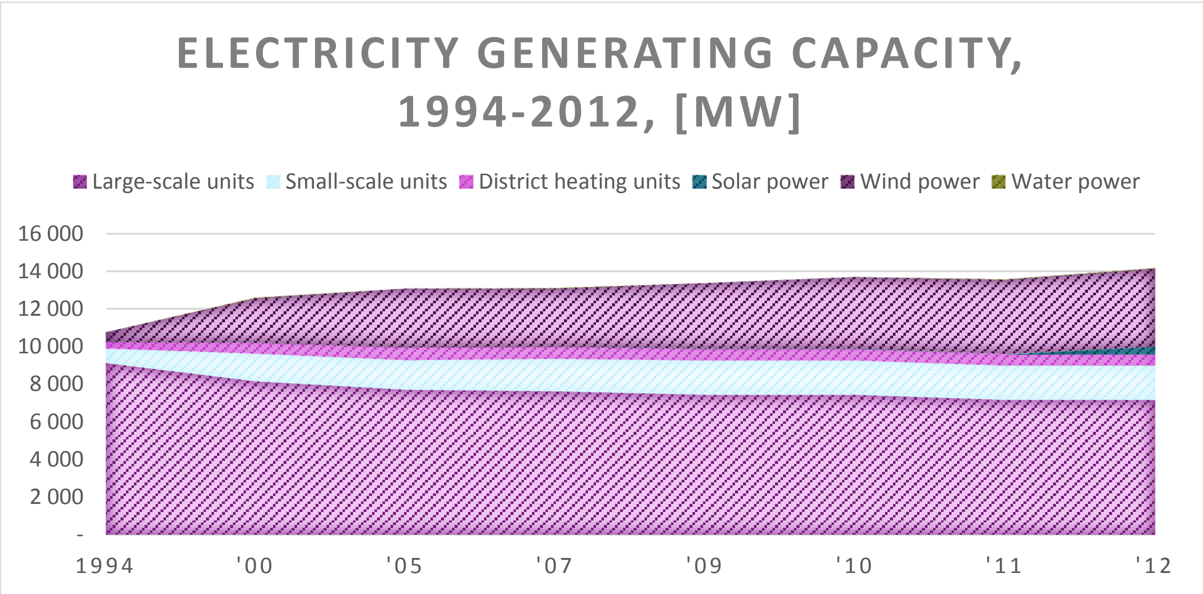

Figure 7 Electricity generating capacity, 1994-2012, [MW]. Source(s) Danish Energy Agency, Energy Statistics 2012.

In 2012, the peak load was 6600 MW. Thus, the peak load is less than half the electricity generating capacity that reached 14166 MW in 2012. Therefore, it immediately seems that there is no electricity capacity problem, and the majority of Danish households could have heat pumps installed. When excluding wind power from Figure 7, a slight declining trend in the electricity generating capacity would actually be revealed. That is to say, on days without wind, the ratio between the generating capacity and the peak load is lower.

2.3. Danish Energy Demand

The Danish final energy demand is currently 785 PJ per year, of which 28.4 % is consumed by the domestic sector. Generally, the tendency seen in many countries is an improved energy efficiency for the use of energy in electric appliances and for transportation, which are kept in check by an ever growing number of electric items in domestic households and a growing private car fleet.

Figure 8 shows the final energy consumption, which is adjusted for fuel linked to foreign trade in electricity and fluctuations in climate with respect to an average reference year. Thereby, underlying tendencies in energy usage are shown more clearly. A declining energy demand is clearly seen since 2007. From 2007 to 2012, the energy demand in the domestic sector has fallen 6.3 % from 238 PJ to 223 PJ. It is debatable whether this tendency is linked to deflating BNP and decreased consumer confidence following the economic crisis or the energy demand really is declining.

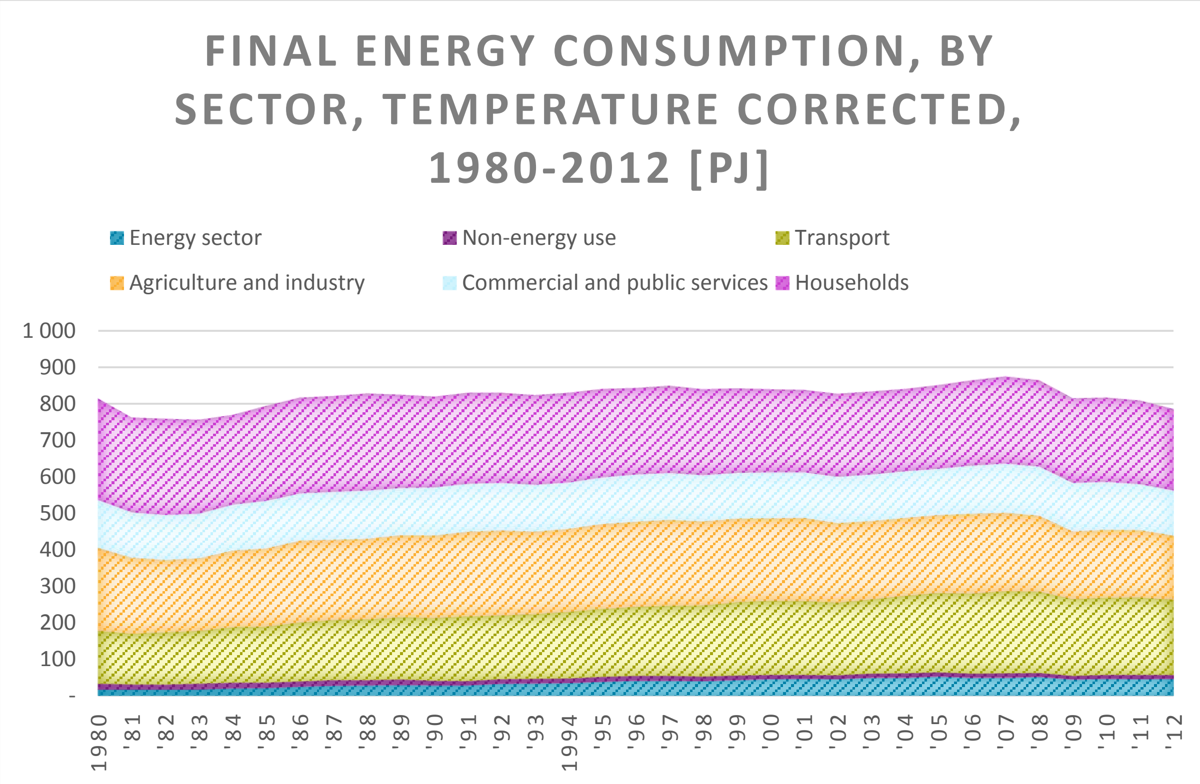

Figure 8 Final energy consumption, by sector, temperature corrected, 1980-2012 [PJ]. Source(s) Danish Energy Agency, Energy Statistics 2012

Further analysis of the energy demand in the domestic sector, see Figure 9, reveals heating accounts for the majority of the energy demand. In 2012, the average household used 60.9 GJ (16917 kWh) for heating purposes and 12.3 GJ (3417 kWh) for electric appliances (lighting, cooking, etc.) Thus, heating accounts for approx. 83% of the energy use in the domestic sector.

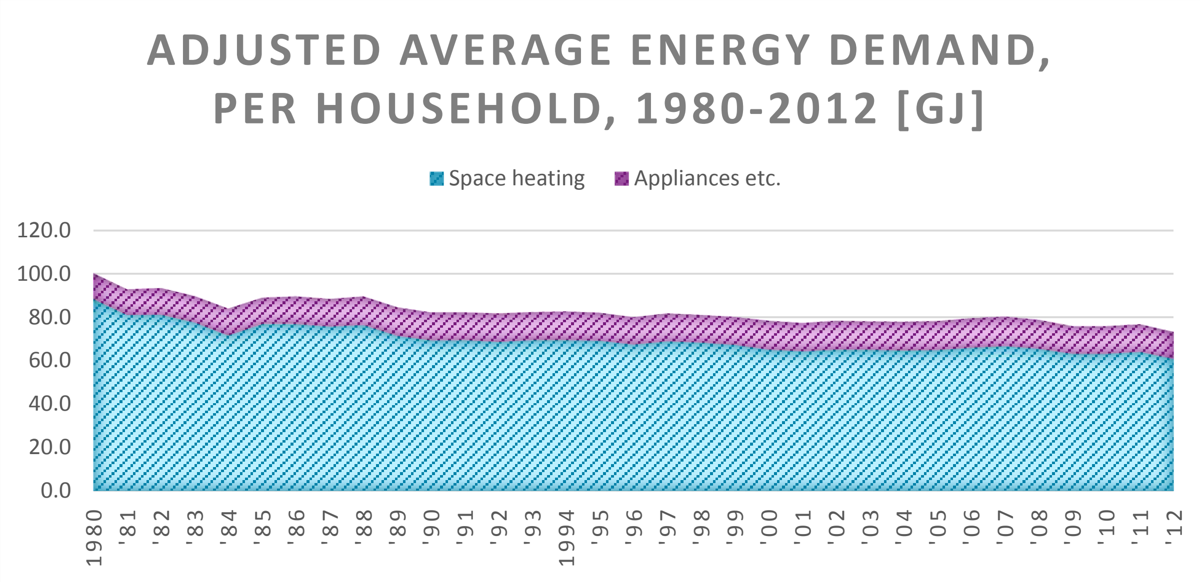

Figure 9 Adjusted average energy demand, per household, 1980-2012 [GJ]. Source(s) Danish Energy Agency, Energy Statistics 2012

Moreover, the remaining 17 % pertaining to electric appliances can be further broken down into end use as seen in Figure 10 and Figure 11. (Note: electricity used for heating/hot water shown in Figure 11 only relates to circulation pumps etc.)

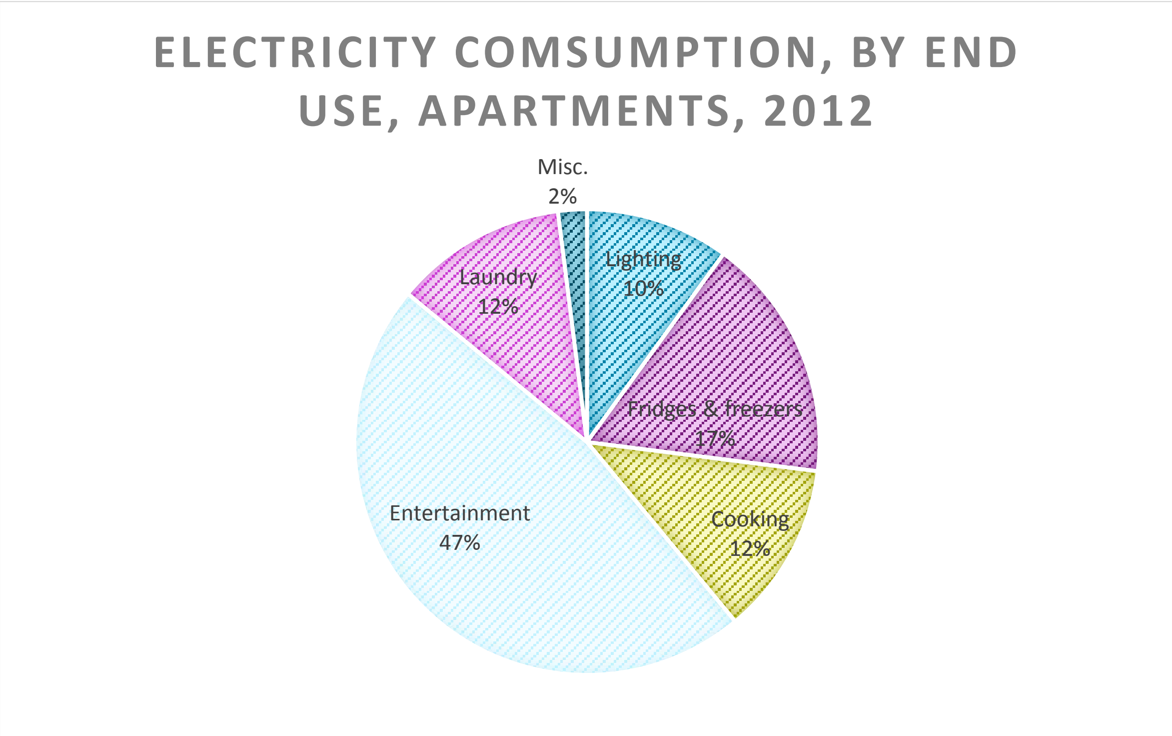

Figure 10 Electricity consumption, by end use, Apartments, 2012. Source(s) Danish Energy Agency, Elmodelbolig Statistics website: http://statistic.electric-demand.dk/

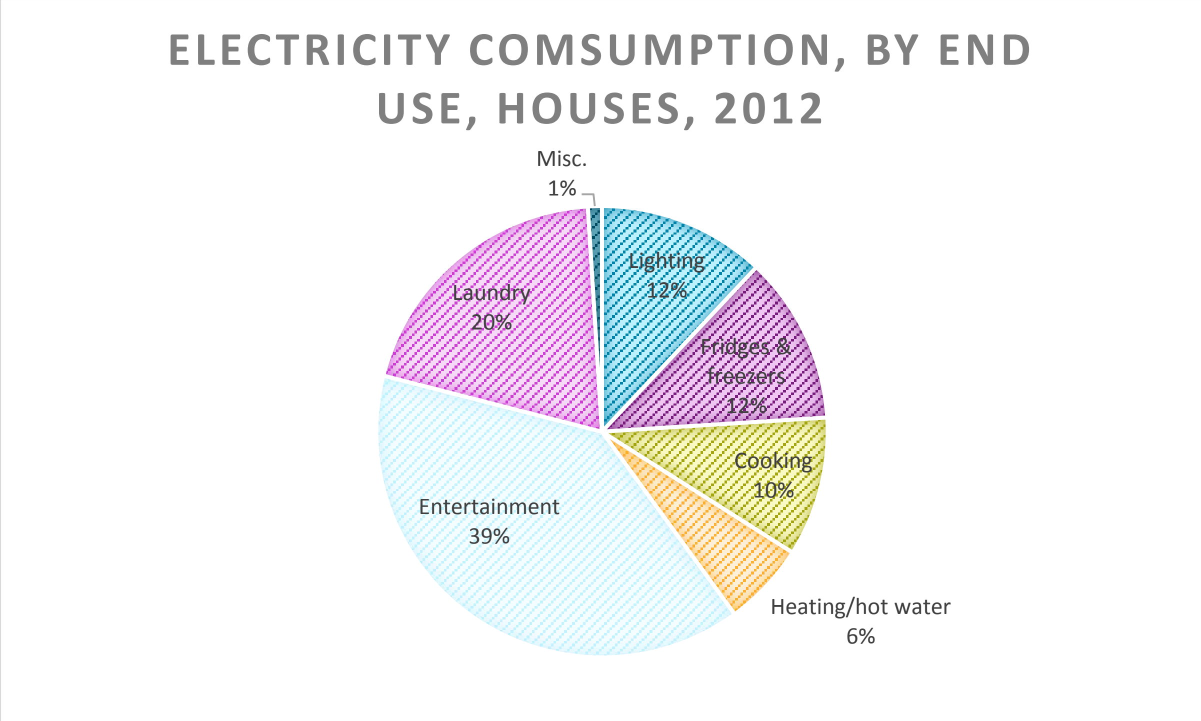

Figure 11 Electricity consumption, by end use, houses, 2012. Source(s): Danish Energy Agency, Elmodelbolig Statistics website: http://statistic.electric-demand.dk/

Energy for the domestic sector is supplied by various means, closely related to the installed heating type, where district heating is the most dominant heating type accounting for 36 % of the total energy supply, as seen in Figure 12. A very clear tendency is seen with oil being phased out and replaced by renewable energy as an energy carrier. Since 2000, the use of renewable energy has risen rapidly, mainly due to the use of firewood and wood pellets for heating purposes.

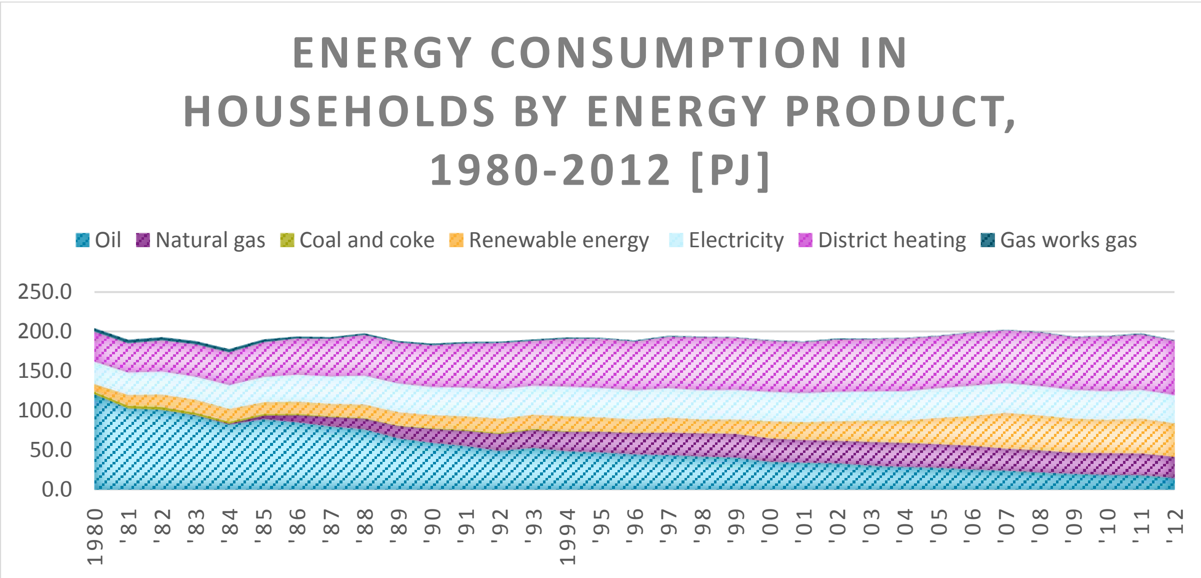

Figure 12 Energy consumption in households by energy product, 1980-2012 [PJ]. Source(s) Danish Energy Agency, Energy Statistics 2012

2.4. Danish Energy Infrastructure

Virtually all Danish households are connected to the electricity grid, and the vast majority are situated in areas that are supplied by either natural gas, district heating, or even both. It is estimated that 258,000 households out of Denmark's 2.62 million households are heated by oil furnaces. 205,000 of these households are situated in an area, which is supplied by neither natural gas nor district heating[3]. For illustrative purposes, the areas supplied by district heating (purple) and natural gas (yellow) are outlined in Figure 13. Essentially, they cover every minor and major city in Denmark.

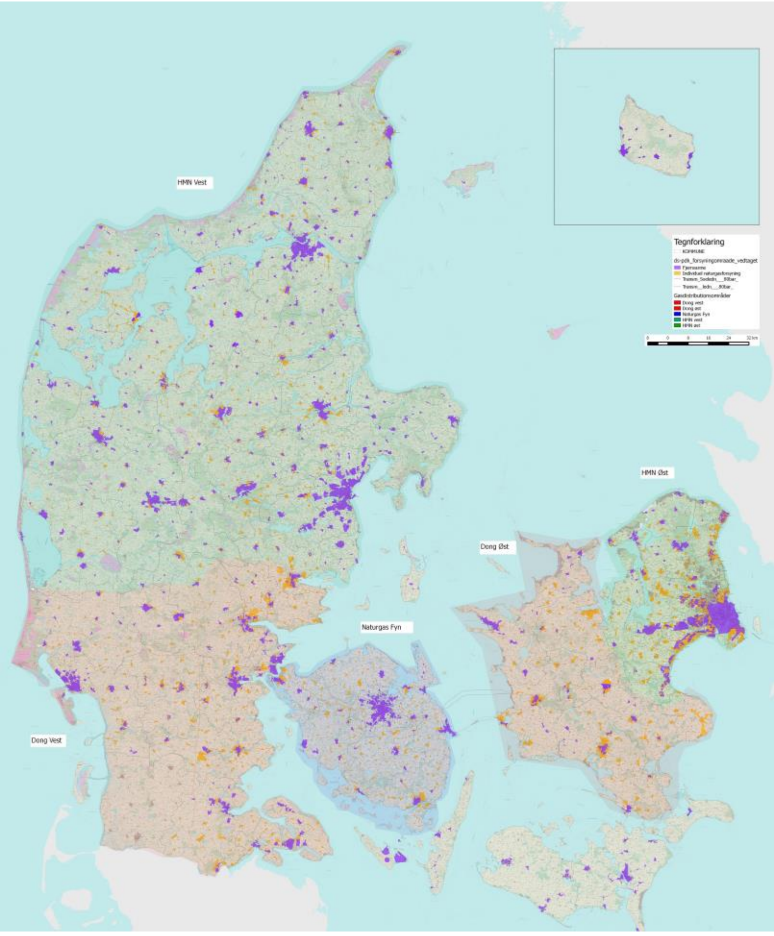

Figure 13 Map of discrict heating and natural gas networks in Denmark. Image courtesy: Danish District Heating Association

[3] COWI, Stock of heat pumps for heating in all-year residences in Denmark, 2011.

The Danish Electricity Grid

The Danish electricity grid is divided into three different voltage levels as illustrated in Figure 14.

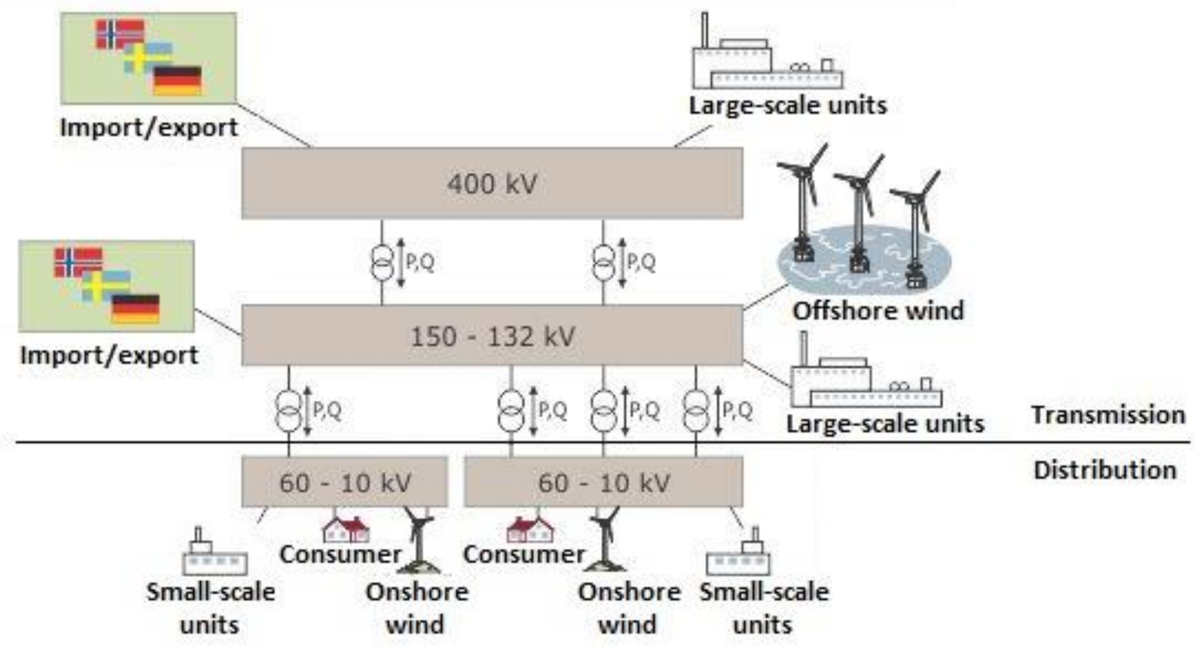

Figure 14 Overview of the Danish electricity grid. Image courtesy: Energinet.dk

1) The overall electricity transmission grid at the highest voltage level 400 kilovolt (kV). This grid connects the large-scale power stations in Denmark and abroad to each other and to the electricity grid at a lower voltage level. This electricity grid is owned by Energinet.dk, which is a non-profit enterprise funded by tariffs and owned by the Danish Climate and Energy Ministry.

2) The regional electricity transmission grid on 132 kV east of the Great Belt[4] and 150 kV west of the Great Belt. This electricity grid connects the overall transmission grid to the distribution grid. Typically, larger offshore wind farms are connected to this net. Energinet.dk also owns this grid. Both the 400 kV and the 132-150 kV transmission grid is linked to the transmission systems in Germany, Sweden and Norway.

3) The distribution grid which delivers power the remaining part of the way to households and businesses. Local grid companies own and are obligated to supply this grid. There are approx. 80 different distribution companies owned by municipalities, cooperatives and commercial players. The grid companies have a monopoly on transporting electricity in defined geographical areas, and they have neither competition nor market-based incentives for efficiency. Therefore, the Danish Energy Regulatory Authority, DERA, regulates the grid operators to ensure that network companies are run efficiently and that profits in general are similar to the

[4] Great Belt: a strait between the main Danish islands of Zealand (Sjælland) and Funen (Fyn) effectively dividing Denmark in two.

products on the open market. Currently, both the 400 kV and 132-150 kV transmission grids are connected via cable to neighbouring countries; Sweden 3.74 GW, Norway 1.05 GW, and Germany 3.88 GW. (See Figure 15)

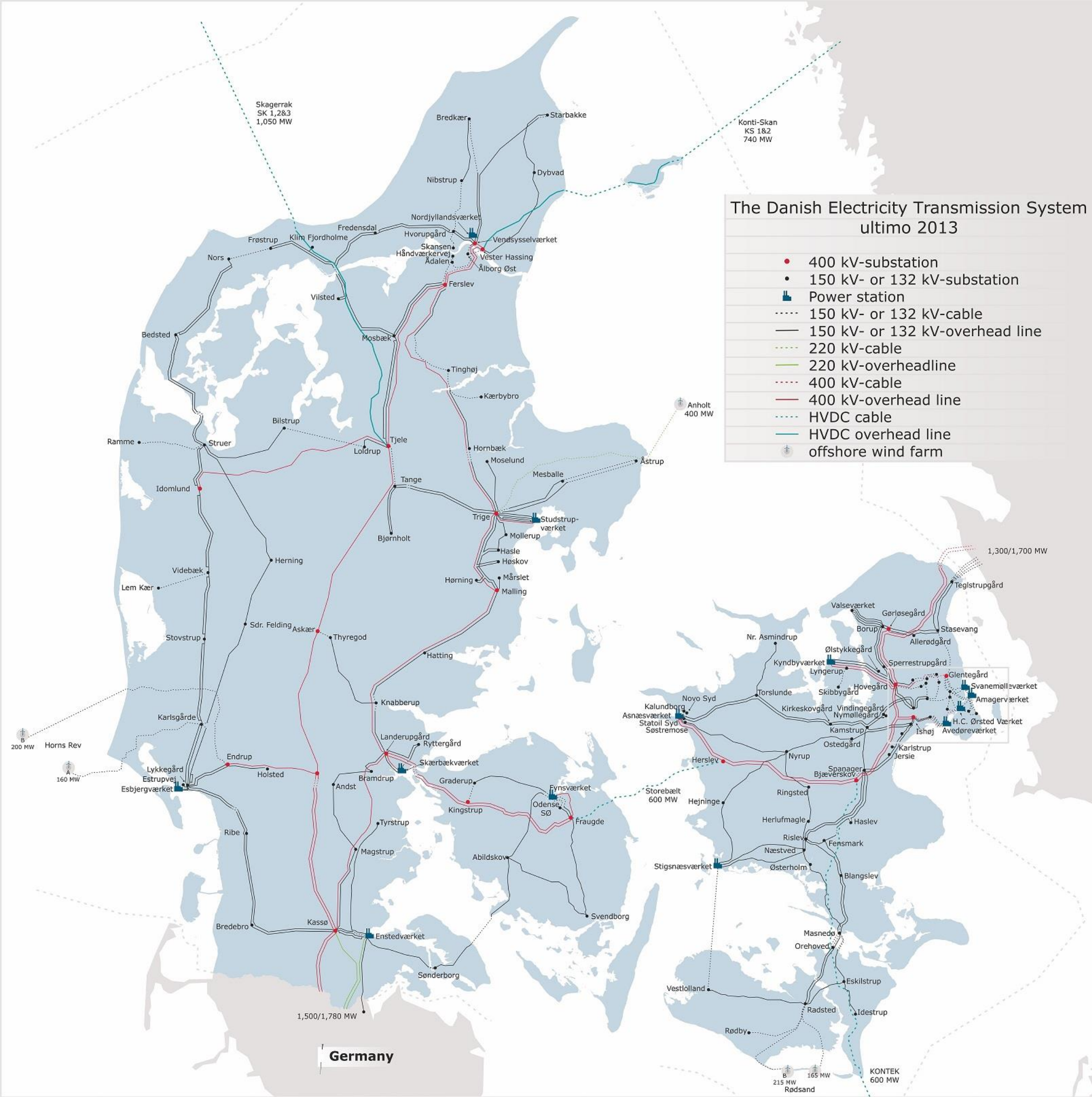

Figure 15 Map of the Danish electricity transmission grid. Image courtesy: Energinet.dk

As of right now, the ability to match supply and demand is excellent with connections to neighbouring countries that total 8.67 GW. This is even greater than the electricity peak load of 6.6 GW. However, the planned increase of wind power, which is going to reach 50 % by 2020 according to the 2012 Energy Agreement, necessitates a massive investment in and expansion of the transmission net and the connections to neighbouring countries.

In the most recent grid development plan from 2013, Energinet.dk is planning 308 km of 400 kV overhead lines and 238 km of 400 kV cables, totalling **DDK 6.1 billion (€ 0.82 billion)**, not including a planned upgrade of a Danish/Swedish cable connection. The long term development of the 132/150 kV grid is planned to include

250 km of new cables and cable laying of 2,600 km existing overhead line, totalling **DKK 12.3 billion (€ 1.65 billion)**.

Currently, collaborative studies investigate possible upgrades or new connections between Denmark and Great Britain, Germany, The Netherlands and Sweden, respectively. This would strengthen the ability to match supply and demand by importing and exporting electricity further.

Thereby, massive investments in the transmission grid are commenced and planned for the next many years to come in order to accommodate the rapidly growing wind share in the electricity mix. It is concluded that heat pumps and electric vehicles, or other measures that could reduce the necessary transmission grid development it will not be significant enough to alter the investments required for the growing wind share. However, in a recent report[5], The Danish Ministry of Climate, Energy and Building investigates the potential for Smart Grid strategies in Denmark and concludes the following:

> *As a consequence of the energy agreement, half of electricity consumption in 2020 will be met by electricity from wind turbines, and at the same time new electricity consumption is expected. An energy system with a smart grid design requires greater exploitation of the energy from wind as soon as it is produced, for example by heats pump and electric cars. This will allow for greater exploitation of cheap wind turbine electricity, and it will mean less need to expand the electricity infrastructure [distribution grid] to meet new electricity consumption.*

In other words, implementing heat pumps and EV's in a **Smart Grid can reduce the costs related to implementing more wind power and reduce the overall investment costs related to the planned upgrade of the distribution net that is necessary to accommodate more heat pumps and EV's**. How much the costs are reduced is hard to quantize, as predictions made just a few years back have not been fulfilled. For example, in 2010 the Danish Energy Association and Energinet.dk published a report[6] based on the assumption that the number of electric and plug-in vehicles totals 600,000 and that there are 300,000 individual heat pumps by 2025. As of right now, there are approx. 2000 EV's[7] on the Danish roads, and the yearly installations of new heat pumps averages 5-6000 units[8]. **Scenarios for Smart Grid in Denmark are very far from reaching the predicted potential from just a few years back.**

---

[5] Danish Ministry of Climate, Energy and Building "Smart Grid Strategy - The intelligent energy system of the future SUMMARY", 2013
[6] The Danish Energy association and Energinet.dk, "Smart Grid in Denmark", 2010
[7] Inventory from the Danish Transport Authority, 2014.
[8] VPF – VarmePumpeFabrikantforeningen. A Danish heat pump trade organization.

The Danish Gas Grid

The gas transmission network is owned and maintained by Energinet.dk, which also owns and maintains the electricity transmission grid as previously explained. The distribution network is owned and maintained by five different companies, which operate in different regions in Denmark as illustrated in Figure 16.

Figure 16 Map of gas distribution company operating areas in Denmark. Image courtesy: Energinet.dk

All natural gas consumers in Denmark have been free to choose their gas supplier as of 1 January 2004. Energinet.dk and the distribution companies collaborate in order to ensure a continued market development.

Until 2010, the North Sea was the only gas supply in Denmark. The North Sea production peaked in 2005-2006. In 2010, the first supplies from Trym, a small Norwegian gas field, were sent through the Danish offshore pipelines. Supplies from Trym are currently being used to supply the Danish, Swedish and Dutch gas markets.

The Danish Energy Agency estimates that gas supplies from the North Sea will decline between 2018 and 2042. **Based on the current knowledge of reserves, natural gas supplies are likely to be exhausted in 2040**, see Figure 17.

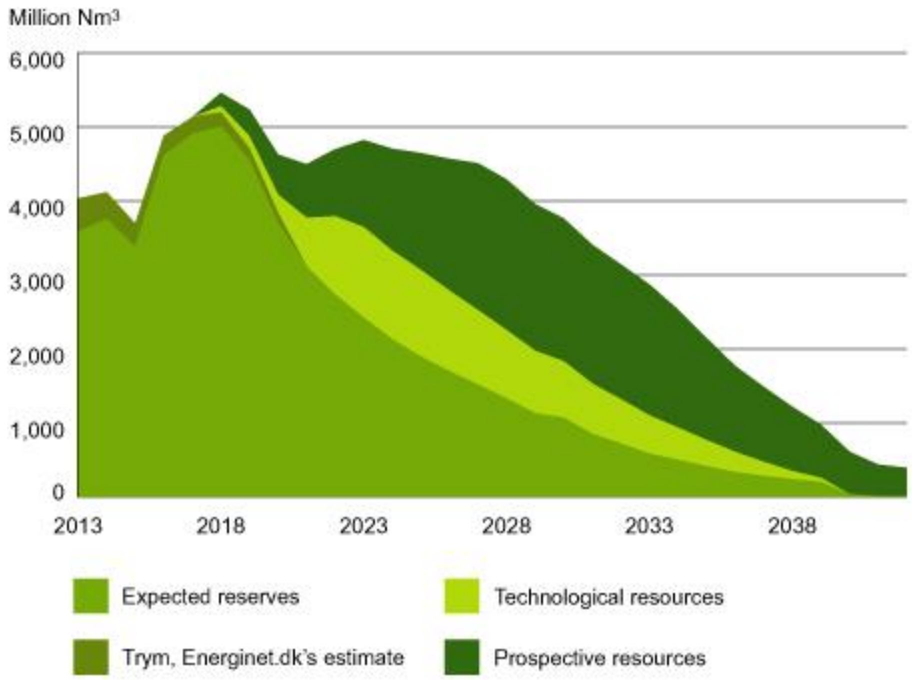

Figure 17 Forecast of Danish gas reserves 2013-2040- Source(s) Danish Energy Agency and Energinet.dk 2013

District Heating Networks in Denmark

In Denmark, district heating networks are very common, and they supply 61% of all households with heating and hot water. Currently, there are 428 district heating plants, DHPs, represented in two associations. Each plant is owned by either a municipality, a company, cooperatives, or a municipal corporation, and they are effectively run as local monopolies. The Danish Energy Regulatory Authority oversees and supervises each plant to ensure operating efficiency and low prices for the consumers. However, the prices for district heating vary considerably ranging from DKK 286-1525 pr. MWh.[9]

District heating plays an important role in satisfying future heating demands. In the near future, it is planned that coal and natural gas will be phased out and replaced with larger heat pumps and solar power in smaller DHPs and with biomass in larger DHPs. By 2035, all fossil fuels are planned to be phased out as illustrated in Figure 18.

[9] According to statistics from The Danish Energy Regulatory Authority

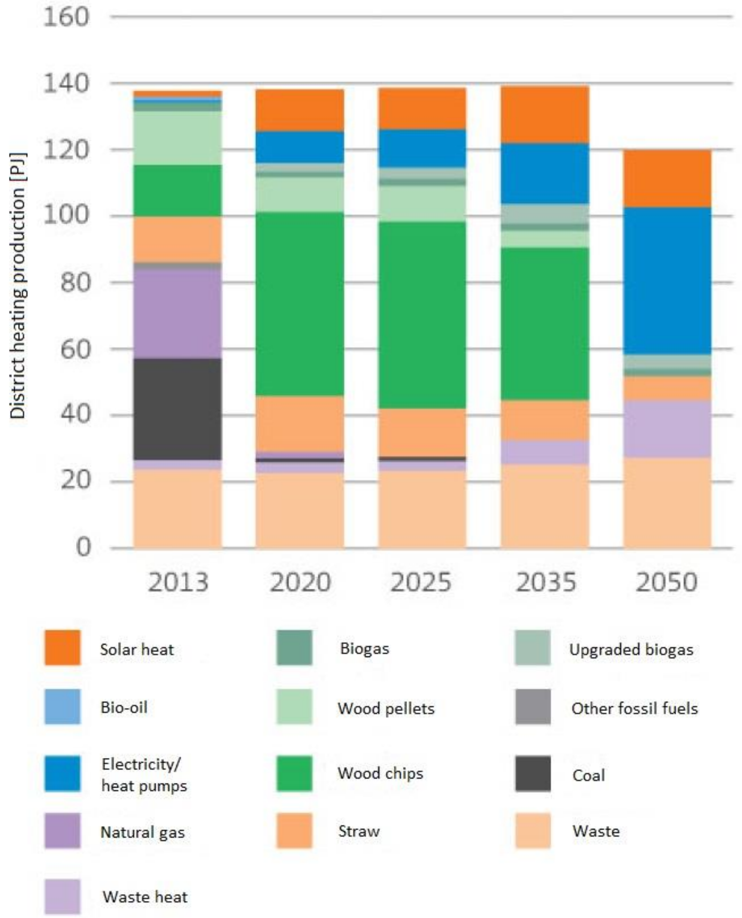

Figure 18 The forecasted district heating energy mix 2013-2050. Image courtesy: The Danish Energy Agency, "Energy analysis 2014"

Waste accounts for a substantial amount of the primary energy supply for district heating plants. A recent article pointed out that **10 out of 27**[10] **incineration plants are importing waste from other countries** as increased recycling among other things create waste shortages in Denmark. Critics argue that it is an adverse trend. In 2012, the Danish Environmental Protection Agency registered an import of 107,000 metric ton waste.

[10] http://ing.dk/artikel/affaldsmangel-oeger-import-136812, August 28th 2014

2.5. Danish Energy Policy

In March 2012, an Energy Agreement was reached in Denmark. Eventually, the milestones of the agreement are to bring Denmark to the target of **100% renewable energy in the energy and transport sectors by 2050**.

The next milestones are:

2020
50 % wind power in the electricity mix

2030
Complete phase out of coal in power plants

2035
100 % renewables in electricity and heating

2050
100 % renewables in all sectors (transport, industry, etc.)

It is expected that the 2020 milestone will result in the following improvements:

- 35 % or more renewable energy in the final energy consumption
- 50 % wind power in the electricity mix
- 7.6 % reduction in gross energy consumption (1990 baseline)
- 34 % reduction in greenhouse gas emissions (1990 baseline)

In order to facilitate these milestones and the final target, many policy measures have been adopted. Since 2013, oil and gas boilers are no longer to be installed in new buildings, and by 2016 oil boilers are no longer to be installed in existing buildings in areas with either gas or district heating grids. Many other measures have already implemented or will be implemented. For example, an incentive scheme, which started in 2011 for tax reductions applying to renovation and extension works in private households, has now been extended twice, and it is expected to continue in 2015 as well.

50 % wind power in the electricity mix will surely add a considerable intermittent generation capacity, considerably greater than the typical demand, as illustrated in Figure 19.

Figure 19 Wind power in the electricity mix by 2035 and 2050. Image credit: Danish Ministry of Climate, Energy and Building, "Smart Grid-strategi", 2013

Due diligence and efficient planning by considerable investments in the transmission grid should accommodate this. Furthermore, Smart Grid initiatives are foreseen to help resolve a more intermittent generation capacity. PSO (Public Service Obligation) funds from tariffs and resources from other sources are invested in Smart Grid projects that are to resolve future challenges in balancing the electricity grid. DREAM, iPOWER, EcoGrid.eu, ESWA, and Smart Grid Open are just a few examples of the funded ongoing Danish Smart Grid projects.

However, Smart Grid appliances are not very common today and the question is whether they ever will be. A recent report[11] published by The Danish Ministry of Climate, Energy and Building estimates that the average household could save DKK 40 a year (€ 5.37) by implementing Smart Grid solutions in the future.

Heat pump related incentives/policies:
Residential consumers are now, as of Jan 1st 2013, benefitting from an electricity taxation reduction on their consumption above 4000 kWh/yr, if their property is registered as being electrically heated, for example by a heat pump. The reduction is approx. DKK 0.52/kWh (€ 0.07/kWh) or 20-25 % of the total electricity price.

Other measures such as subsidies for energy renovations, e.g. replacing an oil boiler with a heat pump, yields a subsidy of approx. DKK 0.25 (€ 0.03) pr. kWh saved during the first year after implementing the renovation. Heat pumps need to meet the following minimum criteria in order to be eligible for a subsidy:

Air-to-air	SCOP ≥ 3.8
Air-to-water & liquid-to-water	SCOP ≥ 3.5 (low temperature application)

[11] Danish Ministry of Climate, Energy and Building "Smart Grid Strategy - The intelligent energy system of the future"2013

Other incentives/policies:
An interesting case in Danish energy policy is found in the installed PV (Photovoltaics) capacity in Denmark during the last three years. A combination of declining installation costs and favourable net meter billing for PV installations owned by private owners resulted in an exponential trend that impeded government revenue due to lost income on energy related tax and VAT. A new billing scheme was adopted by the end of 2012, which effectively halted new installations of PV as seen in Figure 20.

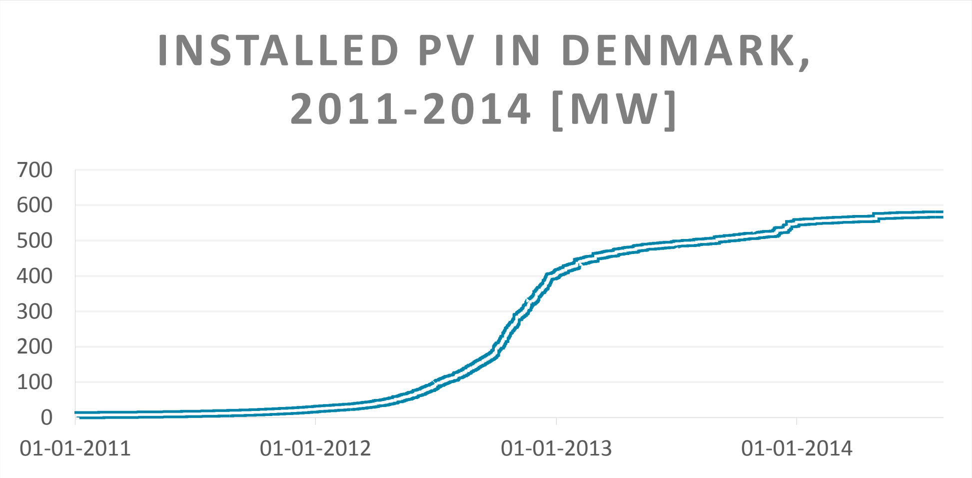

Figure 20 Installed PV in Denmark, 2011-2014 [MW]. Source(s) Energinet.dk

Taxes and VAT on energy products constitute DKK 40.4 billion[12] (€ 5.42 billiion) or 5 % of the government revenue from direct and indirect taxes and VAT. Reducing energy consumption and implementing renewable energy inevitably affect government revenue negatively. This problem has been a hot topic discussed in the Danish energy policy. A proposed “security of supply-tax” on biomass and wood has recently been put on hold as the opposition grew too strong. **Nevertheless, recent political measures and discussions has created a sense of insecurity as to what to expect or which energy related investments are feasible.**

2.6. Energy Prices, Tariffs & Structures

Energy prices in Denmark are comparatively high. According to Eurostat[13] statistics, Danish electricity prices are the highest and natural gas prices second to highest in the EU. See Figure 21.

[12] Statistics Denmark, Taxes and duties 2013, 2013
[13] Electricity and gas prices for domestic consumers, bi-annual data second half 2013.

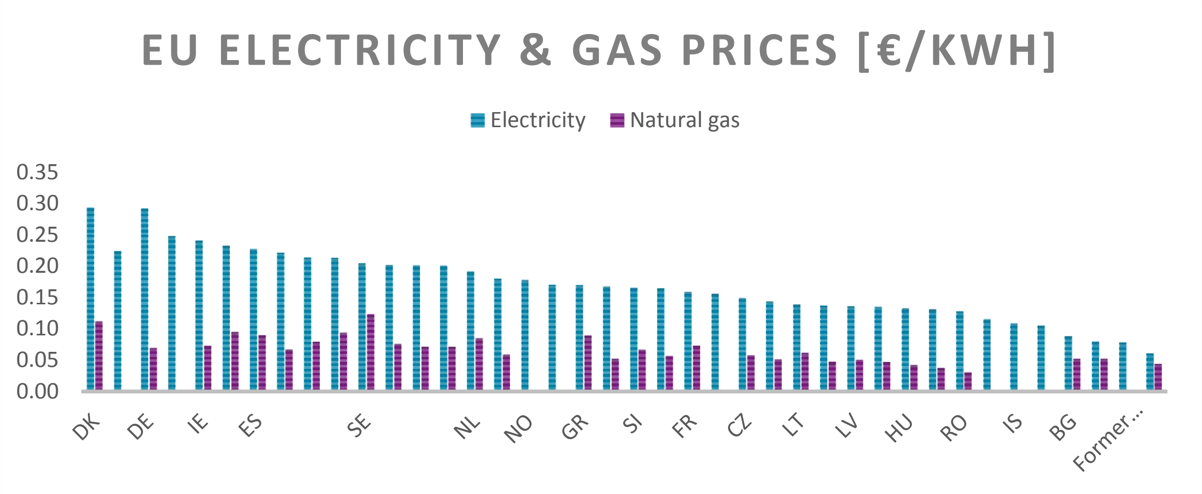

Figure 21 EU Electricity & gas prices [€/kWh]. Source(s) Eurostat

However, as of 1 January 2013, homeowners who have their home registered as being heating by electricity (for example by a heat pump) can get a reduction of the environmental charges for their electricity consumption above 4000 kWh/yr. Still, the electricity prices remain comparatively high in Denmark taking into account that other EU countries also have implemented similar reductions of environmental charges.

The most recent consumer prices from the end of second quarter 2014 are as follows:

Electricity	0.3 €/kWh[14]
Electricity (electric heating >4000 kWh)	0.23 €/kWh
District heating	0.03 - 0.2 €/kWh[14]
Gas	0.089 €/kWh[14]
Heating oil (distillate fuel)	0.159 €/kWh[15]
Wood pellets	0.05 €/kWh

There are currently no electricity tariffs, which promote flexibility on the demand side for private consumers. Grid companies have already installed remotely-read hourly meters at 50 % of the customers, who together account for 75 % of the electricity consumption. It is expected that the hourly settlement will start when all consumers have remotely-read hourly meters installed, which is expected to be completed in 2016[16]. Currently, only industrial consumers with a consumption > 100,000 kWh operate with hourly settlement.

[14] Danish Energy Regulatory Authority
[15] Danish Oil Industry Association (EOF)
[16] Danish Ministry of Climate, Energy and Building “Smart Grid Strategy - The intelligent energy system of the future”2013

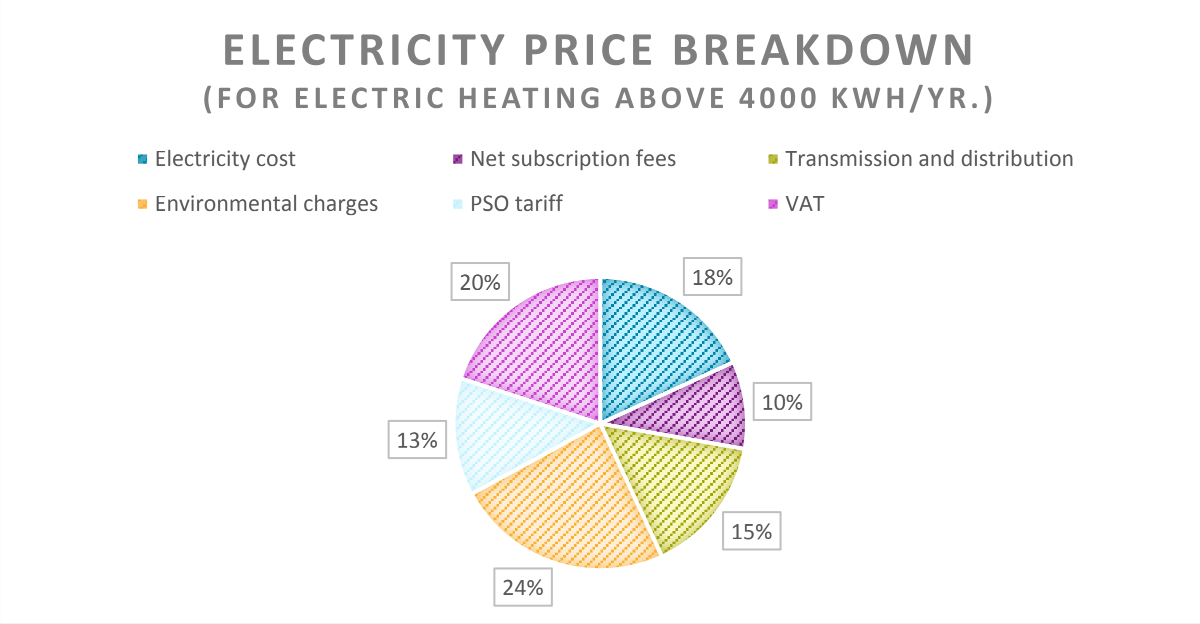

Figure 22 Electricity price breakdown for consumers using electrical heating and thereby eligible for a reduction of environmental charges. Source(S): Danish Energy Regulatory Authority.

As illustrated in Figure 22, the electricity cost itself constitutes only a relatively small fraction (18 %) of the kWh-cost, even considering the before mentioned reduction of environmental fees. Effectively, this does not promote the demand side flexibility as a significant value proposition to the end-customer.

3. Analysis of the Danish housing stock & heating market

3.1. Overview of main challenges in Denmark

It is not economically feasible to install a heat pump for 75 % of the ~ 205,000 owners with dwellings outside areas with district heating or natural gas supply, because the preliminary required renovation works would be too expensive or would account for too large a fraction of the property value.

Gas boilers are very completive, comparatively cheap, and even if a heat pump would be more feasible in the end, the customer value proposition is affected negatively by the high upfront cost of heat pumps in Denmark.

3.2. Danish Housing Stock Characteristics

Type and ownership

As of 2010, there were approx. 2.6 million residential dwellings in Denmark, of which the majority (40.5 %) are detached houses inhabited by the owner. Multi-dwelling houses (apartments) comprise the next largest segment (37.9 %), of which the majority are occupied by a tenant, see Table 1. Energy bills are nearly always paid for separately by the occupant, except in student hostels, where energy use usually is included in the monthly rent. This somewhat promotes energy savings as people pay for their own energy use, but tenants in multi-dwelling houses typically have very little incentive in regard to improving energy efficiency.

Types of dwelling:	Number:	%:	Owned %:	Rented %:
Farm houses	110748	4,3	90	10
Detached houses	1037091	40,5	90	10
Linked or semi-detached houses	369147	14,4	34	66
Multi-dwelling houses	971132	37,9	11,9	88,1
Student hostels	29993	1,2	0	100
Residential buildings for communities	8328	0,3	0,5	99,5
Other residential building	14216	0,6		-
Unknown	481	0,0		-
Occupied weekend cabins (2005-)	17958	0,7	93	7
Total	2559094	100	-	-

Table 1 Breakdown of type and ownership of residential dwellings in Denmark as of 2010. Source(s): Satistics Denmark

Age of the building stock

The most common building type in Denmark is a detached house built during a period with a great economic boom, i.e. in the 1960's or 1970's. 450,000 out of the ~ 1.1 million detached houses in Denmark were built during this period. This type of house is characterized by a relatively light construction with an outer wall with masonry cladding and a bearing inner wall of aerated concrete blocks or in some cases a wooden structure. Typically, cavity walls were not insulated during construction until the end of the period were the oil crisis drew attention to energy savings. Doors, windows, ceilings, etc. are typically not tight, and the ventilation loss can, therefore, account for up to 30 % of the energy use.

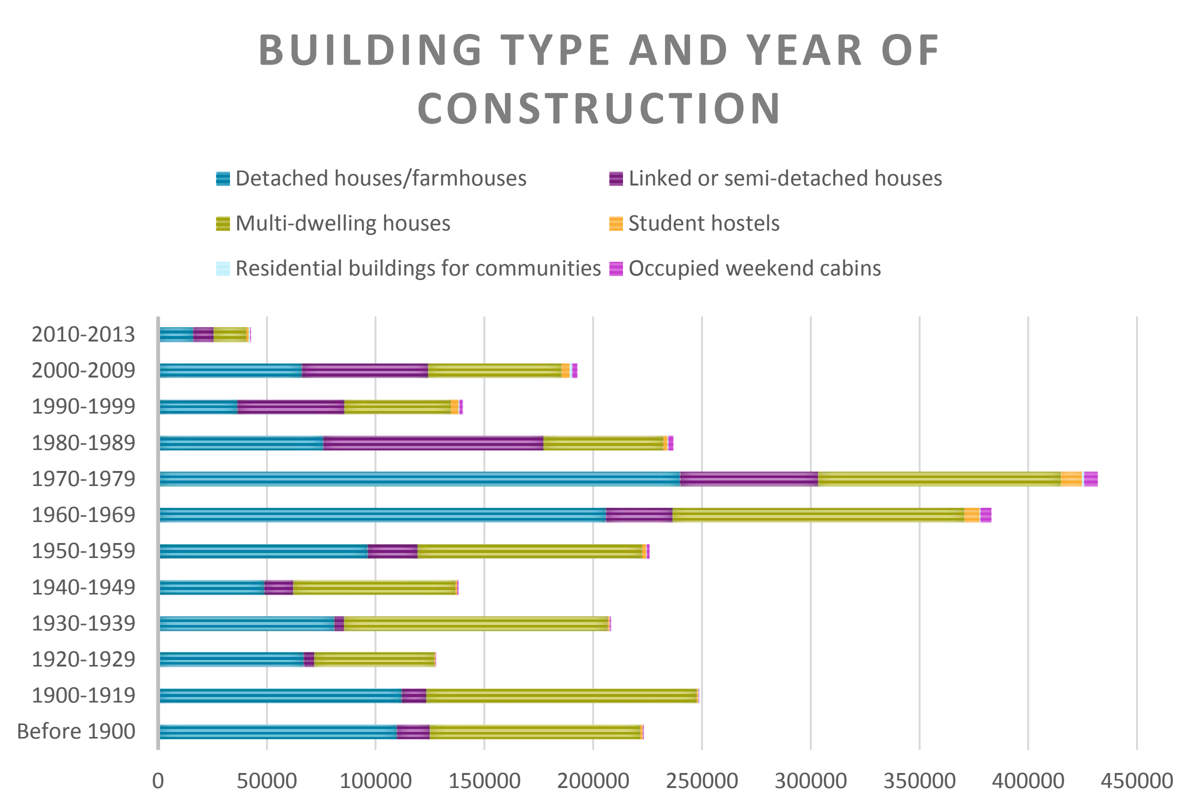

Figure 23 Bar chart illustrating building type and construction year of dwellings in Denmark. Source(s): Statistiscs Denmark

Thermal Performance

The average detached house is 130 m^2, and it has a yearly heating demand of 18.1 MWh. The average multi-dwelling house is 75 m^2 with a yearly heating demand of 15 MWh. Table 2 shows the average yearly net heating demand of detached houses from various decades.

Year of construction vs. net heating demand [kWh/m^2/year]

Area [m^2]	1930-1939	1940-1949	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009
<80	124	139	137	123	105	78	81	71
80-100	125	120	127	122	104	77	82	65
100-120	118	115	119	117	96	76	76	61
120-140	110	111	114	112	96	77	77	59
140-160	108	110	110	110	97	78	78	59
160-180	104	100	106	105	95	79	78	57
180-200	101	95	102	103	93	76	73	53
200-300	93	92	90	96	88	73	70	51
300-400	82	89	89	92	83	73	75	48

Table 2 Net heating demand for detached houses as a function of area and construction year. Source(s): Analysis of 90,000 mandatory energy assessments performed in connection with house sales (Danish Energy, "Den lille blå om Varmepumper", 2011, p. 23)

Most detached houses constructed before 1980-1990 do not have underfloor heating, but radiators, which are often dimensioned based on a heating supply temperature of ~ 70°C. Some older houses still have one-pipe radiator systems possibly requiring an even higher supply temperature, which is arguably incompatible with heat pumps.

A recent study[17] conducted on behalf of the Danish Energy Agency concluded that it is not economically feasible to install a heat pump for 75 % of the ~ 205,000 owners with dwellings outside areas with district heating or natural gas supply. The reason for this is the required and necessary home improvements prior to the installation of a heat pump, e.g. thermal insulation and upgrade or replacement of radiators etc., which effectively bring an investment up to a point where the simple payback or ROI is unattractive. Another reason is dwellings with low property values where a major investment in a heating system is hard to justify, both in regard to a possible resale or a bank loan.

In Figure 24, the national or overall energy use for space heating is broken down, and the figure shows the different types of heating systems in Danish households. District heating is clearly the most common type (61 %) followed by gas (or oil) furnaces. Heat pumps, as a primary heat source, are not yet that common and accounted for 40-45,000[18] registered units in 2014. The before mentioned number seems a bit low, especially when considering the sales figures from a Danish heat pump trade organization[19], which indicate around 5-6000 new air/water and brine/water installations per year. (Note: A sudden drop of heating systems in 2005 is related to a statistical redefinition of households).

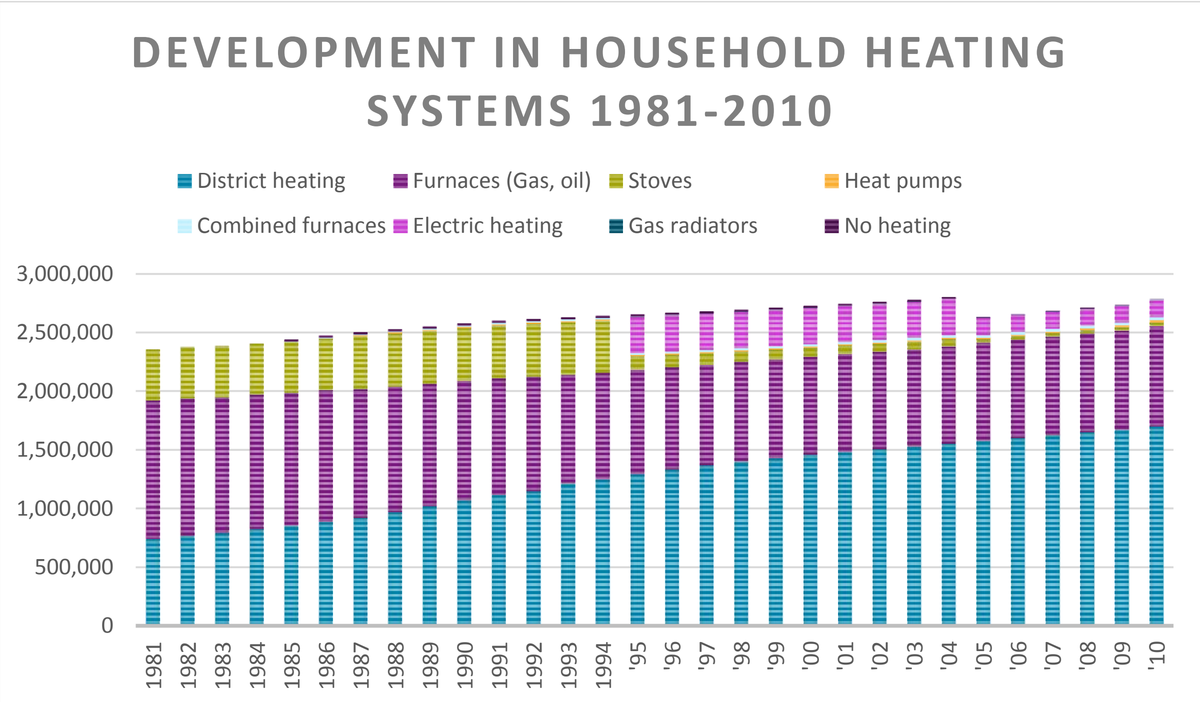

Figure 24 Development in household heating systems 1981-2010. Source(s) Statistics Denmark, "varmeinstallationer" [heating installations]

---

[17] COWI for the Danish Energy Agency, Stock of heat pumps for heating in all-year residences in Denmark, 2011.
[18] Not including air/air, exhaust air/air, or sanitary hot water heat pumps. For a more detailed breakdown see section 4.1 Installed Heat Pump Capacity p. 34
[19] VPF – VarmePumpeFabrikantforeningen. A Danish heat pump trade organization.

3.3. Trends in the Heating Market

In the past few years, energy efficiency has been an area of priority both politically and for private homeowners. As previously described, various political measures have been implemented, e.g. the phase out of oil boilers and tax reductions on electricity for heating purposes.

On the positive side, district heating networks are rapidly expanding in and around most major cities supplying a larger and larger share of multi-dwelling houses as well as detached dwellings.

On the other side, gas boilers are sold and installed at a low price compared to heat pump solutions. The summarized findings of a simplified, but realistic, economic assessment comparing gas boilers and heat pumps is found in Table 3. The table shows that heat pumps are not economically feasible compared to gas boilers. This is due to the initial installation costs of a heat pump, which are up to 400 % more compared to a gas boiler. The assessment does not consider possible necessary preliminary investments such as thermal insulation or the like.

		Gas boiler	Brine/water heat pump	Air/water heat pump	Hybrid heat pump
Net heating demand, installation cost etc.	[kWh/yr]	16800	16800	16800	16800
Purchase and installation	[DKK]	37000	131000	103000	80000
- of which salary	[DKK]	20350	39300	15450	25000
Tax discount	[DKK]	6700	10000	5100	8300
Energy subsidy (0,25 kr/kWh)	[DKK]	0	2800	2700	1800
total installed cost	[DKK]	30300	118200	95200	69900
Depriciation	[DKK/yr]	1377	5910	4760	3495
Interest (loan)	[%]	3,5	3,5	3,5	3,5
Gross interest	[DKK/yr]	611	2667	2097	1423
Net interest	[DKK/yr]	410	1787	1405	954
Energy cost	[DKK/yr]	13341	8553	9408	5326
Service cost	[DKK/yr]	2200	1900	1400	2200
Total annual cost	[DKK/yr]	17328	18150	16973	16813
Index	[-]	1,00	1,05	0,98	0,97

Table 3 Simplified assessment of the average annual cost of different types of heating systems. Please note: Not all intermediate calculations are shown.

Expectedly, according to Statbank Denmark, there are around 400,000 gas boilers installed in Danish dwellings providing heat to more than 850,000 households, and the number is growing. Figure 25 shows the annual average changes of heating supply sources across all types of dwellings as an average for/over the last 4 years. The tendency is the same across all the dwelling sectors (detached houses/farmhouses, linked or semi-detached houses, multi-dwelling houses, student hostels, residential buildings for communities, occupied weekend cabins, and other) namely, that oil boilers are being phased out along with electric heaters and primarily replaced by district heating, heat pumps and gas boilers. (Note: the accumulated number of heating systems being phased in are greater than the number of systems being phased out due to a gross growth in the number of total dwellings)

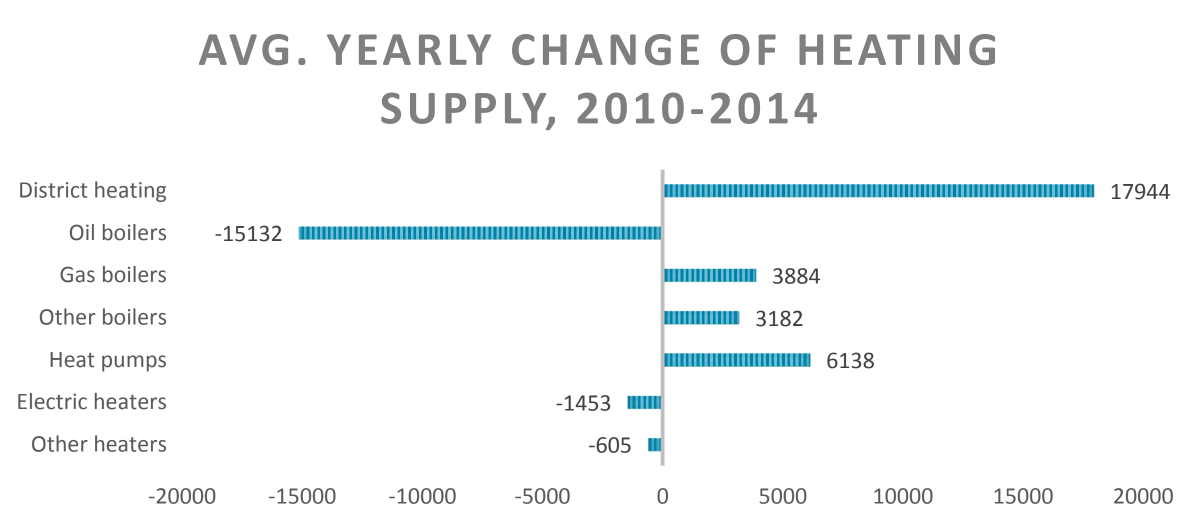

Figure 25 Recent trends in the replacement and installations of heating systems. Source(s): Statistics Denmark

As a summary; it is the low cost of gas boilers and the massive expansion of district heating networks that makes it difficult for electric heat pumps to accelerate, penetrate and compete on the heating market. The replacement with new heat pump installations are nowhere near the needed capacity in order to reach the 2012 Energy Agreement goal of a dwelling sector being heated by fossil free sources by 2035. Moreover, considering the fact that the service life of a gas boiler could very well extend past that deadline.

A new trend, which might mitigate the difficulties of reaching the fossil free goal, is the market introduction of hybrid heat pumps. A few of the major heat pump manufacturers operating on the Danish market have introduced products in 2014 that can be retrofitted to existing gas boilers potentially reducing the demand for natural gas. It is, however, too early to conclude on the possible adaptation on the market.

Another positive trend is the increased sales figures for air/air heat pumps that in effect will replace fossil fuels to some degree or make electric heating more efficient compared to electric heaters alone. For detailed sales figures, see section 4.2.

3.4. Customer Preferences

In a typical Danish home, the preferred and recommended temperature is 20°C. Some people prefer it warmer with an indoor temperature of 22-23°C. It is very rare for people to adjust radiator thermostats, when they leave their homes for a shorter period of time (work or leisure activities), although some people do manually lower the room temperature 2-3 K during night time or when they are away on holiday. Most heating systems are equipped with automatic weather compensation, which adjusts the heating supply temperature. Some systems are also equipped with night time thermostat setback.

Figure 26 illustrates the temperatures measured in an average house with both radiators and floor heating during the heating season. Note the very stable indoor temperature. A stable indoor temperature is the preferred level of comfort for most people, which is well suited for heating by heat pumps.

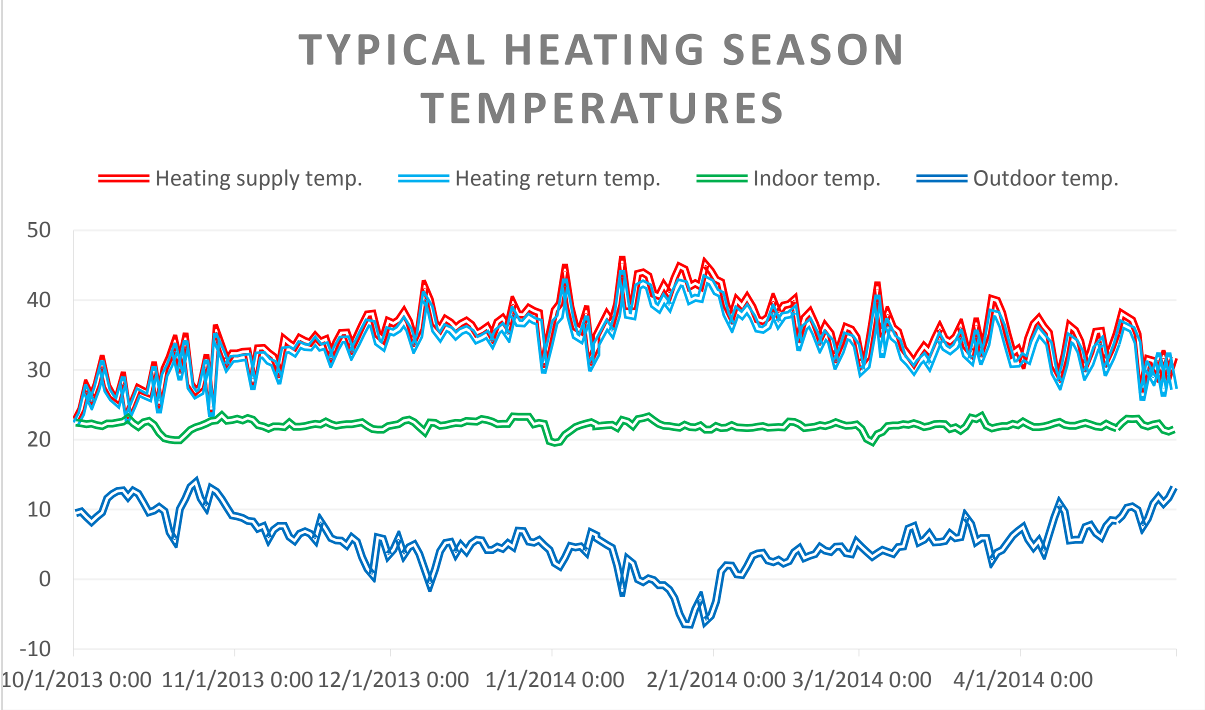

Figure 26 Typical temperatures during a heating season in Denmark. Source(s): DTI measurements

DANISH TECHNOLOGICAL INSTITUTE

4. Analysis of the Danish domestic heat pump market

4.1. Installed Heat Pump Capacity

Officially, information about buildings, their use and technical equipment is supposed to be reported and stored in an official database named BBR (Bygnings- og Boligregistret). However, this database does not contain information on which type of heat pump is installed in a given building, and it could contain incorrectly registered data as heat pumps are prone to be classified as "electric heating" in the sense of electric heaters. Therefore, the best foundation to estimate the heat pump capacity is EHPA sales figures from 2007 to present date. The summarized sales figures are shown in Figure 28, and they represent the best estimate of the installed heat pumps in Denmark as of 2013.

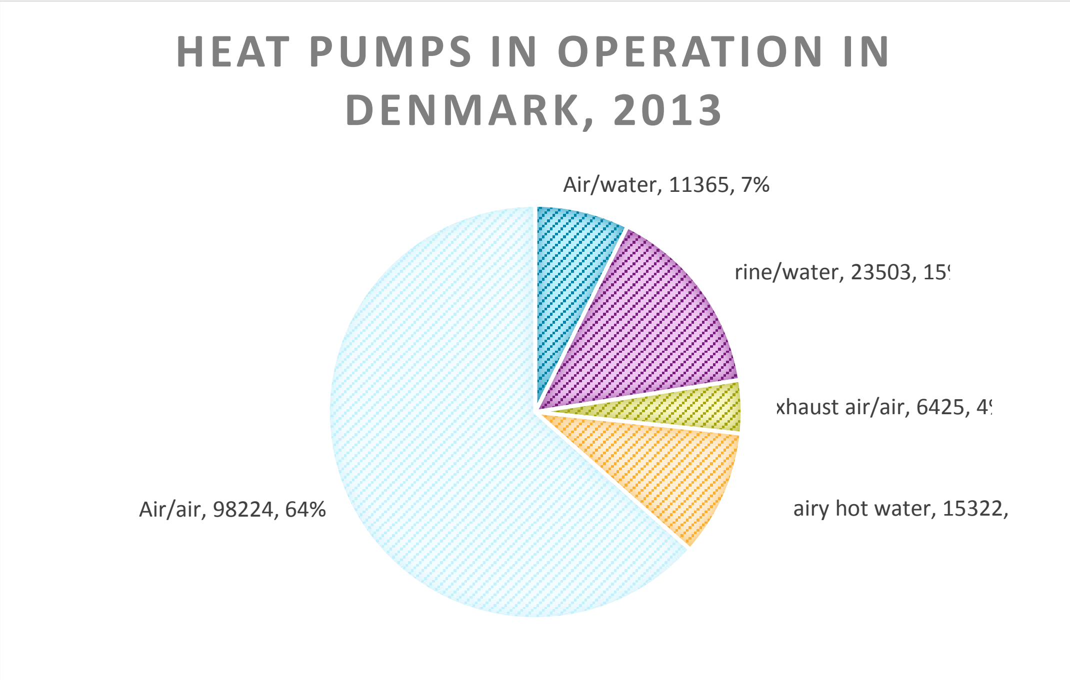

Figure 27 Estimate of the number of heat pumps in operation in Denmark 2013. Source(s): EHPA

By using figures for the average heating capacity and SPF of the different heat pump types and combining them with the estimated numbers of installed heat pumps in Denmark, it is possible to "guesstimate" the installed heat pump heating capacity and corresponding electric demand during a cold spell as seen in Table 4. Thereby, the guesstimated heat pump heating capacity equals 811 MW_{th} requiring 268 MW_{el} electricity.

Heat pump type	Units	Avg. heating capacity [kW]	Summed heating capacity [MW_{th}]	SPF	Summed electric demand [MW_{el}]
Air/water	11365	14	159	2,5	64
Brine/water	23503	14	329	3	110
Exhaust air/air	6425	2	13	4,5	3
Sanitairy hot water	15322	1	15	2	8
Air/air	98224	3	295	3,5	84
Total	154839	-	811	-	268

Table 4 "Guesstimated" heat pump heating capacity and electric demand during a cold spell.

4.2. Trends in the Heat Pump Market

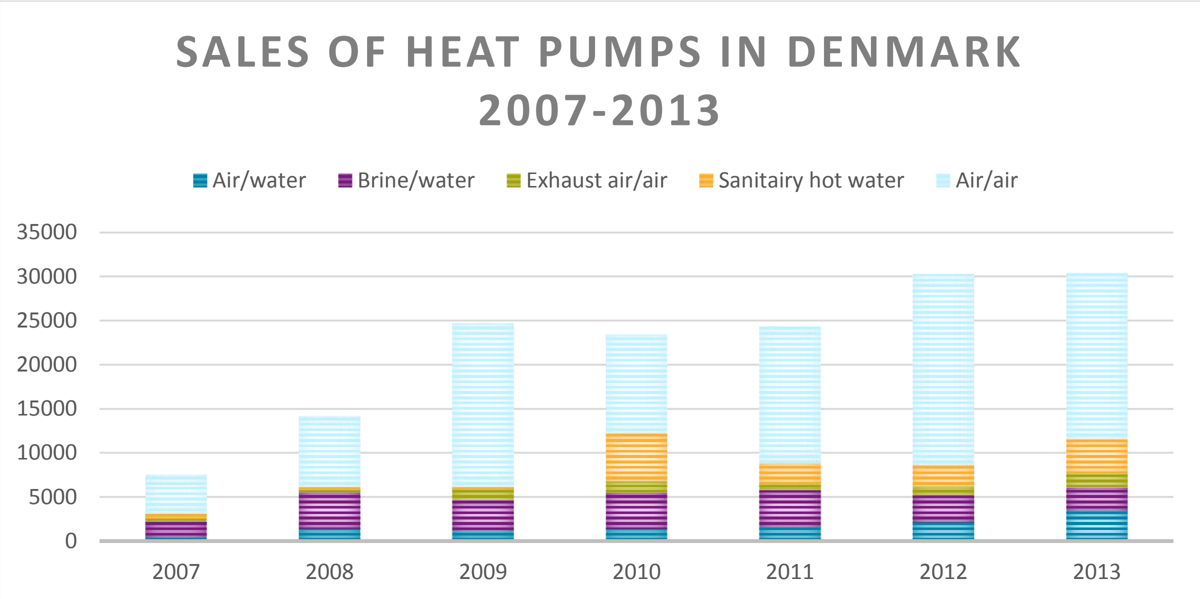

Figure 28 Sales of heat pumps in Denmark, 2007-2013. Source(s): EHPA

Sales of heat pumps for hydronic heating systems (air/water and brine/water) have remained somewhat stable with 5-6000 units sold every year since 2008. An interesting trend is that the ratio between air/water and brine/water heat pumps has changed from mainly being brine/water heat pumps towards air/water heat pumps, i.e. more than half of the heat pumps sold for hydronic systems are air/water.

Air/air heat pumps seems to have an increased sale and market share since 2012. Air/air heat pumps have a market share of 62 % of sold heat pumps, and they is therefore the most sold heat pump type.

The sales of exhaust air to air heat pumps increased suddenly with 428 % from 2011-2012. Sales numbers vary greatly for this product type during the years, but a possible explanation to this rapid growth could be found in the update of the building regulation (BR10), which required new buildings to implement heat recovery in the ventilation systems. Since heat recovery is a requirement in new buildings, this segment is going to grow.

The market is increasing, but not as expected. The government is supporting the sales of heat pumps through different incentive schemes, but the private households are still not investing according to the planned 2012 Energy Agreement.

4.3. Market Drivers

Legislation and building regulation

The ~ 180,000 Danish homeowners that own oil boilers and live in areas with either district heating or gas networks are practically forced to find a new alternative when their oil boiler is due to be replaced. By 2016, these homeowners are no longer permitted to install oil boilers. They can choose between a heat pump, a gas boiler, connecting to a district heating network or another non-fossil alternative. The heat market is perfectly set up to increase the sales of heat pumps, but the homeowners will probably make the economically rational decision.

Since 2013, oil- and gas boilers have been banned in new buildings.

The Danish Energy Agency heat pump positive list

In reaction to a lot of bad press about heat pumps performing poorly or failing market surveillance checks, the Danish Energy Agency has initiated a heat pump positive list with admission requirements that should eliminate all future media scandals. Currently, the list is one of the most visited government owned sites.

National industry associations

The Danish heat pump manufacturers' association (Varmepumpefabrikantforeningen or VPF) represents 30 members, which are either manufacturers or main-distributers. Approximately 140 heat pump installation companies are member of and certified according to the Danish quality scheme for heat pump installers (Varmepumpeordningen or VPO)

Training and certification

Training according to the Danish quality scheme for heat pump installers (Varmepumpeordningen or VPO) is offered by VPO. VPO was established in 1994 and it has been developed since then. During the years, 299 people have participated in the course and passed the final examination.

Incentive schemes

Residential consumers are now, as of 1 January 2013, benefitting from an electricity taxation reduction on their consumption above 4000 kWh/yr., if their property is registered as being electrically heated, e.g. by a heat pump. The reduction is approx. DKK 0.52/kWh (€ 0.07/kWh) or 20-25 % of the total electricity price.

Subsidies for energy renovations, e.g. replacing an oil boiler with a heat pump, yields a subsidy of approx. DKK 0.25 (€ 0.03) pr. kWh saved during the first year after implementing the renovation. Heat pumps need to meet the following minimum criteria in order to be eligible for a subsidy:

Air-to-air	SCOP ≥ 3.8
Air-to-water & liquid-to-water	SCOP ≥ 3.5 (low temperature application)

An incentive scheme, which started in 2011 for tax reductions applying to renovation and extension works in private households, has now been extended twice, and it is expected to continue in 2015 as well. This incentive scheme can, for example, cover parts of the salary related to the installation of a heat pump.

4.4. Market Barriers

Extensive expansion of district heating networks

District heating networks have by far the largest share on the heating market supplying more than 61 % (2010) of all households with heating. By 2020, 70 % of all households are potentially connected to district heating. However, district heating companies are increasingly making use of or implementing large-scale heat pumps and electric boilers in their heat production in order to profit from low spot prices on electricity. In 2014, the installed capacity of electric boilers is 300 MW.

Low or no potential savings compared to gas condensing boilers

With an electricity cost of 0.23 €/kWh and a gas cost of 0,089 €/kWh, the seasonal performance factor of a heat pump needs to be 0.23/0.089 = 2.6 before the energy costs alone equals out. This does not leave much economical room for an heat pump installation that is 400 % more expensive to install, and more expensive to service, compared to a gas boiler.

High start-up cost

Even when a heat pump is shown to reduce the energy costs for a homeowner, the customer value proposition is negatively affected by the high upfront cost of a heat pump. The average installed brine/water heat pump costs € 17,580, the air water heat pump € 13,825, while the gas condensing boiler costs € 4,900.

Heat pump reputation and perception of heat pumps

A couple of market surveillance checks performed by the Danish Energy Agency in 2010 and again in 2011 showed that 10 out of 10 checked air/air heat pumps failed miserably on their energy labelling. Heat pumps sold as energy class “A” were in fact energy class “C”. That coupled with an unusual cold winter of 2010/2011 which increased the electricity bills to heat pump owners resulted in a lot of bad press affecting the general perception of heat pumps.

Overwhelming, confusing, and extensive purchase process

Admittedly, heat pump technology can be complex and overwhelming to grasp with different heat pump types, each with their different pros and cons. Traditionally, customers tend to obtain 2-3 offers from different heat pump installers. If the offers differ with regard to the necessary heat output, length of the ground source or preliminary replacements of radiators to larger ones (to accommodate a lower heating supply temperature), the confusion is total. Adding to this the obtaining of the required permissions and subsidy applications as well as obtaining capital – this is enough to scare off all but the most persistent homeowners.