ANNEX 47

HEAT PUMPS IN DISTRICT HEATING AND COOLING SYSTEMS

IEA Heat Pumping Technologies Annex 47

Heat Pumps in District Heating and Cooling Systems

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1) Executive summary

In the global warming context and following the Paris agreement, United Kingdom has to reduce its CO_2 emissions. Since 1990, UK carbon dioxide emissions have decreased by 39% (from 596 to 364Mt/year). However, the temperature-adjusted[1] emissions from the building sector which account for 19% of total emissions had risen by 1% from 2015 to 2017. This shows the need to use a new form of heating which is more environmentally friendly and more efficient. The Committee on Climate Change examined pathways to decarbonise heat within buildings by 2050. Their report clearly states that by 2050, heat will have to be delivered in non-hydrocarbon forms. A good solution provided by CCC is the use of heat pumps and district heating.

This is particularly challenging for UK because the main part of heating and cooling demand (accounting for 44% of total energy demand) is mainly fulfilled by gas (65% in 2015). Nevertheless, the energy trend leads to reduce the gas demand and to decarbonise the electricity generation. Indeed, 2017 gas demand was down by more than a fifth compared with 2000 and the renewable part of electricity generation had risen from 6.9% in 2010 to 33.3% in 2018. Therefore, heat pumps represent the opportunity to decarbonise the heat (as the electricity tends to be decarbonised).

By accommodating a wide range of heat sources, district heating can reduce fuel costs and help cut CO_2 emissions (by using low carbon heat sources and waste heat). Currently most of district heating are high temperature networks with gas as a heat source, which has several negative points. Firstly, using gas as heat source doesn't help to decarbonise. Secondly, high temperature networks suffer from heat losses and lose lots of energy in residential building. Indeed, a significant amount of heat is lost during the heat path along the long pipes (A study published by BRE for the National Calculation Methodologies for Energy Rating of Dwellings (SAP) found that the distribution heat losses in DH were between 23 and 66%.), this is due to the large difference between the network temperature (typically 70-80°C) and the residential building temperature. Moreover, higher the temperature network, higher the heat loss and thus less efficient is the network. The only way to reduce this loss is to use low temperature networks (even an ambient temperature network can be achieved). Besides, Low temperature heat networks enable waste heat to be distributed to a wide range of end users. Using energy from the environment and waste heat (from air, river or ground sources to industrial sources) is a good opportunity to decrease the use of high carbon heat sources and to decarbonise heat supply. Through their ability to extract and upgrade the heat available from waste or environment, heat pumps can play a key role in these networks. Therefore, next generation district heating should implement heat pumps to apply low temperature networks and efficiently use energy from the environment and waste heat.

Several studies have been made on the utilisation of heat pump in DH. They showed that the utilisation of heat pumps leads to the CO_2 emissions reduction. Especially when heat pumps take the heat from the environment (from the ground, river, …) and provide energy to a low temperature network. From the economic point of view, heat pumps are often linked to a higher capital cost compared to

[1] It's important to compare emissions to temperature as energy consumptions vary as a function of the temperature. If the annual temperatures are higher, the energy consumption are lower.

traditional systems. Nevertheless, the operation cost is often lower and incentives (as Renewable Heat Incentive, …) can have a significant impact on the costs. Therefore, heat pump is economically viable and competitive.

Currently, district heating only provides 3% of heating and cooling demand in UK but this proportion is supposed to rise. Heat Roadmap Europe is a project that studied the heat market in Europe. They made a projection which gives a redesigned heating and cooling system, considering different types of energy schemes in order to decarbonise UK heat market in 2050. Several keys information came out of this scenario:

- District heating should be expanded to cover around 35% of the heating market in the United Kingdom in 2050. The district heating sector is designed so that it uses no fossil fuels directly, in order to fully decarbonise the sector. Not using the excess heat sources from industry and cogeneration ignores the potential to recover energy already used in industry and power generation, limiting the overall efficiency of the system and possibility of coupling the electricity and heating sector. The main sources for heat are large scale heat pumps and cogeneration (supplying around 28% and 37%, respectively), with large shares for excess heat from various industrial activities. Geothermal and large scale solar thermal are also used, with (biomass) heat only boilers producing less than 2% of the district heating supply.
- Heat pumps provide almost all the remaining heating demand in the United Kingdom, covering almost 56% of the heating sector.
- Energy-related emissions are reduced by 90% compared to 1990 levels.
- Their scenario achieves a deeper level of decarbonisation and a higher efficiency at a reduced cost, compared to a conventionally decarbonised scenario.

Thermal energy storage (TES), is also supposed to play a key role in the future because it provides a way to shift heat production away from peak demand times and higher cost periods, leading to reduced peak loading, lower heating costs and less mechanical wear on equipment. Department of Business, Energy and Industrial strategy made a scenario about the future market development of TES. This scenario assumes a more positive outlook for TES in the UK based on strong drivers from the decarbonisation of heat, primarily through its electrification and favourable frameworks for providing flexibility to the network. In the residential and small commercial sector sales of hot water cylinders would increase and new TES products would emerge. Additionally inter-seasonal TES would receive a stronger push with trial projects looking to exploit the potentials for solar thermal integration as efforts to decarbonise heat further develop.

2) Introduction

Since 20th century, the phenomenon of global warming has been discovered. Warming of the climate system can't be denied, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.

In 1988, the UN founded the Intergovernmental Panel on Climate Change (IPCC) to synthesize scientific studies on climate. In its fourth report, in which more than 2,500 scientists from 130 countries participated, the IPCC stated that global warming since 1950 is "very likely" due to the increase in anthropogenic origin greenhouse gases emissions. [1]

Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century. [2]

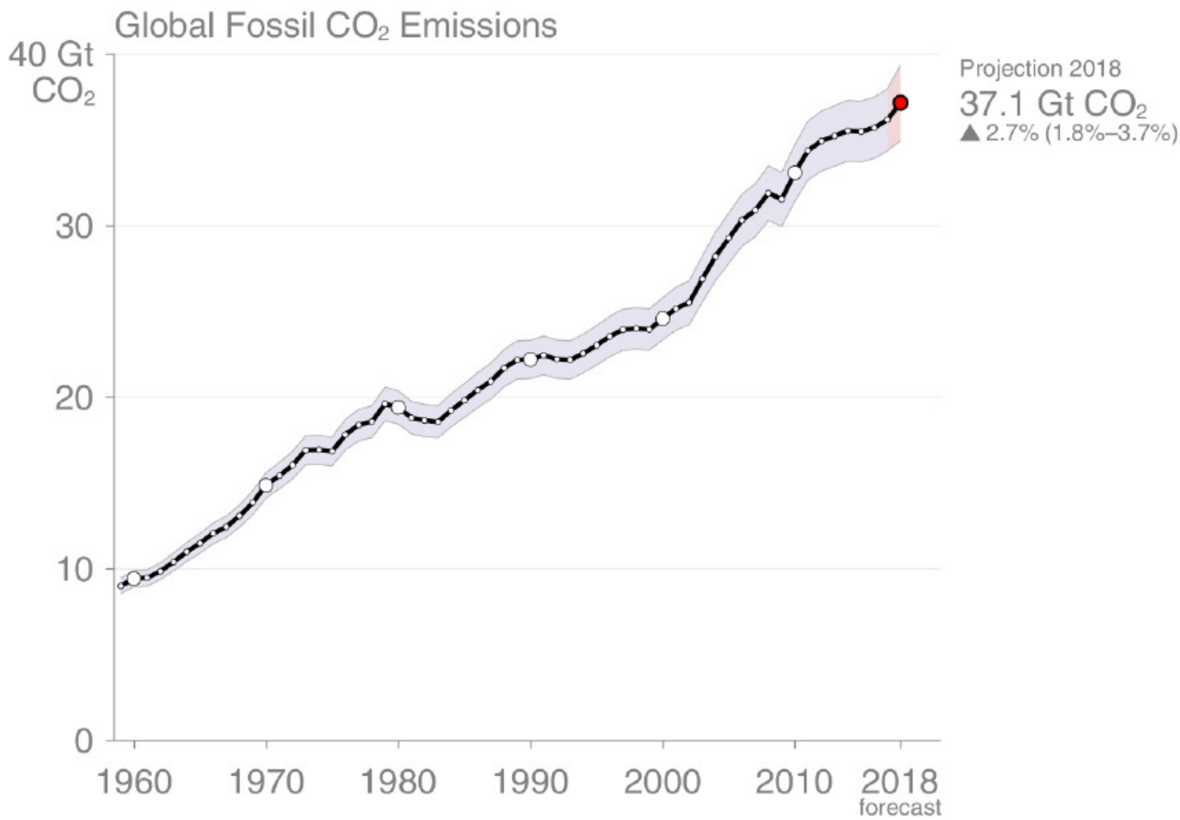


Figure 1: Global CO_2 emissions [3]

To counter this threat, The Kyoto Protocol which commits United Nations Framework Convention on Climate Change (UNFCCC) to reduce greenhouse gas emissions was adopted in 1997. The Protocol's first commitment period started in 2008 and ended in 2012. A second commitment period was agreed in 2012, known as the Doha Amendment. Negotiations were held in the framework of the yearly UNFCCC Climate Change Conferences on measures to be taken after the second commitment period ends in 2020. This resulted in the 2015 adoption of the Paris Agreement, which is a separate instrument under the UNFCCC rather than an amendment of the Kyoto Protocol [4]. As of March 2019, 195 UNFCCC members have signed the Paris agreement, and 185 have become party to it. The aim is to hold the increase in the global average temperature to well below 2°C above pre-industrial levels. [5]

To respect this agreement, UK needs to reduce its carbon emissions. A significant part of greenhouse gases emissions comes from the heating sector. Therefore, there is the need to find new heating methods that don't emit CO_2. In this context, heat pumps in district heating have been considered as a possibility to fulfil this goal. The aim of this report is to synthesis the current situation of this solution as well as its benefits and its potential in the UK heat market.

The report is structures as follows. Chapter 3 provides an overview of the current and future energy demand and supply situation in UK and a detailed description of the heat demand in the UK building stock. In chapter 4, the potential for district heating and heat pumps is discussed and explained. Finally, chapter 5 gives the current and potential market for thermal energy storage.

3) The energy situation at the moment and for the future

3.1.Overview of the main challenges in the country

3.1.1. Conventional heaters and solutions

The main source of CO_2 emissions from the residential sectors is the use of natural gas for heating and cooking. Indeed, gas boiler in a central heating is the most common form of heating in UK. This system is composed of a single boiler heating up water that is pumped through pipes to radiators throughout the house as well as providing hot water to the kitchen and bathroom taps.

Following the Paris agreement, UK needs to reduce its carbon emissions. Therefore, there is the need to use a new form of heating which is more environmentally friendly and more efficient. A CCC (Committee on Climate Change) report examined pathways to decarbonise heat used within buildings by 2050. The report clearly states that by 2050, heat will have to be delivered in non-hydrocarbon forms. It recommends that gas boiler installations should end by 2035 to avoid the need for scrappage schemes. It highlights electricity (e.g. heat pumps) and low carbon district heating for dense areas (which could include heat pumps) as alternatives. [6] [7]

3.1.1.1. District heating definition

District heating or heat networks are a distribution system of insulated pipes that take heat from a central source and deliver it to a variety of different customers that can include public sector buildings, shops and offices, sport facilities, universities and homes (it may also provide cooling). Heat network pipe infrastructure is technology- and fuel-agnostic and can accommodate a wide range of heat sources. Networks can utilise single or multiple sources of heat, controlled through 'energy centre(s)', which can include conventional boilers or Combined Heat and Power plants (CHP or cogeneration), but can and do also include large sources of low-carbon heat such as heat pumps, energy from waste, deep geothermal and industrial waste heat and a wide range of water sources and urban recovered heat. [8]

Therefore, by its flexibility, DH can reduce fuel costs for occupants and building operators and help cut carbon dioxide emissions.

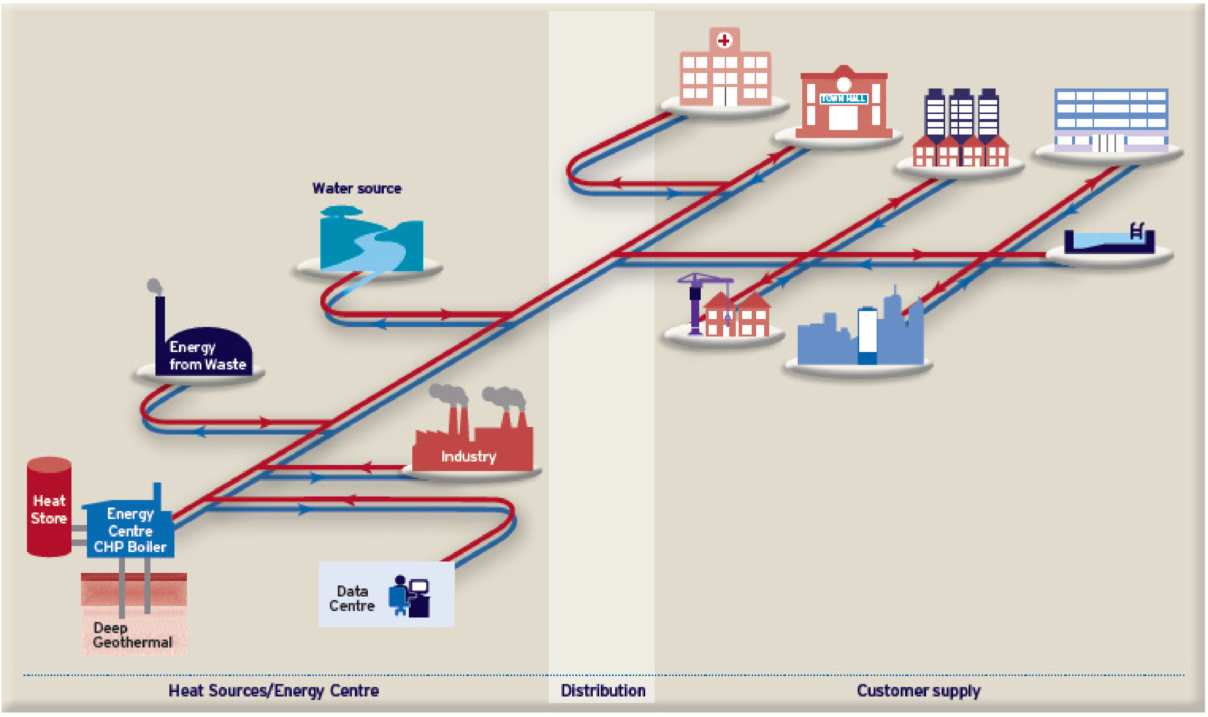


Figure 2: District heating diagram [8]

3.1.2. CO_2 emissions

3.1.2.1. In UK

In March 2019, Department for Business, Energy & Industrial Strategy (BEIS) released a report on the evolution of UK Greenhouse gas. The following information was taken from this report [9] and from the data published [10].

Since 1990, UK carbon dioxide emissions have decreased by 39% (Figure 3). This decrease has resulted mainly from changes in the mix of fuels being used for electricity generation, with a shift away from coal and growth in the use of renewable energy sources. This was combined with lower electricity demand, owing to greater efficiency resulting from improvements in technology and a decline in the relative importance of energy intensive industries.

In 2018, an estimated 33% of carbon dioxide (CO_2) emissions were from the transport sector, 27% from energy supply, 18% from business and 18% from the residential sector. Between 2017 and 2018, provisional estimates indicate that carbon dioxide emissions decreased by 2.4% (9.1 million tonnes (Mt)).

Carbon dioxide emissions in the energy supply sector decreased by 7.2% (7.7 Mt), between 2017 and 2018 driven by a change in the fuel mix for electricity generation. There was also a fall of 2.6% (3.2 Mt) in transport carbon dioxide emissions. Changes in transport emissions are usually as a result of traffic volumes or improvements in fuel efficiency.

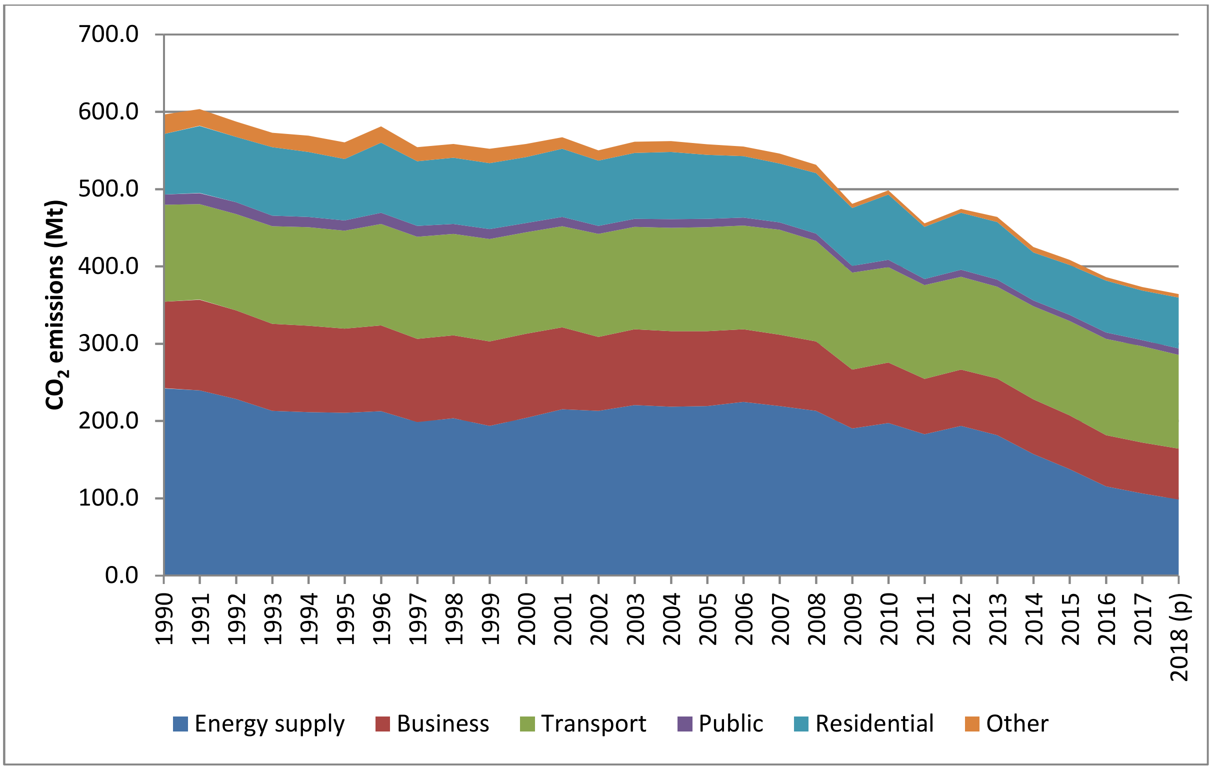


Figure 3: CO_2 emissions by years and sectors (made from data [10])

3.1.2.2. In Buildings

Direct greenhouse gas (GHG) emissions from buildings were 85 $MtCO_2e$ in 2017, accounting for 19% of UK GHG emissions (Figure 4) [7]:

- Direct building CO_2 emissions were 83 $MtCO_2$ in 2017, split between homes (77%), commercial buildings (14%) and public buildings (10%).
- Buildings are responsible for 66% of UK electricity consumption, equivalent to a further 48 $MtCO_2e$ of indirect emissions. These emissions are falling due to both reductions in demand and the decarbonisation of electricity supply.
- Around 2 $MtCO_2e$ of non-CO_2 emissions (methane and nitrous oxide) were associated with buildings in 2017.

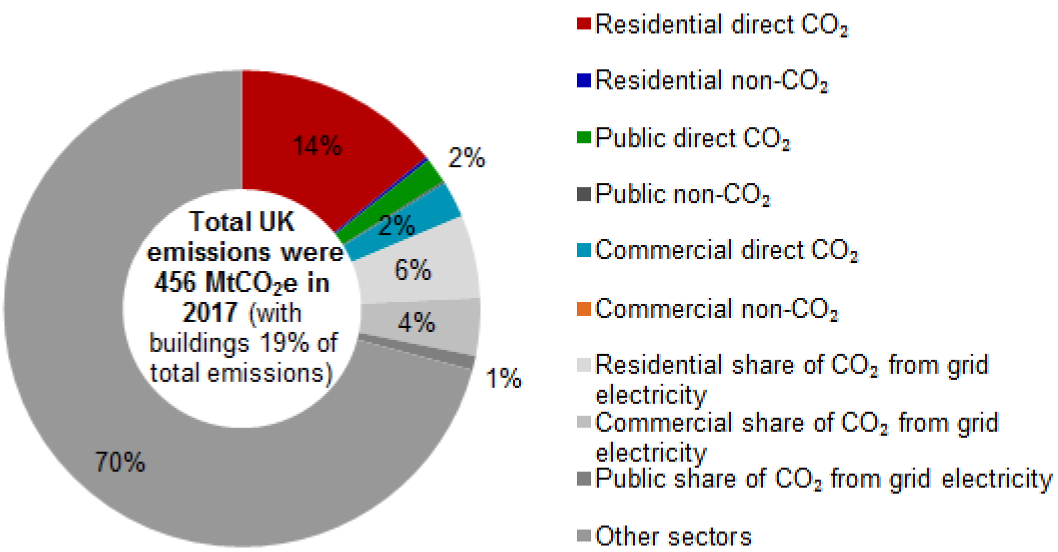


Figure 4: Buildings emissions as a share of UK total (2017) [7]

Direct CO_2 emissions from buildings fell to 83 $MtCO_2$ in 2017. This was entirely due to higher winter temperatures: adjusting for this, annual emissions rose by around 1%. This is the second successive year that temperature-adjusted emissions have risen. The report notes that [6] [7]:

- The rates of installing insulation have stalled (down over 90% from 2012)
- New buildings with high-carbon heating systems are still being built
- The deployment of heat pumps and low-carbon heat networks is below what is required for meeting future carbon budgets.

The Committee on Climate Change suggests measures to deliver carbon reductions in the building sector [6] [7]. These include:

- Energy efficiency improvements to existing buildings, including insulation of all practicable lofts by 2022 and cavity walls by 2030, and 2 million solid walls by 2030
- Stronger new build standards for energy efficiency and low-carbon heat
- Low carbon heat, including 2.5 million heat pumps in homes by 2030, around 40 TWh of low carbon heat networks by 2030 and around 20 TWh of biomethane to the gas grid by 2030.

3.2. Energy demand in the country

In July 2018, BEIS released a report on the UK energy. The following data was taken from this report [11] and from the data provided [12].

In 2017, the inland primary energy consumption is composed of 39% gas, 36% Oil, 5% Coal, 12% primary electricity and of 8% bioenergy.

In the last 30 years or so, the inland energy consumption has decreased from 213.6 (in 1990) to 192.1 million tonnes of oil equivalent (in 2017). The consumption of natural gas and primary electricity has risen considerably, whilst consumption of oil and coal have fallen. However, over the past decade or so, consumption of bioenergy and waste has also grown (Figure 5).

Primary energy consumption was 1.2% lower in 2017 than in 2016. The average temperature in 2017 was 0.3 degrees Celsius warmer than in 2016, though the summer months of July to September were cooler. On a temperature corrected basis, primary energy consumption was 0.3% lower than in 2016, continuing the general fall seen since 2005 (Table 1).

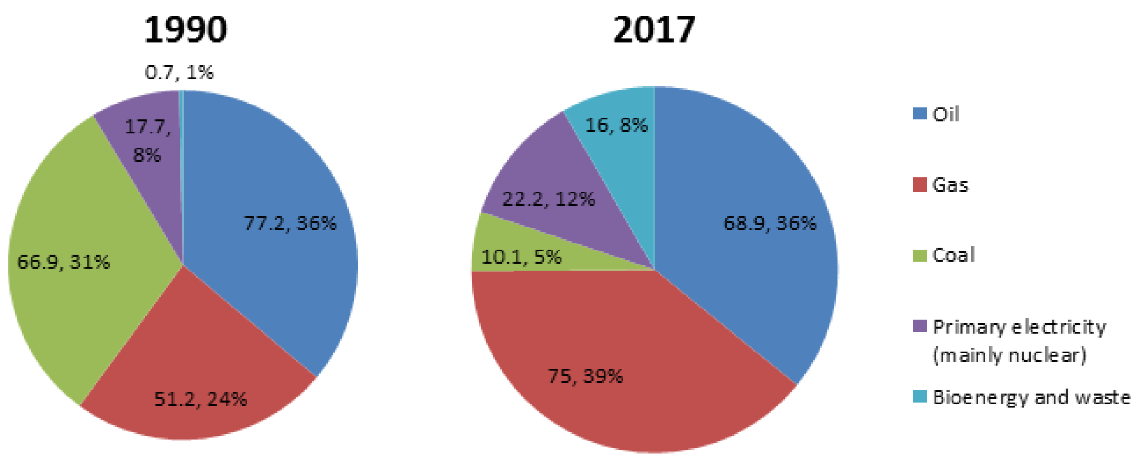


Figure 5: Inland energy consumption in 1990 and 2017 [million tonnes of oil equivalent] [12]

Table 1: Inland primary energy consumption by year [Million tonnes of oil equivalent] [11]

	Million tonnes of oil equivalent				
	1990	2000	2010	2016	2017
Total inland primary energy consumption[1]:	213.6	234.8	219.5	194.5	192.1
Conversion losses:		53.8	50.3	37.4	35.8
Distribution losses	66.4				
and energy industry use:		20.7	18.0	15.0	15.0
Total final energy consumption:	147.3	159.4	150.5	142.2	141.2
Final consumption of which:					
Industry	38.7	35.5	27.0	23.7	24.1
Domestic sector	40.8	46.9	49.4	41.7	40.1
Transport	48.6	55.5	54.6	56.0	56.5
Services[2]	19.2	21.5	19.4	20.8	20.5
Temperature corrected total inland consumption:	221.6	240.2	213.7	195.7	195.2

(1) Excludes non-energy use
(2) Includes agriculture

Figure 6 illustrates the total final energy consumption per sector in 2017. The transport sector accounts for around 40% (of which 97.5% are based on fossil fuels), industry makes up for 17%, households account for around 28% and the service sector for 15%.

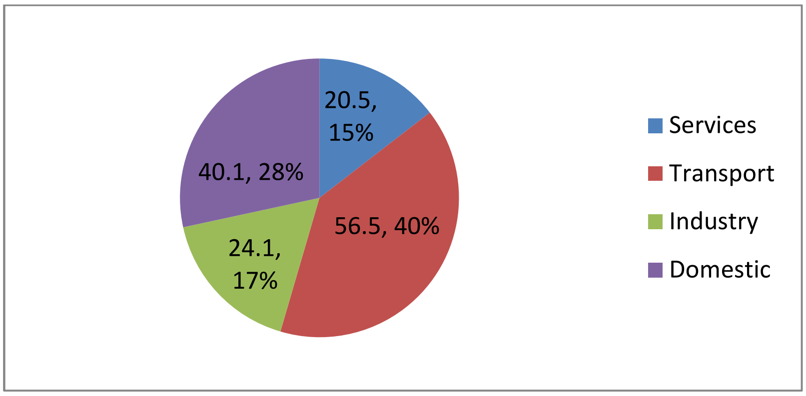


Figure 6: total final energy consumption per sector [Million tonnes of oil equivalent] [12]

Total final energy consumption (excluding non-energy use) was 0.7% lower in 2017 compared to 2016. It fell by 3.7% in the domestic sector, and by 1.4% in the service sector, but rose by 0.9% in the transport sector, and by 1.6% in the industry sector. The falls in the domestic and service sectors were due to reduced demand for heat reflecting the warmer winter period (October to December) in 2017. Overall final energy consumption, when adjusted for temperature, was up by 0.9%, in 2017.

In terms of fuel types, final consumption of gas, the main fuel used for heating, fell by 3%. Oil use rose by 1%, with a 1% increase in fuel used for transport. Electricity consumption fell by 1%, however there was increased use of bioenergy in all sectors except transport.

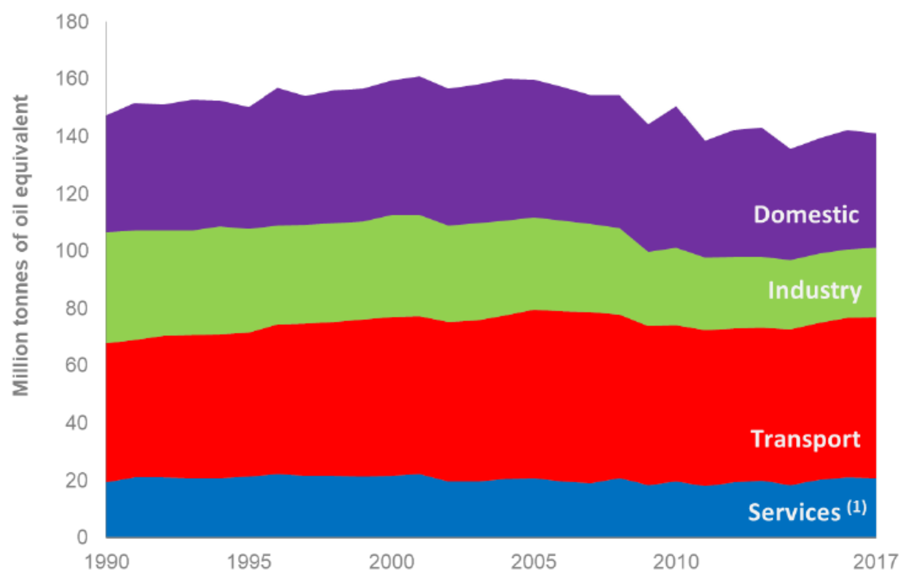


Figure 7: total final energy consumption evolution per sector [Million tonnes of oil equivalent] (1) includes agriculture [11]

3.2.1. Energy demand for Heating and cooling (H&C)

Heat Road Map Europe (HRE) is a project which has received funding from the European Union's Horizon 2020 research and innovation program. The goal of Heat Roadmap Europe 4 (HRE4) is to develop low-carbon heating and cooling strategies, called Heat Roadmaps, by quantifying and implementing changes at the national level for 14 EU Member States, which together account for approximately 85-90% of total heating and cooling in Europe. The following data was taken from few reports from this project which were based on UK datasheet 2016. [13] [14] [15] [16]

Currently, heating and cooling is the largest demand for energy in the United Kingdom, comprising 44% of the UK's final energy demand (see Figure 8). This is slightly lower than most European countries, where the average is around 50%. Of that, more than half of the energy is used for space heating of buildings, with process heating (in industry and the service sector) representing the second largest demand. Process cooling and space cooling, currently amount to less than 2% of the overall UK heating and cooling demand, and as such does not represent a large part of the sector or energy system. However, it is also the sector with the greatest variability looking towards the future. This underwrites the idea that pathways towards a decarbonised energy system need to include an efficient, renewable heating and cooling sector, and that by their sheer scale, primary attention should be primarily given to space heating, which dominates the sector, and process heating, which includes the industry sector.

UK account for 11% of the EU28's final delivered H&C demand. Compared to EU28, UK uses way more gas and less of all the remaining sources (Figure 9).

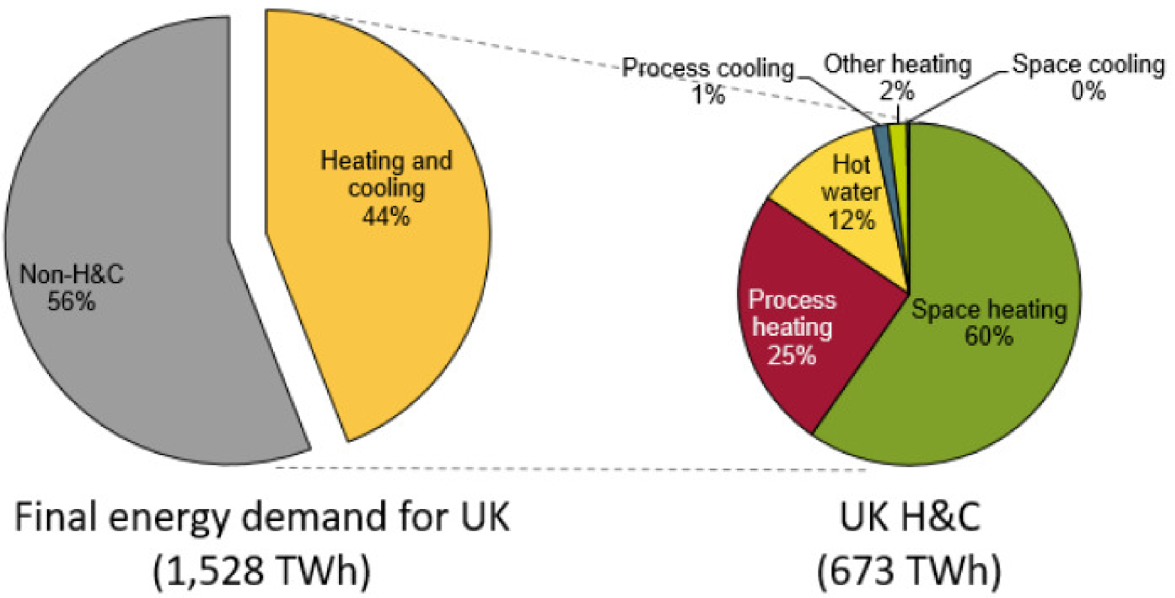


Figure 8: Energy demand for heating and cooling [13]

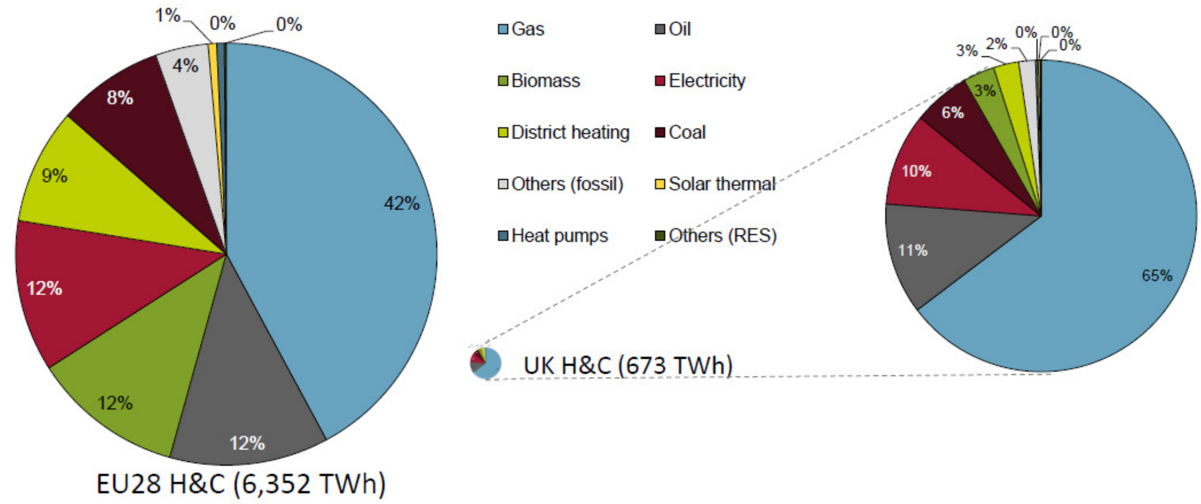


Figure 9: UK U&C energy by energy carriers compared to EU28 [13]

Heating and cooling demand can be divided in 3 sectors; industry, residential and services. As we can see in Figure 10, UK industries are overwhelmingly dominated by process heating, other sectors by space heating. These sectors use mostly gas and oil. Besides, District heating is used in the industry and services sectors. Finally, Households also use some biomass.

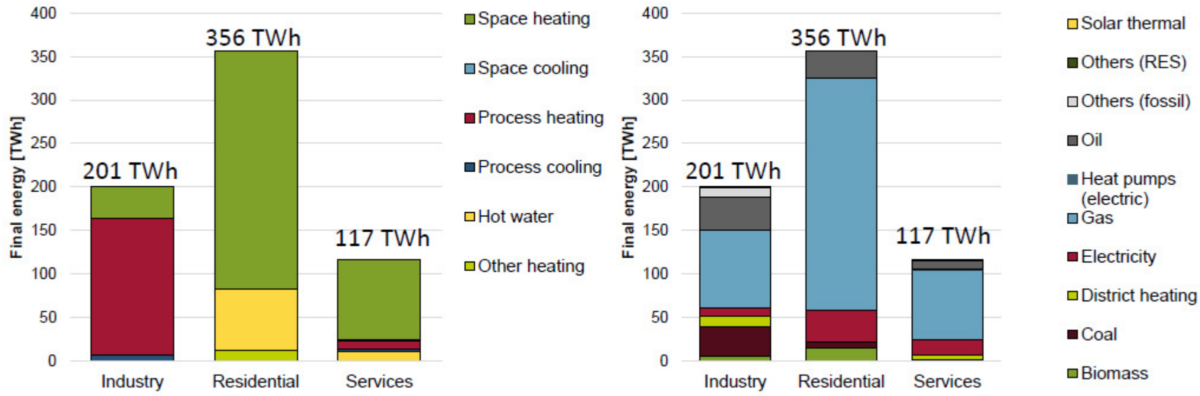


Figure 10: H&C energy demand by sectors [14]

3.2.1.1. H&C energy demand for Industry sector

UK industry is dominated by process heating at very high and medium temperatures (Figure 11). Most of the high temperature heating is used for the metals industry, chemicals and non-metallic minerals. The medium temperature process heating is used mainly in the others industries. To attain the high temperatures, industries relies on fossil fuels, mainly gas but also oil and coal (Figure 12). Industry mostly uses gas and oil for space heating (Figure 13). Nevertheless, District heating is also used for space heating even if it's mostly used for process heating with low temperature (< 100°C).

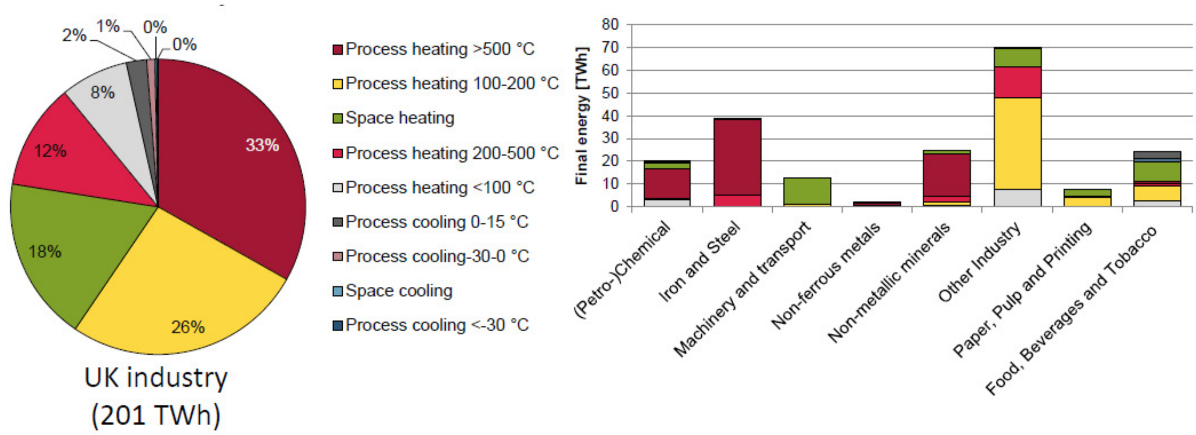


Figure 11: H&C energy demand for Industry sector by utilisation [14]

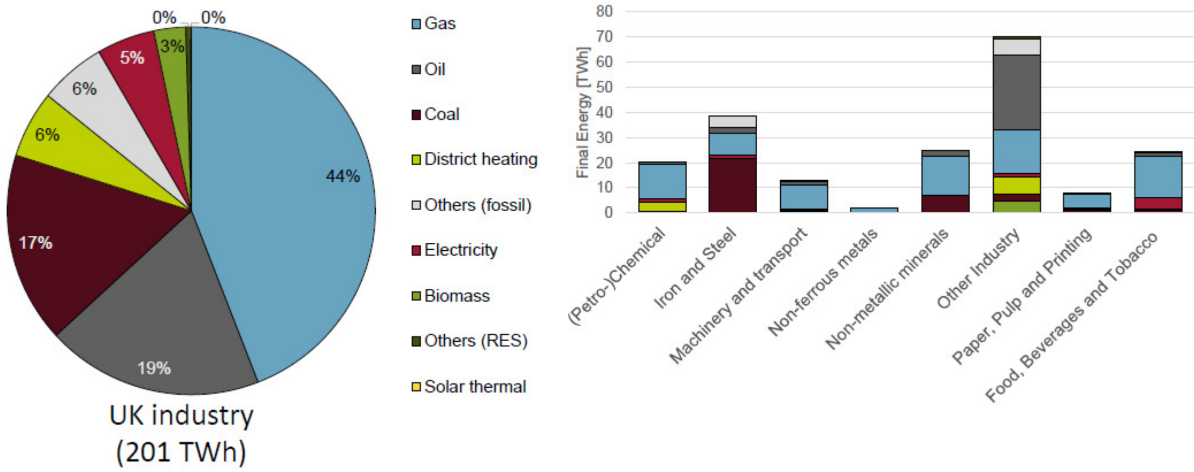


Figure 12: H&C energy demand for Industry sector by carriers [14]

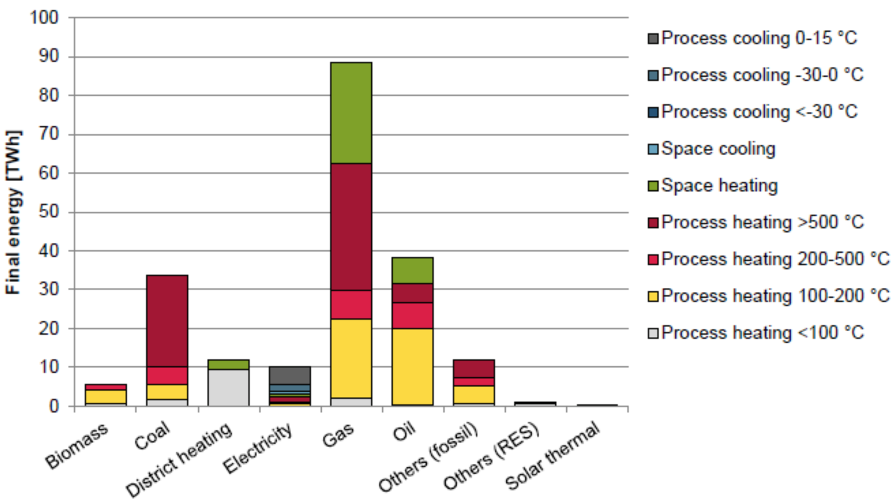


Figure 13: H&C energy demand for Industry sector by utilisation and by utilisation [14]

3.2.1.2. H&C energy demand for residential sector

Figure 14 shows the H&C energy demand for residential sector by carriers and by utilisation (SFH and MFH respectively stand for Single family homes and Multiple family homes), some information comes out:

- The most commonly used way to heat in the residential sector is gas.
- Space heating for single-family homes is the biggest energy demand and is the only market for biomass heating.
- In 2016, District heating is used but in a very small part (less than 1%)

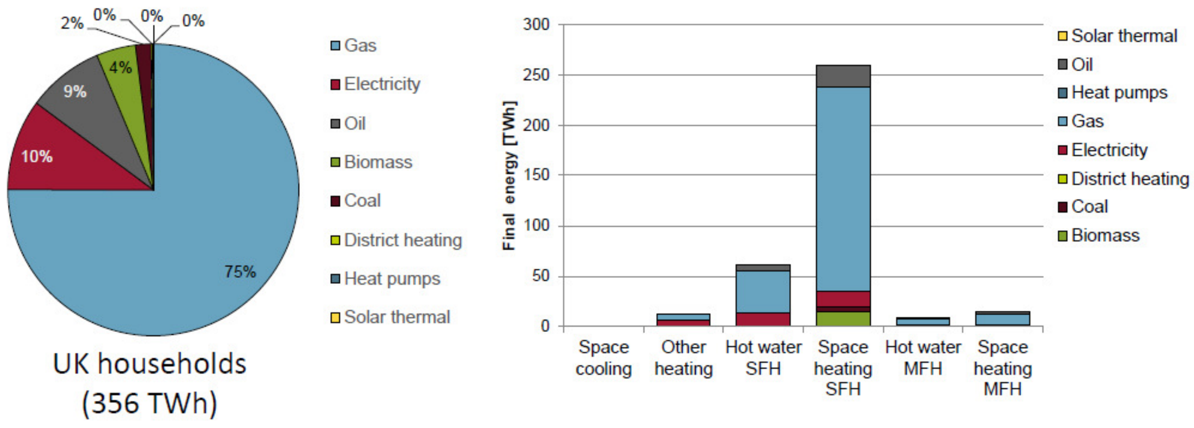


Figure 14: H&C energy demand for residential sector by carriers and by utilisation [14]

Evolution of household's energy carriers from 1970 to 2011

It's interesting to take a look on the evolution of household's energy carriers. This study was made by DECC in 2013. [17]

More and more central heating has been installed in the housing stock over the last four decades, and now most homes have it (Figure 15. The rise has been steady, and within living memory central heating has changed from a relatively rare luxury to being standard almost everywhere. By 2011, only 10% of the housing stock had yet to install a central heating system. (Here, central heating excludes homes with electric storage heaters, which are sometimes counted as "centrally heated".)

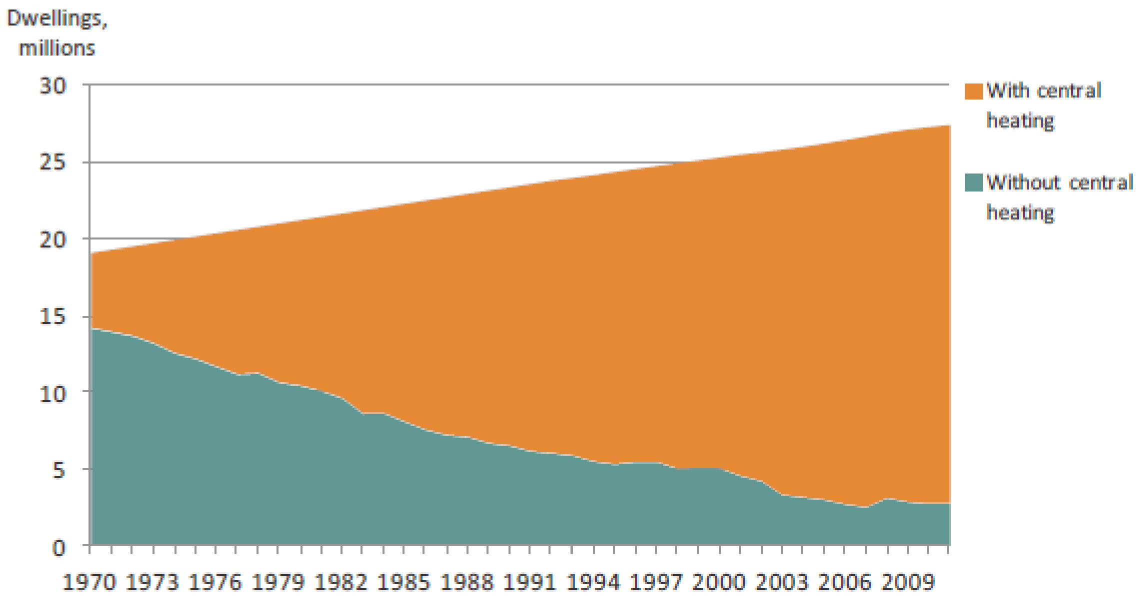


Figure 15: Evolution of household heating type from 1970 to 2011 [17]

The last four decades have seen significant changes in the fuels used to heat homes in the UK. Solid fuel, electricity and oil have been replaced by gas as the main fuel for heating in homes with central heating.

As the Figure 16 shows, in 1970 more than a third of homes with central heating used solid fuel and about a tenth used some form of electric heating or oil, and only two-fifths used gas. In 2011, less than 1% used solid fuel, just 2% used electricity, while the proportion using oil had more than halved to 4%. By then, the proportion of households using gas for their central heating had risen to 91%.

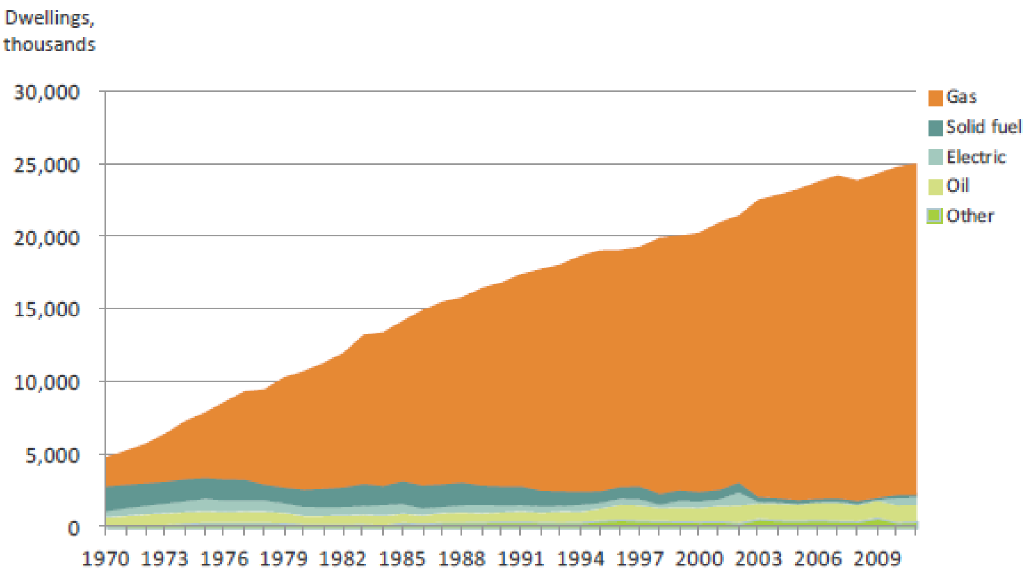


Figure 16: Evolution of energy carriers for home with central heating from 1970 to 2011 [17]

The last four decades have also seen significant changes in the fuels used for heating homes without central heating (currently 10% of dwellings). But, as the Figure 17 shows, here solid fuel has been replaced by electricity as well as by gas. In 1970, a quarter of these homes used gas, while nearly a fifth used solid fuel and electric, and just 2% used oil room heaters. By 2011, gas use had fallen to just 6% of homes without central heating, solid fuel had declined to 1%, while electric heating had risen to 82% of these homes. The majority (four-fifths) of the electric heating was from electric storage heaters.

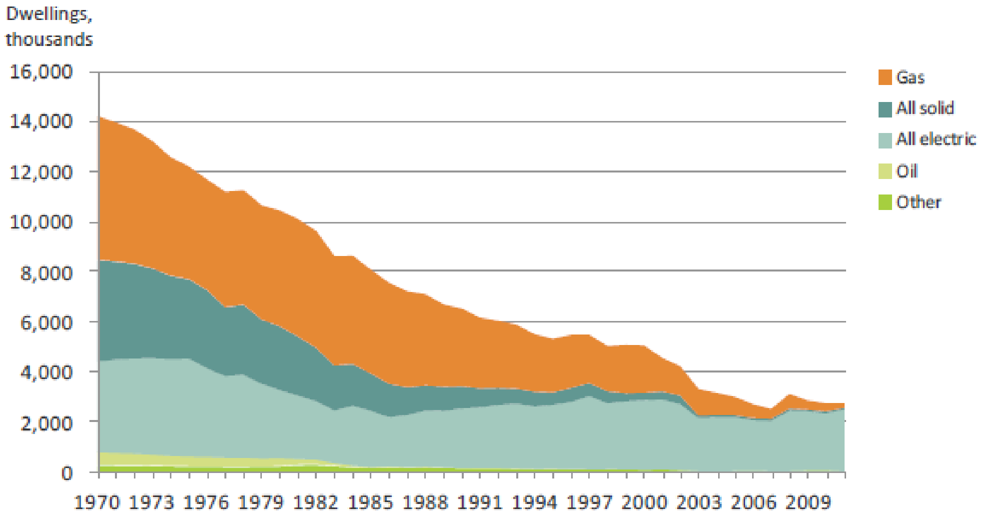


Figure 17: Evolution of energy carriers for home without central heating from 1970 to 2011 [17]

Household's energy carriers in 2018

A more recent study was made in 2018 on a sample of 4259 people [18]. The results are presented in Figure 18. In 2018, the central heating with gas is still the most commonly used heating (86%) in UK.

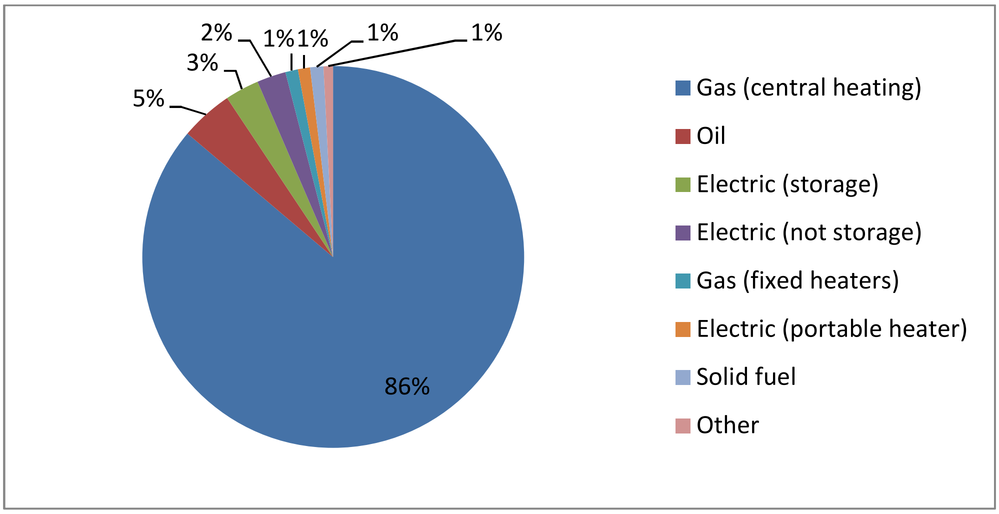


Figure 18: household's energy carriers in 2018

3.2.1.3. H&C energy demand for services sector

Figure 19 and Figure 20 show the H&C energy demand for residential sector by carriers and by utilisation, some information comes out:

- Space Heating is the main concern for UK's service sector.
- The demand for cooling is very small. The only sub-sector using cooling is the hospitality one.
- UK's service sector relies greatly on gas, most of which goes to space heating.
- All cooling and process heating, are powered by electricity only.
- District heating represents 4% of service energy demand and is used for space heating.

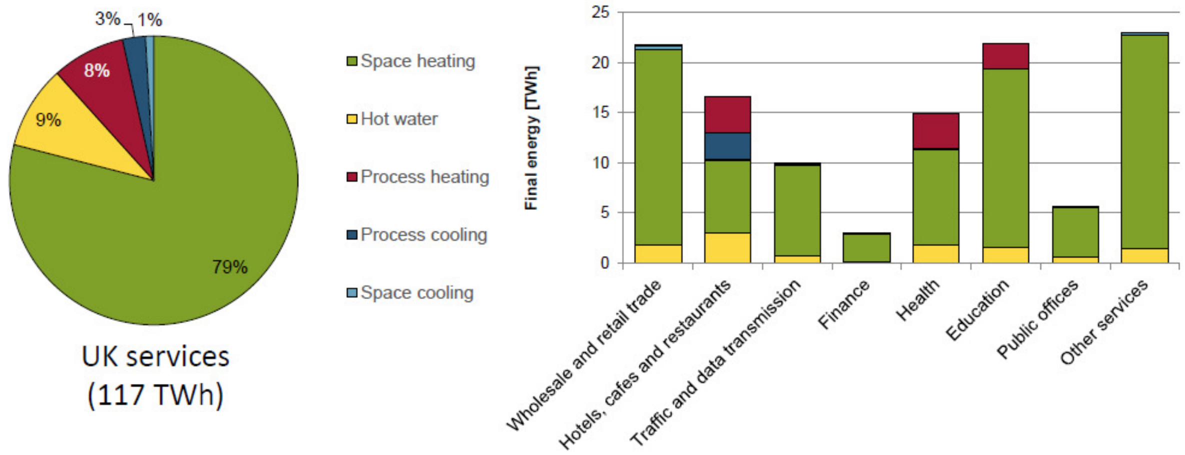


Figure 19: H&C energy demand for services sector by utilisation [14]

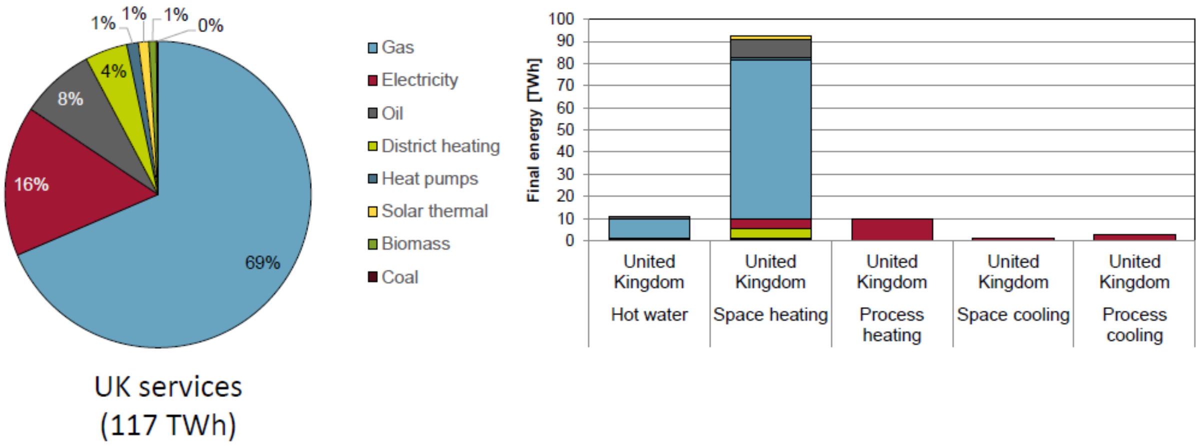


Figure 20: H&C energy demand for services sector by carriers and by utilisation [14]

3.2.2. Energy demand map

The Pan-European Thermal Atlas (Peta) is an interactive map that can be used for district energy planning [19]. For Heat Roadmap Europe, an updated version was created that models heat demands to the hectare level, and identifies continuous heat and cold demand areas that have potential for district energy. In addition, Peta spatially identifies (sustainable) resources like geothermal, solar thermal, excess heat, biomass, and heat for heating and cooling, and allows for efficient allocation to the local potential DH areas.

An important aspect in heat planning is to realise the geographically explicit nature of heating. It is not possible to move large amounts of thermal energy over large distances without increasing transmission losses. The possible distances depend on the size of the application, and while large-scale district energy systems can have a reach of many kilometres, small systems in smaller towns need sources of thermal energy within much shorter ranges. It is therefore vital to know the spatial distribution of both heat demands and potential sources for the production of heating when looking at the potential for district heating. The mapping of both demands and resources in the Pan-European Thermal Atlas 4 (Peta4), done in the HRE project, provides this information for each of the 14 member states in the project.

When investigating the potential of district heating, it is often beneficial to start in places with high heat demand densities. This is due to the nature of district heating networks, which decrease in cost per delivered energy unit when the distance travelled is reduced. The demand density is the driver of the infrastructure costs of a district heating network and is typically a result of local urban planning. The final extent of the district energy system is governed by the infrastructure costs, but also the availability of resources and energy system dynamics. This is why spatial planning must be combined with energy system analysis. [13]

Figure 21 is a map (from Peta) that represents heat demand, cold demand and the excess heat in UK, some information comes out:

- Largest heat demand are localised in big cities (London, Glasgow, Manchester)
- The excess heat mostly comes from powerplants

The excess heat (at least 1,130 Twh) would cover 65% of the final energy demand for space heating and hot water. The biggest excess heat sources are located in central region of UK, around the metropolitan area of London and in Glasgow. [14]

With the spatial explicit information on both heat and cold demand and potential resources for heat production, a prioritisation of heat synergy regions has been made for all of the 14 member states in the HRE project. A very high priority is given to regions with high levels of both excess heat and heat demand and high priority is given to regions with moderate levels of excess heat and high heat demand. These types of regions are found in all 14 member states.

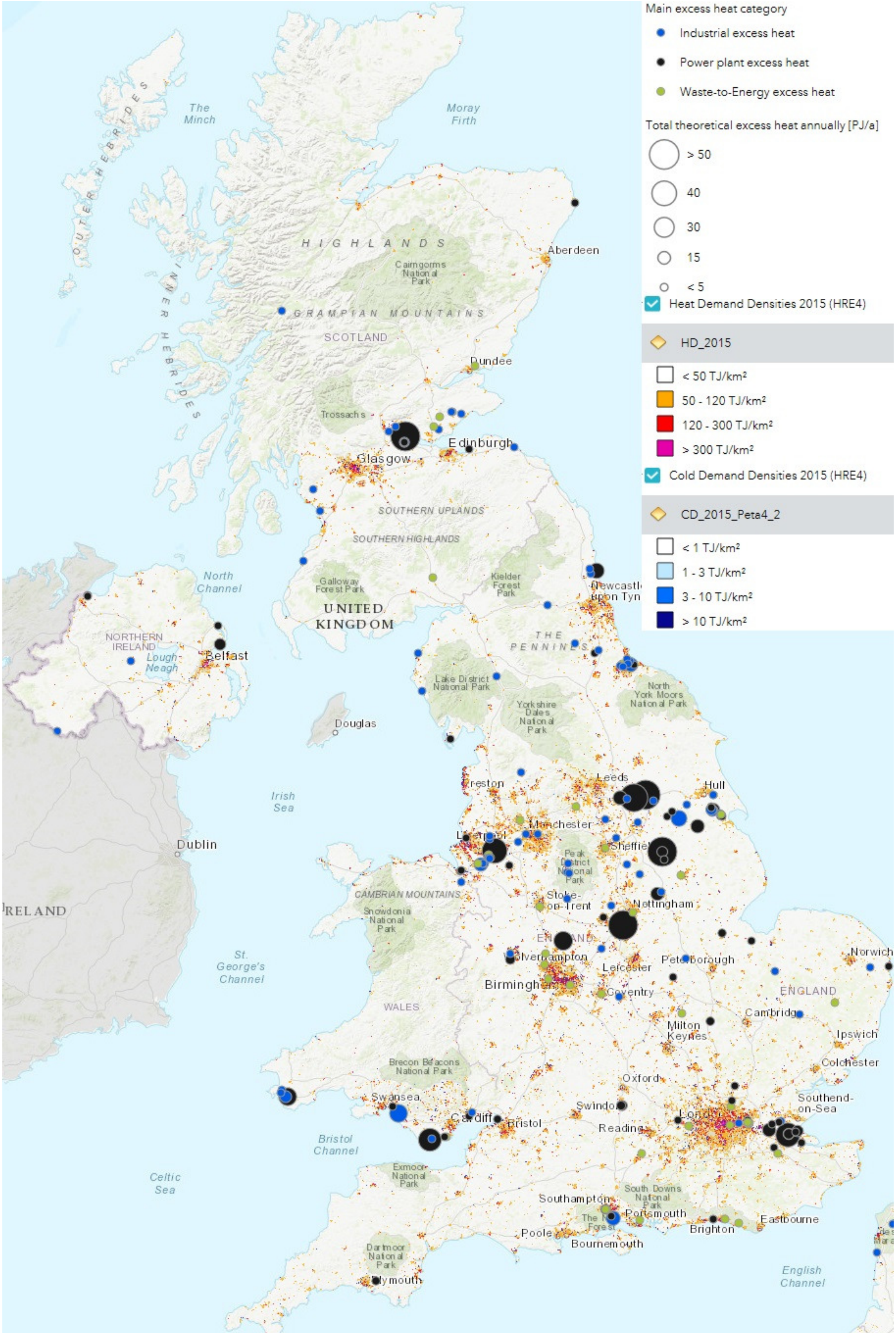


Figure 21: heat demand, cold demand and the excess heat in UK (from Peta [19])

In the United Kingdom, a total of 21 regions are assigned with the highest two priority levels, which is one of the highest numbers in HRE (Figure 22). A good local example of heat synergy region is South Teesside (Figure 23). The city of Middlesbrough has a total heat demand of 6,3 PJ, of which 1 PJ is located in areas with a heat demand density of more than 300 TJ/km^2. While the Middlesbrough area does show a distinct and discrete potential district heating area, it is not particularly dense and the synergy is in large part driven by the high volume of available excess heat. Within a distance of less than 8 kilometres from the centre of the city, excess heat facilities with a theoretical output of more than 34 PJ are located, which represents more than 5 times the heat demanded in the area. Even if only a part of the excess heat is recovered, this could already substantially contribute towards both the sustainable supply of a district energy system and the valorisation of energy otherwise wasted and additional support for the industries that are present in the region. [13]

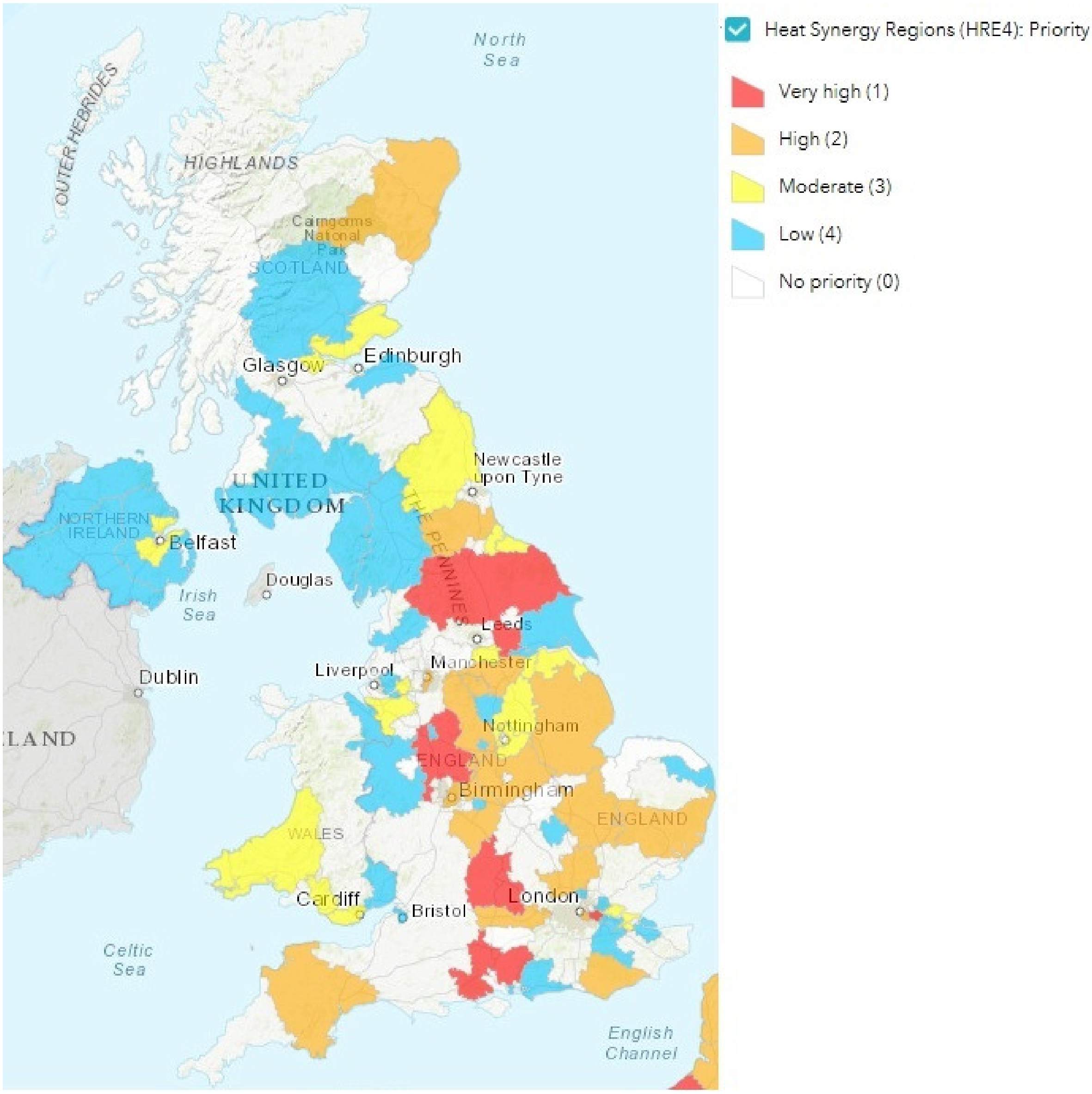


Figure 22: Heat synergy regions in UK (from Peta [19])

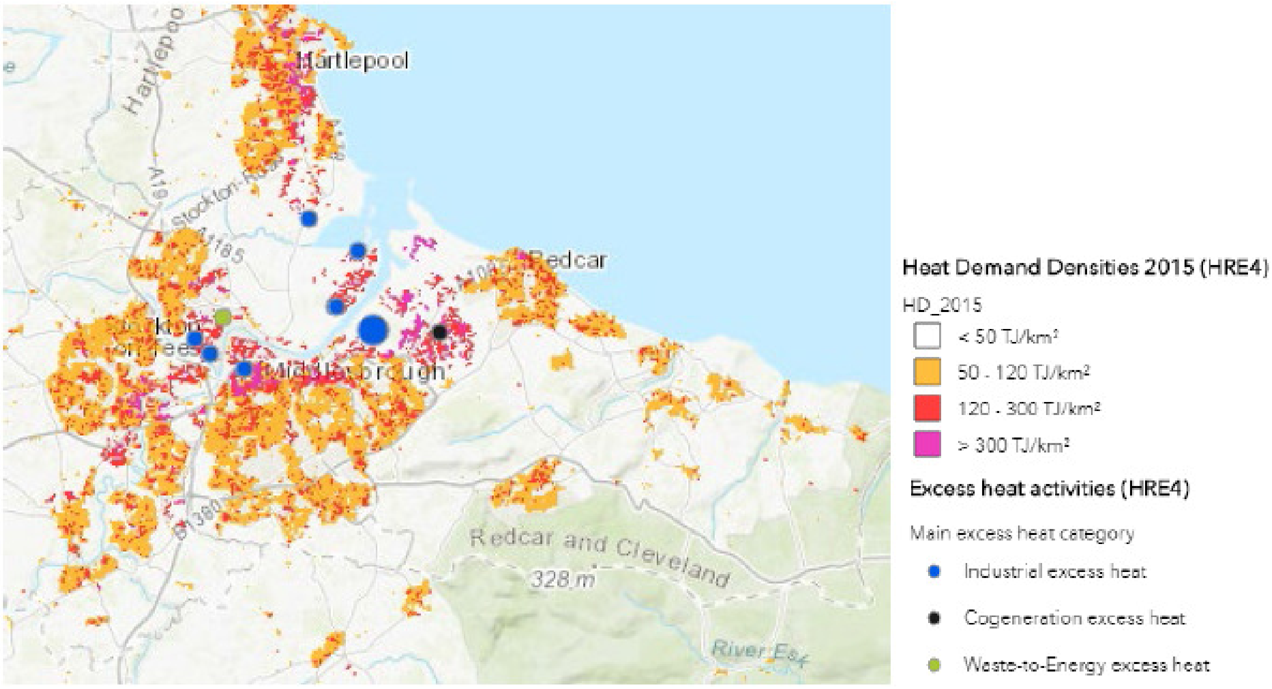


Figure 23: heat synergy in South Teesside [13]

3.2.3. Housing stock characteristics

Energy use in homes is driven by householders' need for energy services, such as light, comfort and hot water. The amount of energy required to meet these energy services is shaped by the level of service required and the type of home, heating systems, lighting and appliances in place. It comes as no surprise that total energy use in homes across the UK is strongly affected by both the size of the population and the number of households. Hot water use and the use of some appliances (kettles, hairdryers, washing machines) increase in proportion to household size. However, heating energy (which is the biggest slice of energy use in homes) usually correlates more strongly to the size of dwellings, and household size makes little difference to heating. [17]

The UK population rose from 55.6 million in 1970 to 66 million in 2017. However, the number of households grew more rapidly over the period, from 18.8 million in 1970 to 28 million in 2017. The total energy consumption for the residential sector has growth from 35621 ktoe to 40116 ktoe in 2017. Nevertheless, it has decreased by 9217 ktoe since 2004. Therefore, the consumption per household has decreased in these years. [20]

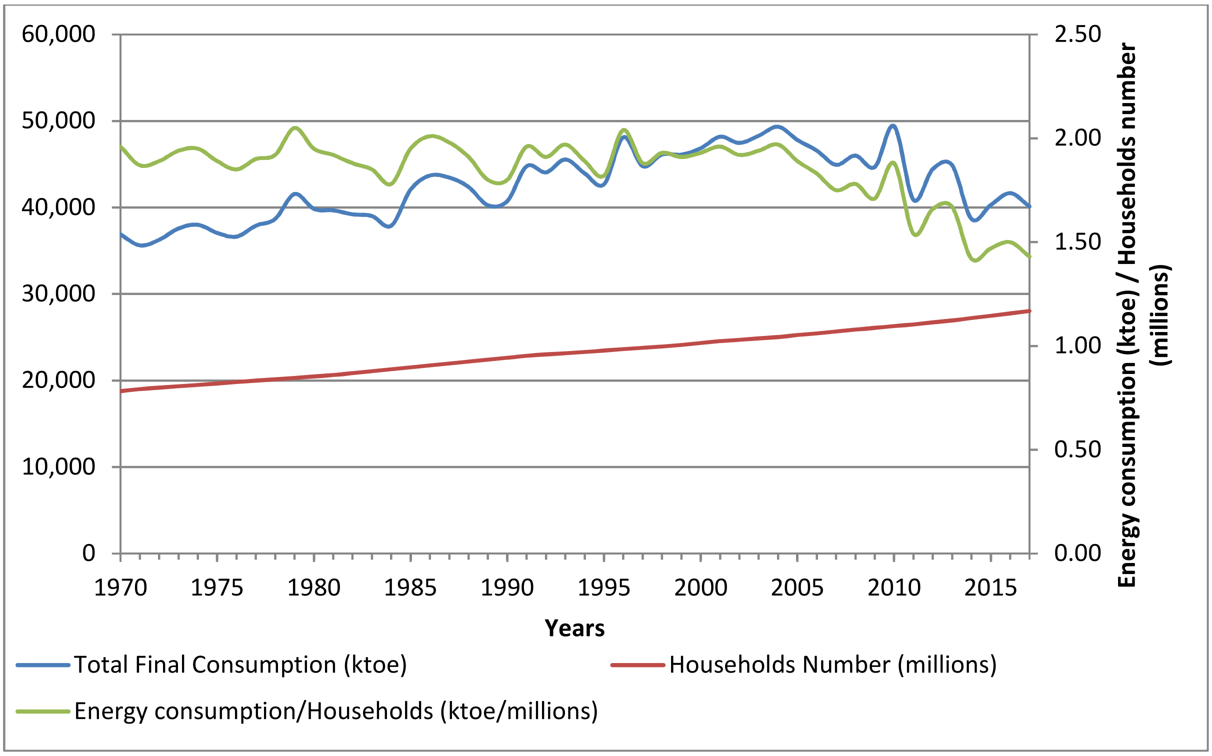


Figure 24: total energy consumption for domestic sector and households number from 1970 to 2017 (from data [12])

House type

'House type' refers to whether dwellings are semi-detached houses, terraced houses, detached houses, flats or bungalows. Unsurprisingly, the housing mix changes slowly over time – due to new house building and some demolition of dwellings.

However, over 40 years the change is quite pronounced (see Figure 25). While semi-detached and terraced houses have always been the most common house types (each representing just under a third of the housing stock throughout the period), flats and detached houses have become more common. (Flats are now 20% of the housing stock, and detached houses are 17%.)

This is significant in energy terms because heating energy is related to external wall area and window area. Flats tend to have less external wall area compared to their floor area (so have less heat loss in winter), while detached houses typically have more external wall and more windows than equivalent homes of other types. [17]

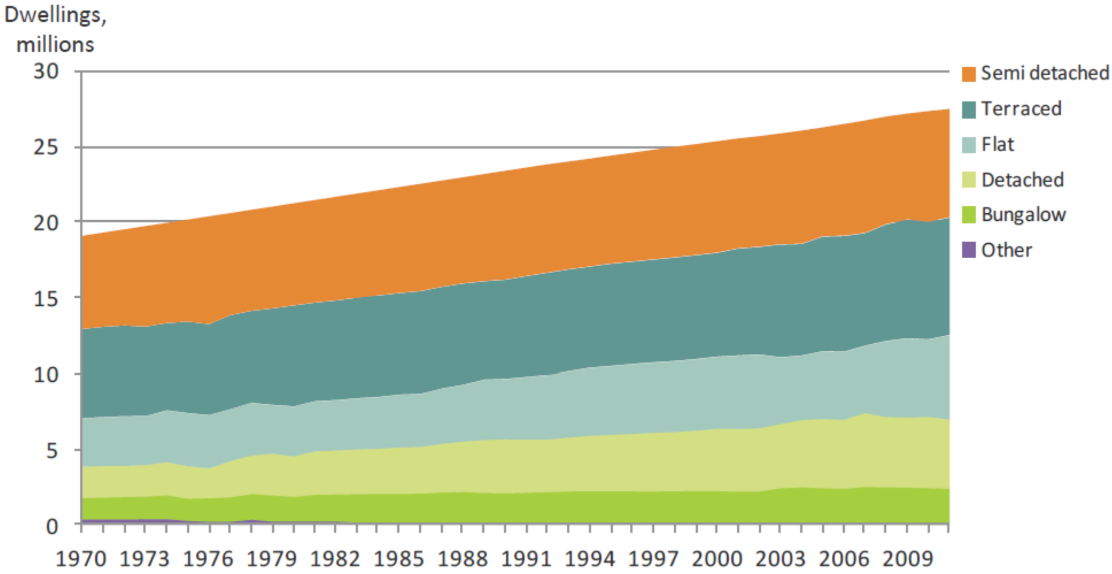


Figure 25: Housing stock distribution by type [millions] [17]

Heat demand in the five dwelling types in 2009 was estimated. The average amount of gas consumed in 2009 was approximately 18,900 kWh per household. Figure 26 displays the estimated average annual heat demand from the monitored households. On average, a household consumes approximately 15,200 kWhth of heat a year. As expected, a detached house requires the highest amount of heat among all types of dwellings, with annual heat demand reaching over 18,600 kWhth, while a flat consumes only about 10,400 kWhth. Additionally, this study only considers heat demand supplied by individual gas boilers, and does not consider supplementary heating measures used in those households, such as electric heating or fireplaces due to limited metadata. [21]

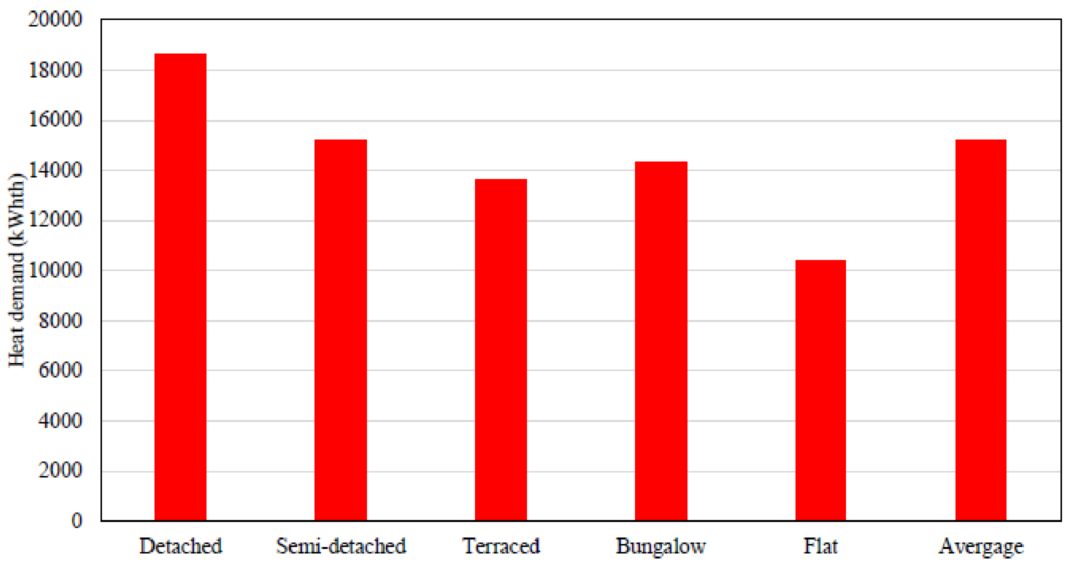


Figure 26: Annual heat demand by house type [21]

More recent study was made in 2017 and estimates that the average energy consumption for a dwelling heated by gas fell to 12000 kWh in 2017. [22]

3.3. District heating network in the country

3.3.1. Number and location of District Heating

En 2018, Energy trends published an article "Experimental statistics on heat networks" [23]. This paper sets out results of the data collected. [24]

Heat networks can be considered as either district or communal heating as defined in the guidance;

"District heat network means the distribution of thermal energy in the form of steam, hot water or chilled liquids from a central source of production through a network to multiple buildings or sites for the use of space heating or process heating, cooling or hot water."

"**Communal Heating** means the distribution of thermal energy in the form of steam, hot water, or chilled liquids from a central source in a building which is occupied by more than one final customer for the use of space heating, process heating, cooling or hot water. It is not necessary for the heat supply to be within the building only that a single building is making use of the heat."

There are 13995 heat networks in the UK. The majority of heat networks are communal heating with district heating (2087 networks) representing 15% of total networks for the UK as a whole. This proportion varies by region (Figure 27) with the North West having the lowest percentage of district heat networks (8%) and London the highest (20%). Densely populated areas lend themselves better to district heating due to the infrastructure required to link end users to the heat source.

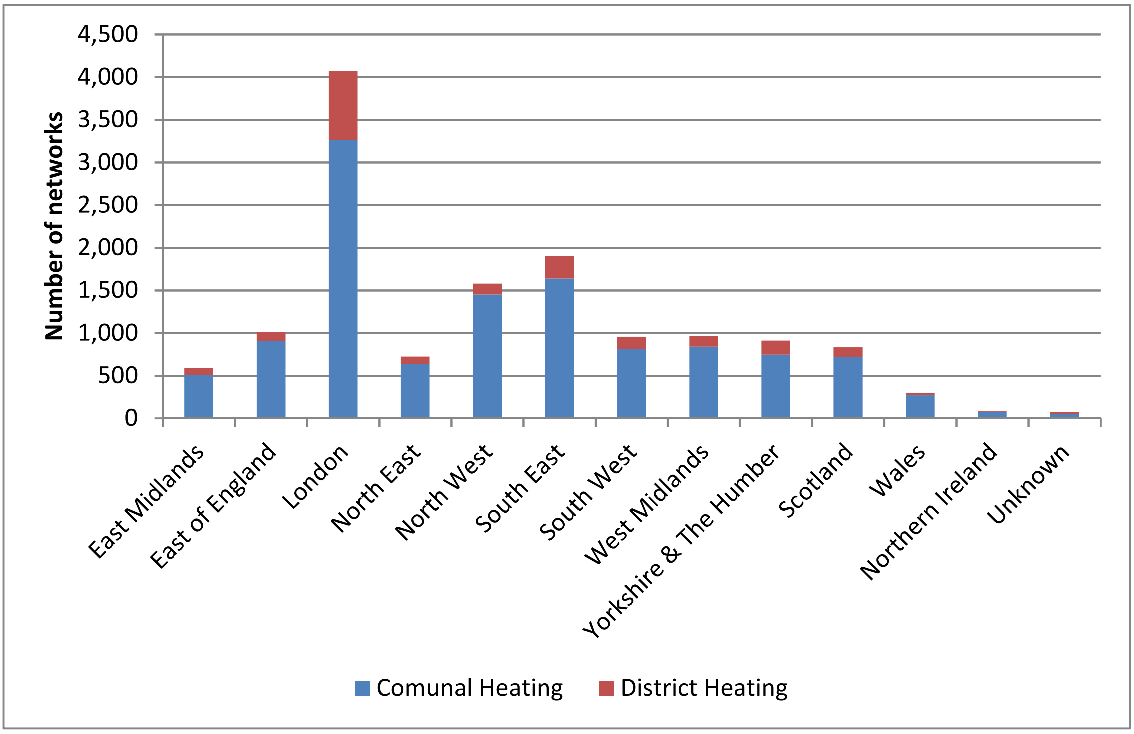


Figure 27: Number of heat networks by region (from data [24])

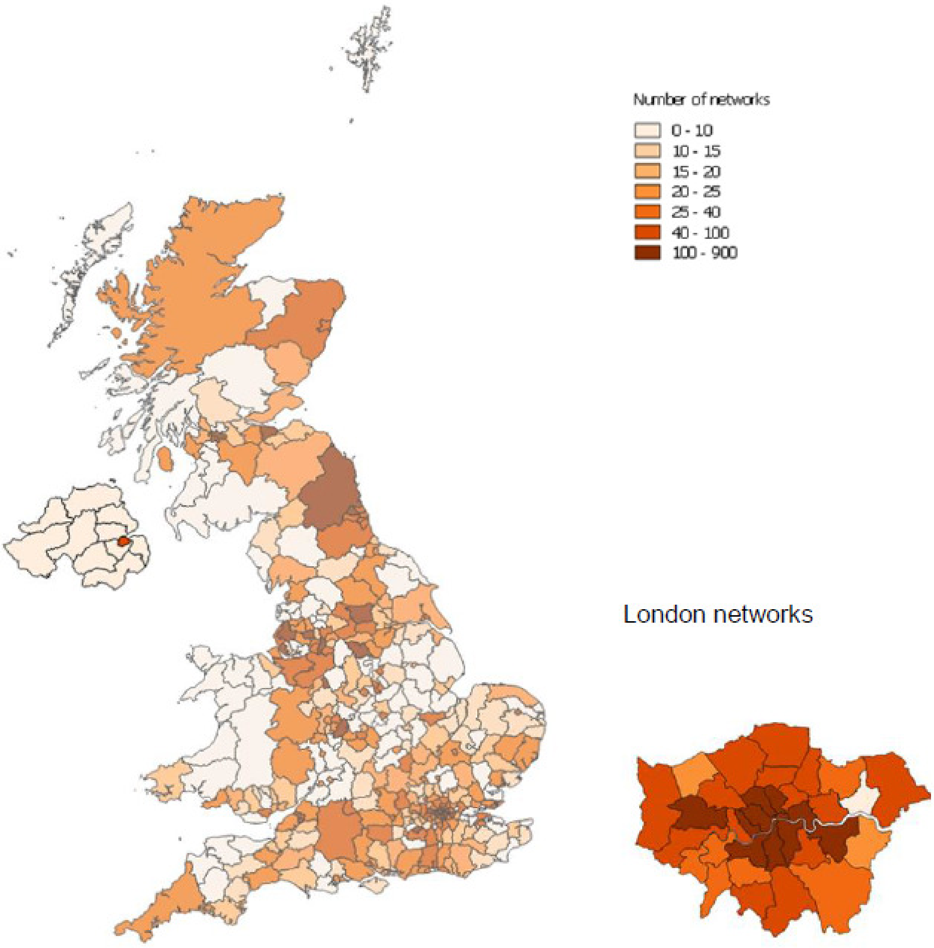


Figure 28: Networks number by location [23]

Figure 29 shows the number of networks operational for various combinations of end uses. A large proportion (70%) of networks provides space heating and hot water, though very few (8%) provide heating, hot water and cooling. Even less provide cooling only (1%).

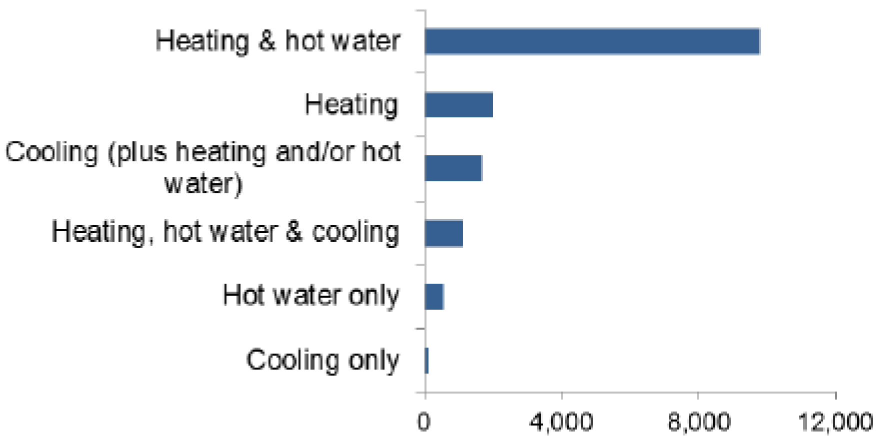


Figure 29: Heat networks number by end uses [23]

Another study was done to determine what energy sources are used on heat networks [25]. Diverse energy sources are used on heat networks: mostly gas (56%) and efficient gas CHP (32%), but increasingly other energy sources form part of heat networks' energy mix, such as large-scale biomass (10%), energy from waste and large-scale heat pumps.

Figure 30: energy sources in current heat networks [25]

Capacity, generation and supply by type of networks are shown in Figure 31**,** generation by region is shown in Figure 32. Across the UK, installed capacity for heating/hot water is 19.4 GW with Yorkshire and The Humber showing the highest capacity for heating and hot water (6.0 GW). London has the highest levels of generation and supply at 3.7 TWh and 2.8 TWh respectively, compared to 17.7 TWh and 14.4 TWh for the UK as a whole. London also has the highest installed capacity, generation and supply for cooling. For the UK as a whole, cooling generation represents 10 per cent of total generation.

Although the number of district heat networks is relatively small compared to the number of communal schemes (showed previously in Figure 27), heating generation from DH is disproportionately higher. This reflects the increased demand from larger installations and also the small number of unusually large schemes. In opposition, the cooling generation is mostly performed by communal heating.

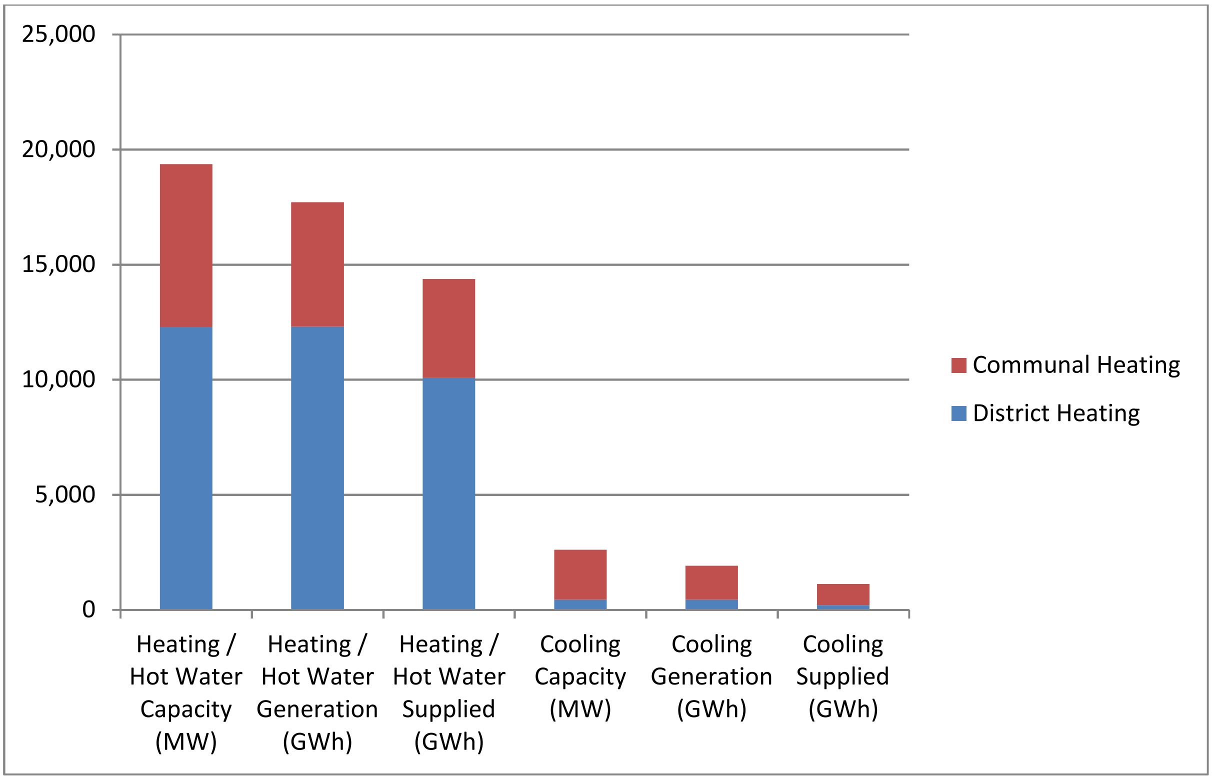


Figure 31: Capacity, generation and supply by type of networks (from data [24])

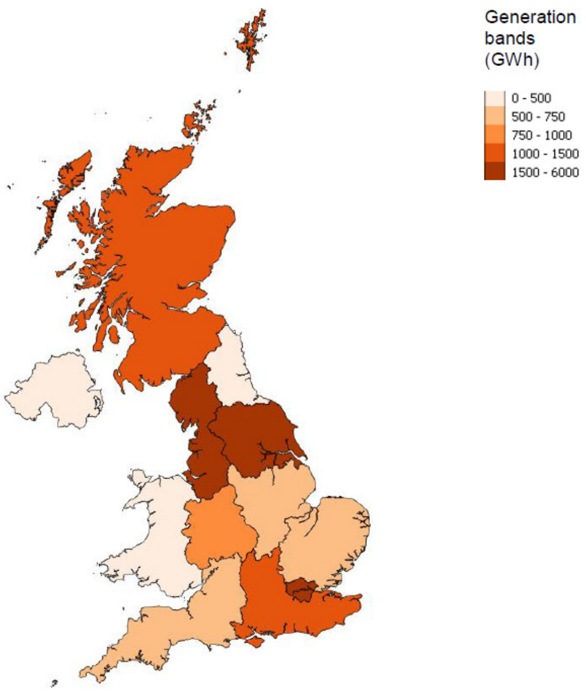


Figure 32: All networks heating generation by region [23]

3.3.2. Electrical grid

3.3.2.1. Electricity flow chart 2017

Figure 33 summarises the sources of electricity generation and the way this electricity is used (The values are from 2017).

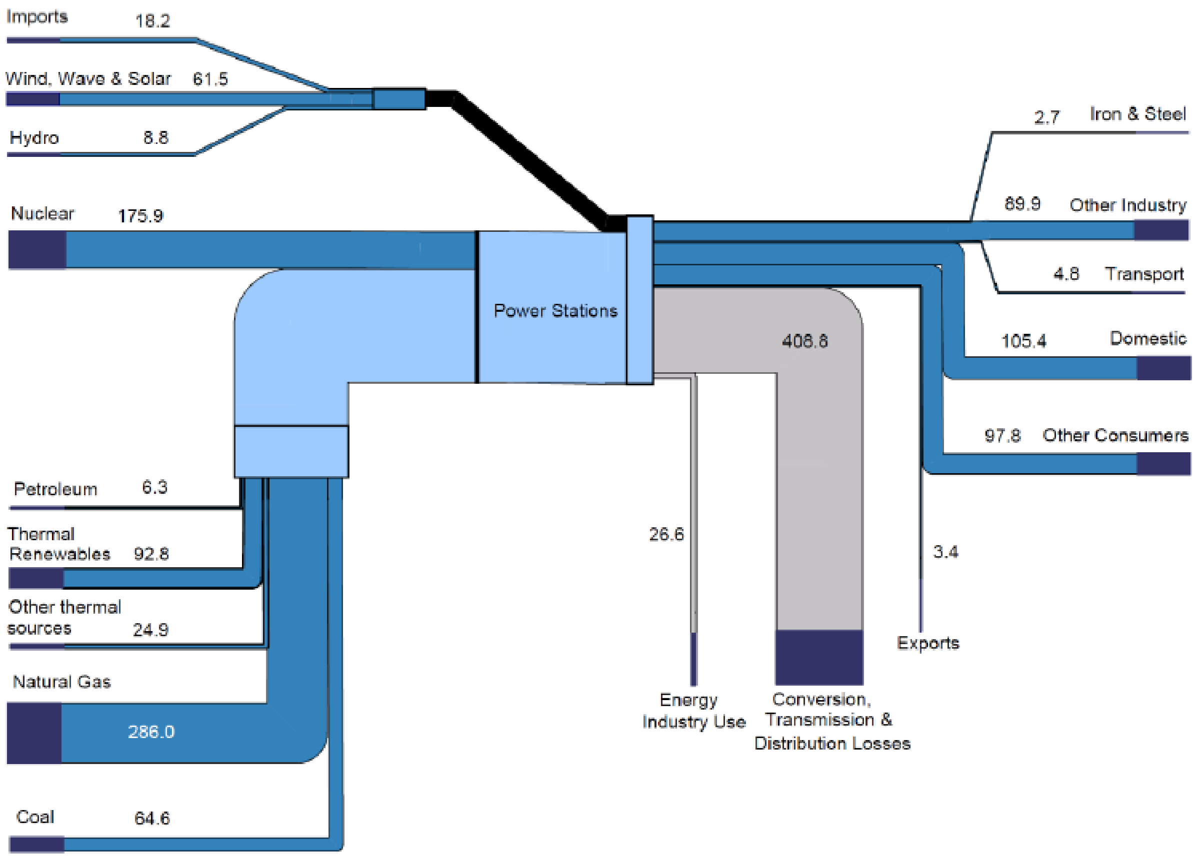


Figure 33: Electricity flow chart 2017 (TWh) [26]

3.3.2.2. Electricity generation, import/export and capacity

Electricity generation is down 14% since 2008, but within that are significant changes in the mix of fuels used to generate electricity (Figure 34). The principal trend has been the move away from coal to renewables sources. Generation from coal decreased from 124 TWh in 2008 to 17 TWh in 2018, a decrease of 86%. The trend for gas is more variable but has remained strong, with gas being the most dominant fuel source. Over the same period, electricity generation from renewables increased from 22 TWh in 2008 to 111 TWh, an increase of over 400%. [27]

In 2018, the generation mix consisted of 5.0% from coal, 39.4% from gas, 19.5% from nuclear, 33.3% from renewables and 2.8% of Oil and other. Further, renewables increased their share of low carbon generation to 63% in 2018, up from 29% in 2008 and 59% in 2017. [27]

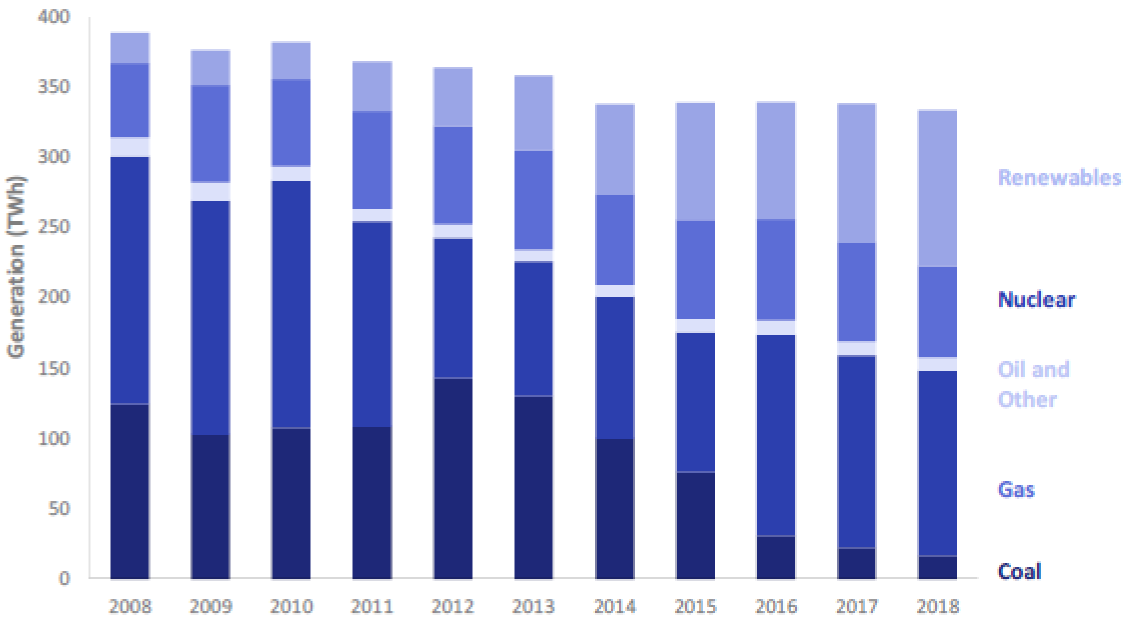


Figure 34: Electricity generation by sources [27]

In 2018, net imports were 19 TWh, an increase of 30% on 2017. Imports from France to the UK and Ireland to Northern Ireland each increased by 40.9% and 39.2%. Exports from the UK increased for all the interconnectors, apart from with France. Exports to France were reduced in comparison to 2017, when high electricity prices in France led to particularly high exports from the UK. [27]

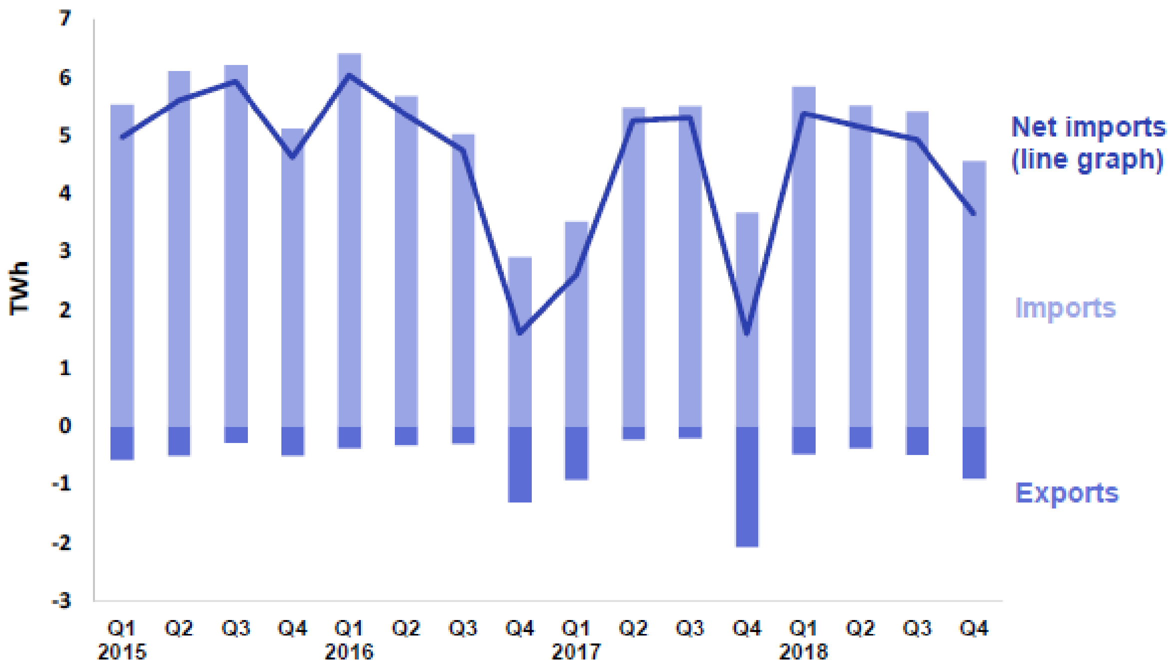


Figure 35: Electricity import and export [27]

Total electricity generated from renewables in 2018 Q4 was up by 18% on 2017 Q4, from 27.8 TWh to 32.7 TWh [28], driven by record generation from wind (Figure 36):

- Generation from onshore wind increased by 6% to a record 10.1 TWh. Generation from offshore wind increased by 14%, from 7.8 TWh to a record 8.9 TWh. The increase in generation from both onshore and offshore wind was due to increased capacity.
- Solar PV generation increased by 19%. Although there was only 2.5% of additional capacity in 2018 Q4 compared to a year earlier, solar generation was helped by higher load factors, a result of 0.4 more sun hours per day than in 2017 Q4.
- Generation from bioenergy increased by 39%, from 7.3 TWh in 2017 Q4 to 10.2 TWh in 2017 Q4. Within this, there was a large increase in generation from plant biomass as new capacity came online.
- Hydro generation increased by 9.3% on a year earlier to 2.0 TWh.

In 2018 Q4, bioenergy had the largest share of generation with 31% (10.2 GWh), marginally ahead of onshore wind with 31% (10.1 GWh). Offshore wind accounted for 27% of generation so that total wind and bioenergy provided 89% of renewable generation. [28]

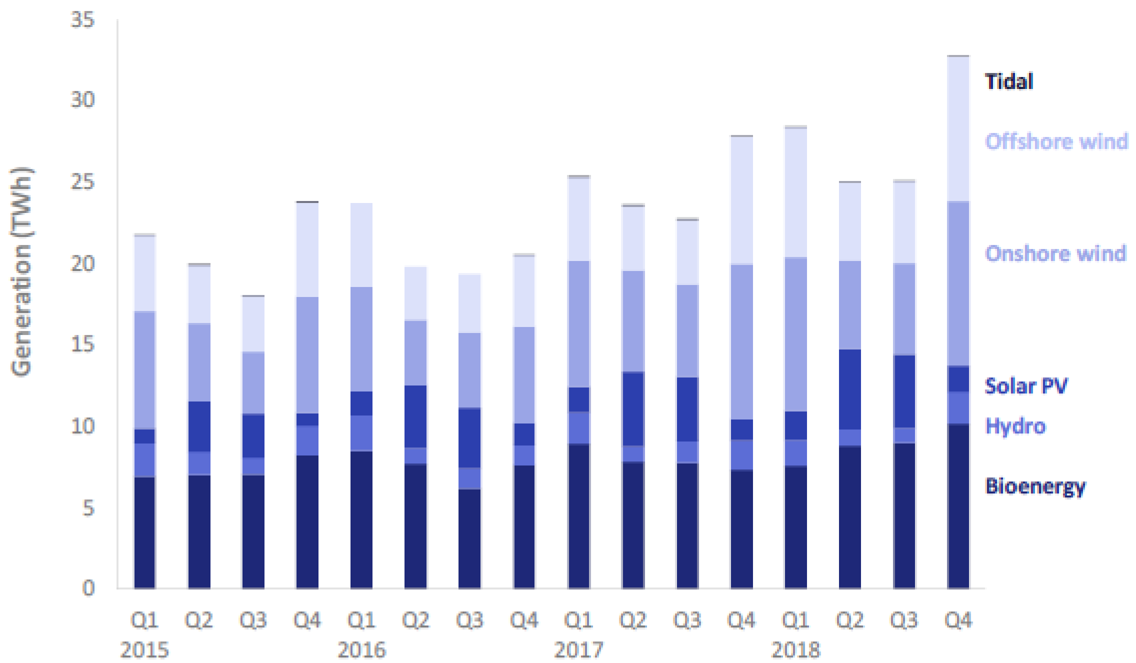


Figure 36: Electricity generation from renewable sources [28]

At the end of 2018 Q4, the UK's renewable electricity capacity totalled 44.4 GW, an increase of 9.7% (3.9 GW) on that installed at the end of 2017 Q4 (Figure 37). At the end of 2018 Q4, onshore wind had the highest share of capacity at 30.5% (13.5 GW), followed by solar photovoltaics at 29.5% (13.1 GW), offshore wind (18.5%), bioenergy (17.3%) and hydro (4.2%). [28]

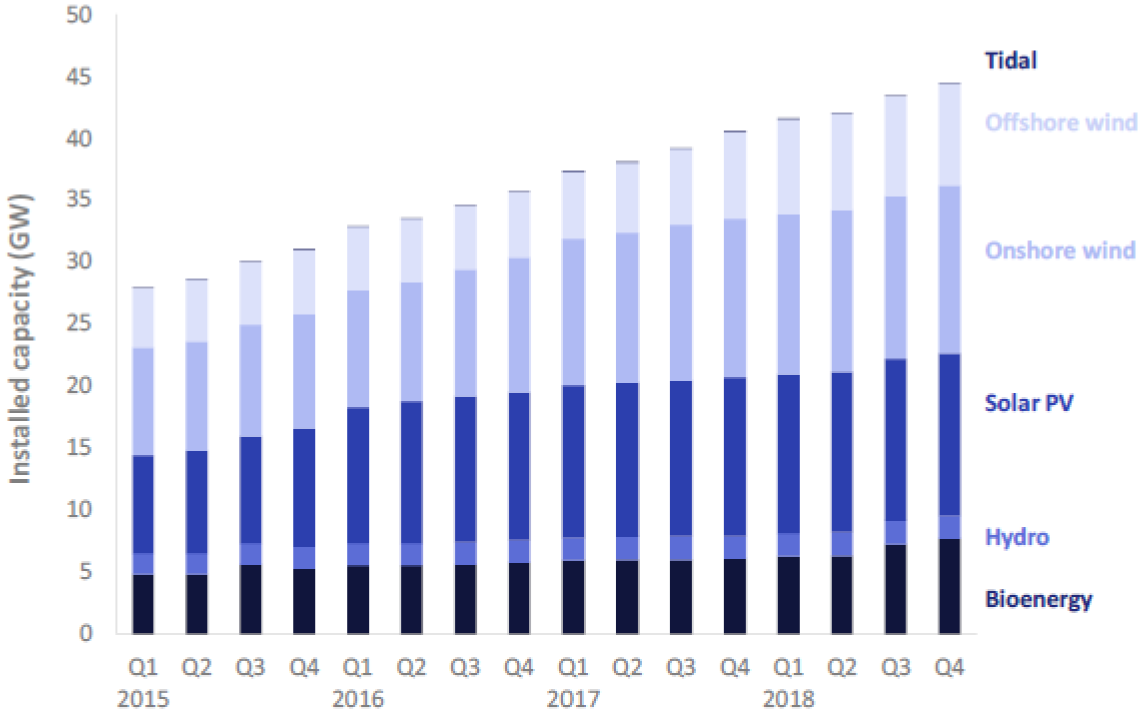


Figure 37: Renewable installed capacity [28]

3.3.2.3. Electricity consumption

Since 2010, Industrial and domestic consumption has respectively decreased by 11.4% and by 11%. The total electrical consumption has fallen 9% (Figure 38).

In 2017, from the total electricity demand of 353.8 TWh, 26.2% was consumed by the industrial sector. Domestic consumption accounted for 29.8% of total demand. The services sector (covering transport, public administration, commercial and agriculture) accounted for a further 29.0%.

Within industrial consumption (92.6 TWh), the largest specified consumers were chemicals, food and paper, together accounting for 40.3% of industrial consumption (Figure 39). The two engineering consumers and vehicles accounted for a further 18.5% of industrial consumption. The iron and steel sector was also a substantial user of electricity but part of its consumption is included against blast furnaces and coke ovens under energy industry uses. [26]

Losses accounted for 7.5% of total electricity demand in 2017. Losses comprise three components [26]:

- Transmission losses (6.5 TWh) from the high voltage transmission system, which represented about 24.5%.
- Distribution losses (19.1 TWh), which occur between the gateways to the public supply system’s network and the customers’ meters, and accounted for about 71.8% of losses
- Theft or meter fraud (just under 1.0 TWh, around 3.7%).

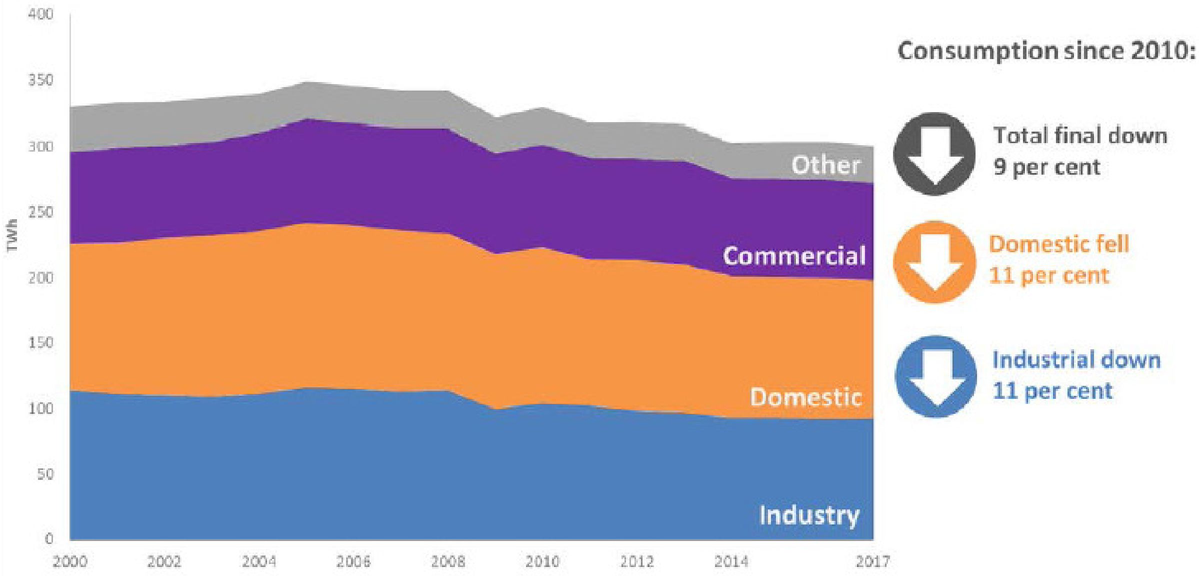


Figure 38: Total electrical consumption [26]

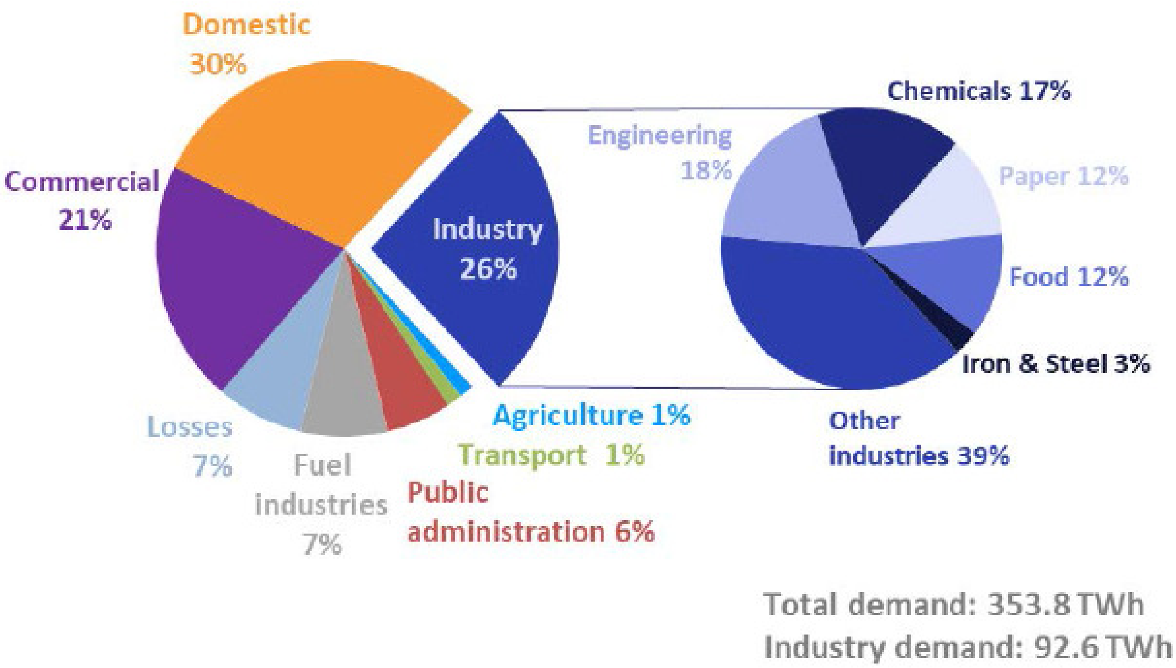


Figure 39: total electrical consumption by sectors [26]

3.3.2.4. Electrical supply network

Figure 40: Electrical supply network [26]

3.3.3. Gas grid

3.3.3.1. Gas flow chart 2017

Figure 29 summarises the sources of gas and the way it's used (The values are from 2017)

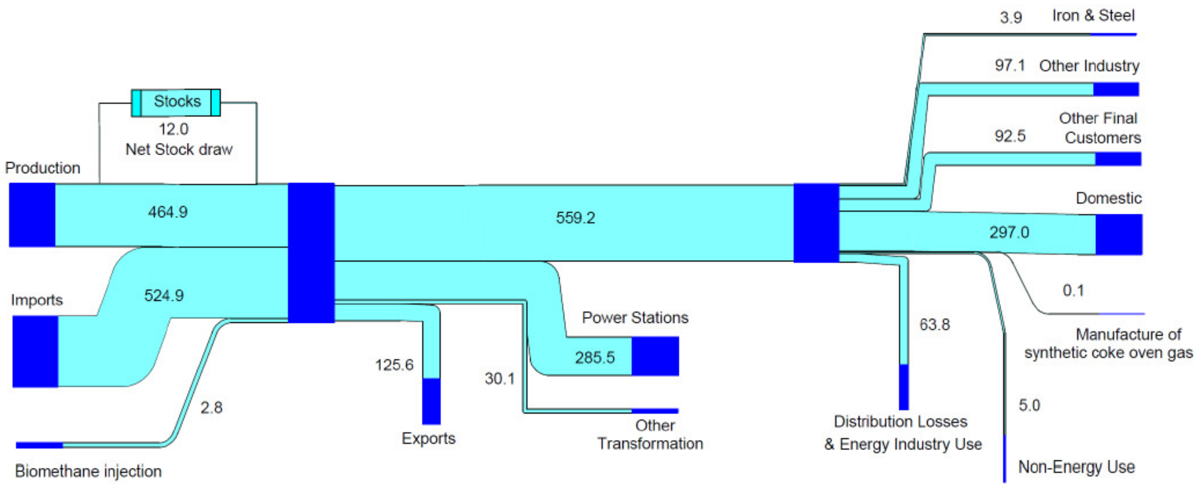


Figure 41: Gas flow chart 2017 (TWh) [26]

3.3.3.2. Gas production and import/export

The pattern of gas production since the turn of the century has generally been one of decline with production falling by an average 8% per year since production peaked in 2000 (Figure 42). The value for the production is 465TWh in 2017. Despite this, the UK, along with the Netherlands, is one of the two major gas-producing nations within the EU. [26]

Figure 42 illustrates the growth in net imports despite a decrease in demand since the mid-2000s. The UK imports natural gas via pipeline from Norway, the Netherlands and Belgium and by ship in the form of Liquefied Natural Gas (LNG), to terminals at Milford Haven (South Hook and Dragon), the Isle of Grain and Teesside Gasport. [26]

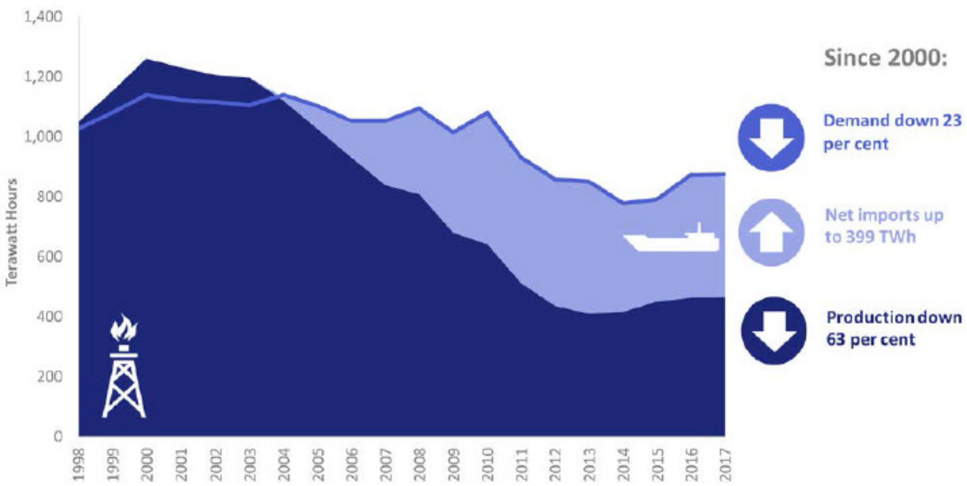


Figure 42: Production and import of gas (TWh) [26]

With demand outstripping supply from the UK's continental shelf it is perhaps surprising to note that the UK is a large exporter of gas, with exports in several recent years outstripping export volumes at the peak of the UK's indigenous production. Figure 43 shows that export volumes have been considerable but somewhat erratic in recent years. UK exports were up 7.5% in 2017, driven by an increase of nearly a third in exports to Belgium. Exports to all other countries were substantially reduced (in particular, exports to the Republic of Ireland and the Netherlands were down 17 and 31 per cent respectively) meaning that volumes to Belgium comprised more than 70 per cent of all UK exports. [26]

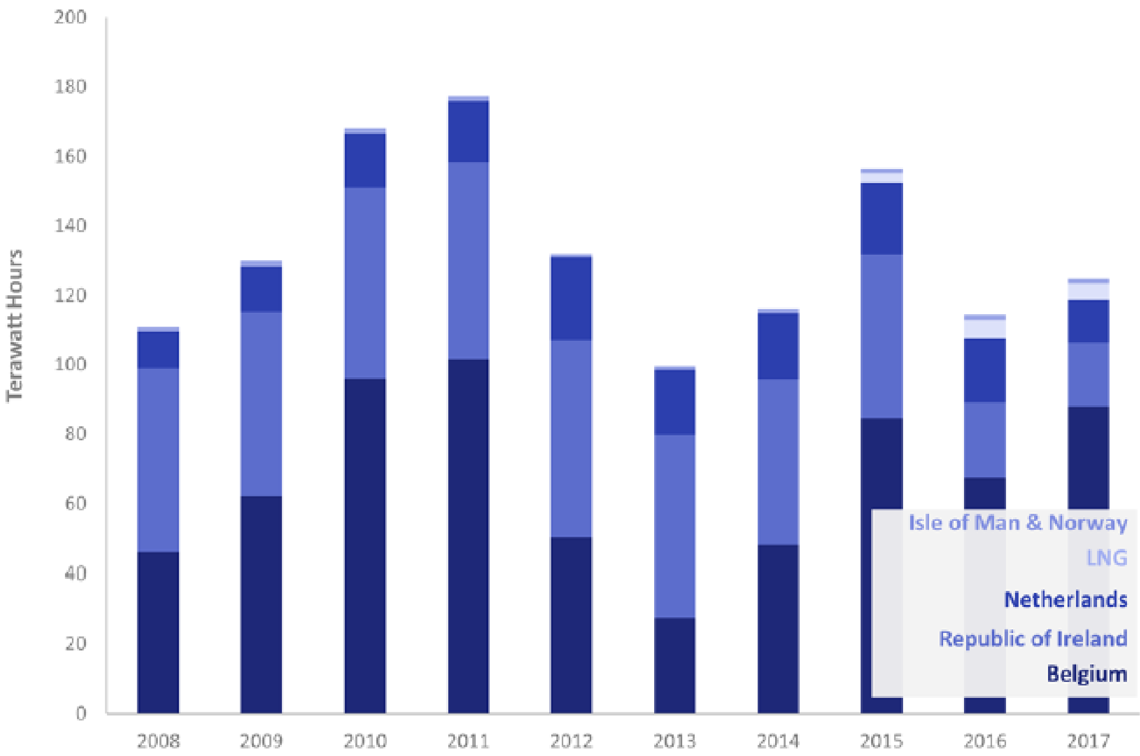


Figure 43: Gas export by country [26]

3.3.3.3. Gas consumption

In recent history, gas demand can be broadly broken down into two main sectors of very substantial size; domestic consumption and gas for electricity generation, with demand for industry, commercial, public administration and other sectors making up the rest (Figure 44).

Whilst gas is a critical part of the UK's energy demand, in 2017 demand was down by more than a fifth compared with 2000. Most notably, it is industry demand that has shrunk over this period, down to just over a half of what it was in 2000. However, demand for power generation was also down (just over a tenth) and domestic demand has shrunk by around 20% in the context of both a rising population and a rising number of homes. Increased efficiencies in heat use, including greater levels of home insulation, are a factor.

Compared to last year demand has remained relatively stable at 875 TWh, down 3.0%. Notably, including colliery methane, power generation fell by 4.0% as a result of an uptake in low carbon electricity sources such as renewables and nuclear. In 2016 demand here had increased by more than a third because of the drop off in coal power generation. [26] [29]

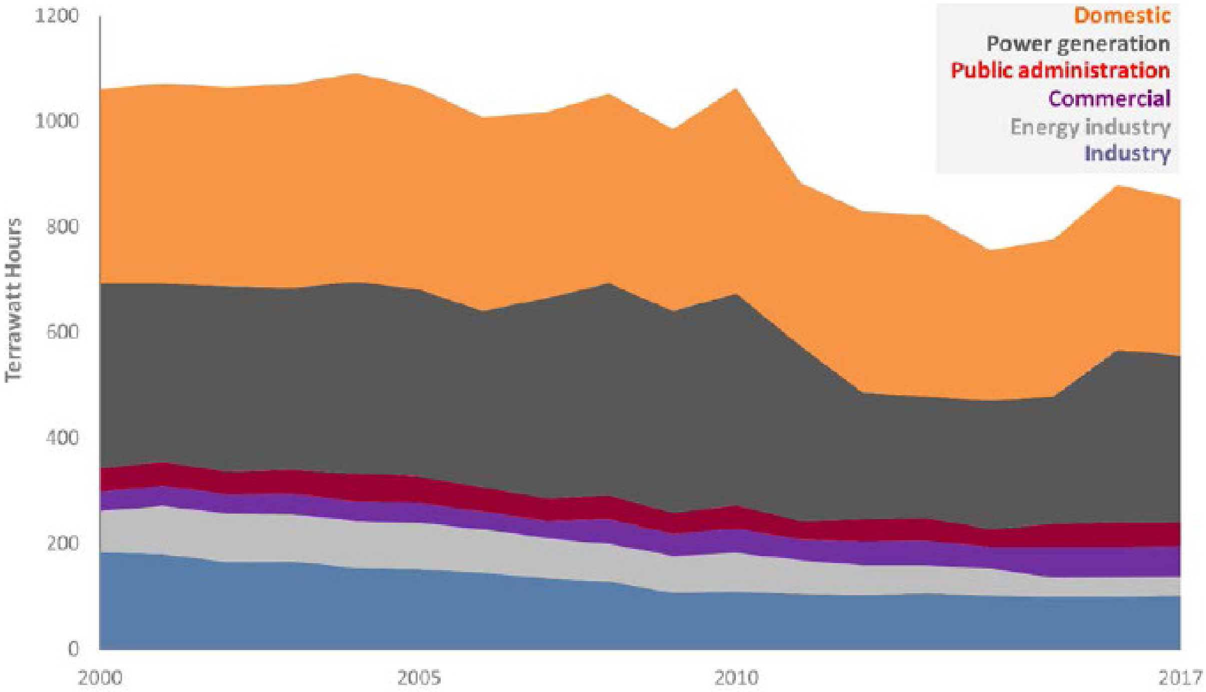


Figure 44: Gas consumption over the years by sectors [26]

3.3.3.4. Gas supply network

Figure 45 is a map of the UK's gas transmission system, owned and operated by National Grid. The red lines show the gas transmission system and the black triangles the terminals, where pipe gas enters the system; the red squares are the LNG terminals, both pipe and LNG, where gas enters the system. [26]

The United Kingdom has 3 large LNG terminals: Grain, Dragon and South Hook. The largest of these terminals, Grain, can, on its own, provide 20% of the UK's demand and combined, the three terminals can meet over 50% of the UK's demand. [30]

Figure 45: Gas network map [26]

3.4. Energy prices and projection to 2050

3.4.1. 2018 Situation

UK wholesale gas prices have been increasing since the early 2000's, due to upward pressure on prices in Europe and the decline in the UK Continental Shelf gas production, however wholesale gas prices have fallen back since the start of 2014 till into the second half of 2016 before rising again (Figure 46). In 2018, wholesale prices rose by 35% (an increase of 4% on the previous year). Electricity prices have generally been on a rising trend. With gas an important part of the UK generation mix, and also as a result of higher coal prices, wholesale electricity prices have been rising from unsustainably low levels, and also due to the introduction of the EU Emissions Trading scheme in 2005. Liquid fuel (heating oil) prices typically follow crude oil prices. Apart from a sharp fall in 2009, between 2003 and 2012 liquid fuel prices increased strongly in real terms. Since 2013 prices have fallen but more so between 2014 and 2016. Liquid fuel prices have risen over the past two years and in 2018 were 23% higher in real terms compared to the previous year. Motor fuel prices similarly follow crude oil prices, but vary according to changes in the duty payable on petrol and diesel, and to the rate of VAT. [31]

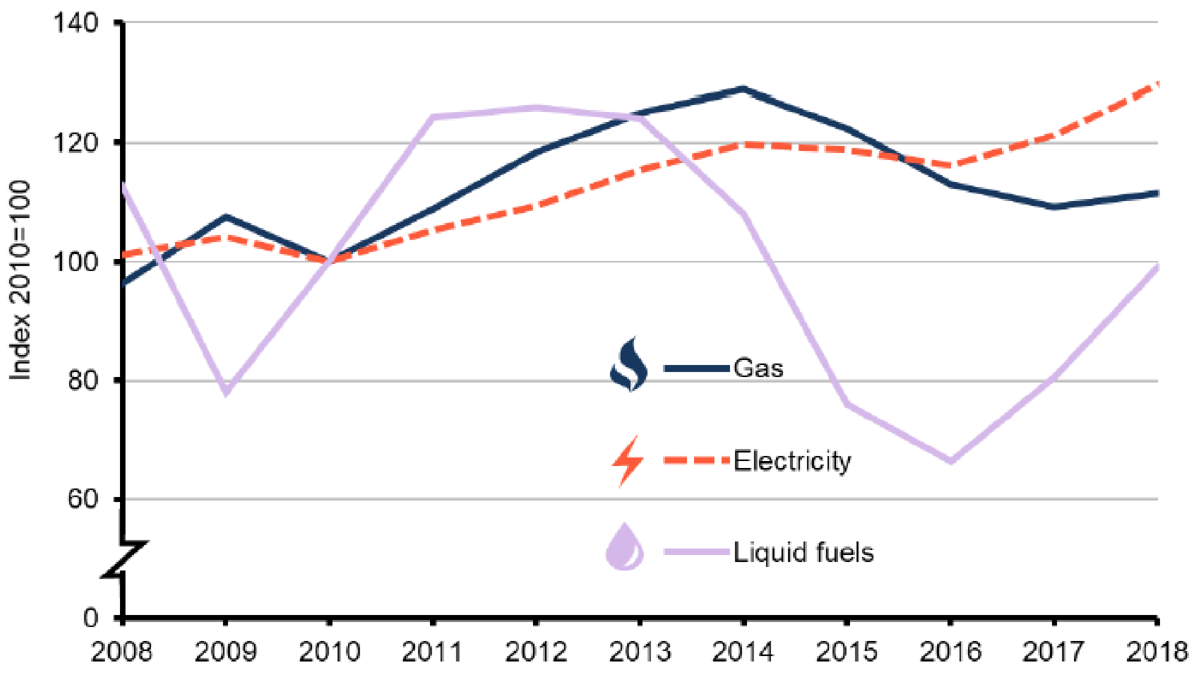


Figure 46: Real terms fuel price indices in the domestic sector [31]

BEIS estimates for bills are based on fixed annual consumption levels of 15,000kWh for gas and 3,800kWh for electricity, to allow comparisons over time of the effects of actual price changes, whilst excluding any change in consumption. Actual average domestic consumption of both gas and electricity varies from year to year due to changes in weather and energy efficiency improvements.

The majority of the major six domestic energy suppliers announced increases to their gas prices in early to mid-2018. All the major six domestic energy suppliers announced price rises for electricity and gas customers between March 2018 and December 2018, with some of the suppliers announcing price increases twice within this period.

The average energy bills in 2018 were higher than in 2017; this was mainly due to price increases for electricity and gas implemented between March and November 2018.

Figure 47 shows the average standard domestic energy bills, in cash terms. Combined gas and electricity bills have increased by £65 (5.2%) between 2017 and 2018 (to £1,314). Average standard electricity bills in 2018 increased by £49 (to £668, to a unit cost of £0.175/kWh). Average gas bills increased by £16 (to £646, to a unit cost of £0.043/kWh) compared with 2017. With the exception of a 3.0% fall in 2010, combined bills increased each year between 2002 and 2014. Between 2014 and 2016 combined bills decreased, however in 2017 they started to increase again and are now 2.2% lower than their peak in 2014 in cash terms. [31]

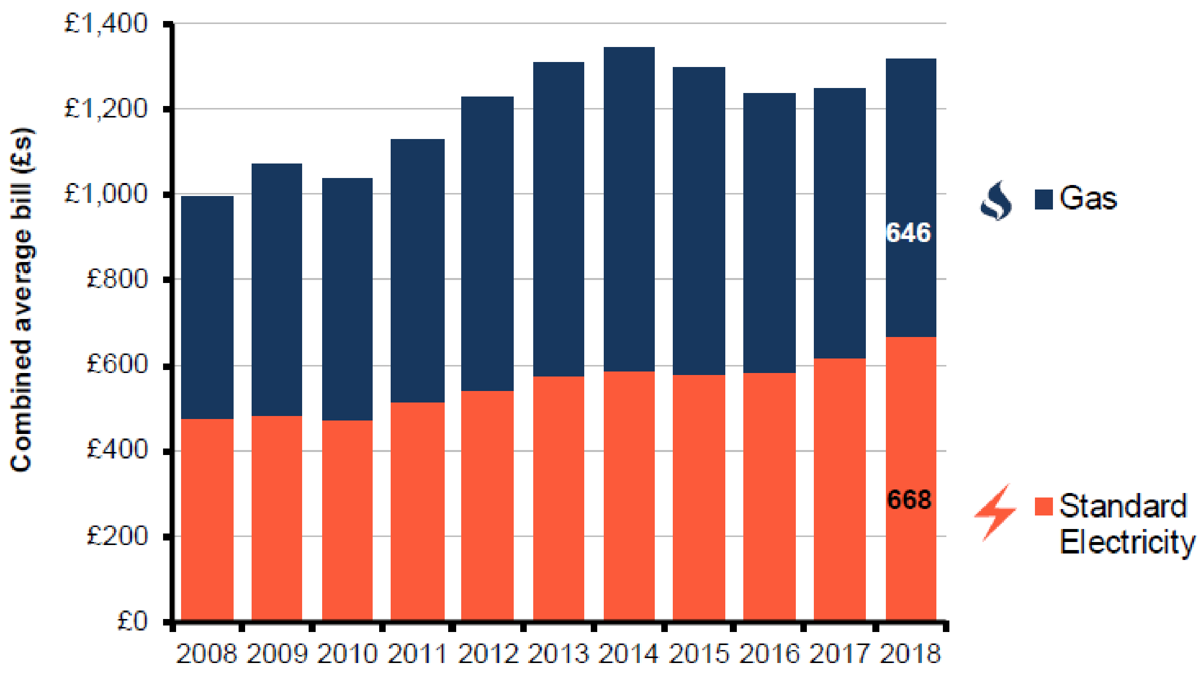


Figure 47: Average standard electricity and gas bills [31]

3.4.2. 2050 projection

In 2018, a study on the cost of future heat infrastructure options was made by Element energy and E4tech [32]. In this analysis, there are two potential large scale solutions for low carbon heat, and a range of smaller solutions which may complement one of them. The first option is electrification, using heat pumps to increase the efficiency of using electricity for heating. Alternatively, hydrogen (which creates only water vapour when burnt) from a zero carbon source could be used as a direct replacement for natural gas, fuelling boilers and appliances.

In an annexe of this study [33], the energy and fuel bills were modelled for 2050. Calculations use an unweighted average of two alternative heat solutions. Table 2 shows the results of this study:

Table 2: Average annual household bill for power and heat in 2018 and 2050

	2018			2050		
	Consumption (kWh)	Unit cost (p/kWh)	Total (£)	Consumption (kWh)	Unit cost (p/kWh)	Total (£)
Power (domestic appliances and lighting, but excluding electricity for heat and driving)	3400	15.8	540	3400	13.3	460
Heat: fuel/electricity costs	14300	5.2	750	7000	8.4	590

3.4.2.1. Electricity for domestic appliances and lighting

The cost of electricity relies on power modelling produced for the Commission by Aurora Energy Research [34]. The model estimates the unit prices of electricity for the two heat scenarios. Based on a low carbon power sector with 70% of generation from renewable sources in 2050, the average unit price of electricity is estimated to be 13.3 p/kWh.

Consumption for domestic appliances and lighting in 2050 is assumed constant at today's levels, to give a like for like comparison to today's bills. In practice, the same level of services (appliance outputs, such as washing or cleaning, and light levels) will require less electrical input in 2050, since appliances and lighting become more efficient over time. People may also choose to consume different quantities of electricity, as incomes and relative prices change, and as new electrically powered devices become available. However, this does not affect the cost of today's level of consumption in 2050.

3.4.2.2. Heating and hot water

The cost of heat in 2050 relies on the heat modelling produced for the Commission by Element Energy.

Energy consumption in 2050 differs from that today to achieve the same levels of heating for two reasons. Firstly, energy efficiency measures mean less heat is wasted. Secondly, the technologies vary in their efficiency of converting input energy into heat. Heat pumps, which transfer rather than generate heat, are particularly efficient, reducing the amount of input energy required for the same level of heat.

Averaging the two scenarios then gives average consumption of 7.0 MWh of energy consumed in 2050 for heating per household, at a weighted average unit cost of 8.4p/kWh.

4) Market potential for district heating/cooling

4.1. Heat pumps in District heating as a solution

4.1.1. Waste heat for District heating

Low carbon heat networks have a key role to play in areas of high density of heat demand. They enable waste heat to be distributed to a wide range of end users and can minimise the space taken in individual apartments. However, as the electricity grid decarbonises, the carbon benefits of gas-fired Combined Heat and Power (CHP) significantly reduces as the electricity produced by CHP becomes higher carbon than that supplied by the national grid. This reduction in the carbon benefit, along with the need to reduce combustion in large cities for air quality reasons, means that the heat generation for DH networks will need to evolve significantly compared to the current approach. DH using low carbon sources and distributing heat at very low temperatures will be required and heat pumps can play a key role in these networks though their ability to extract and upgrade the heat available from waste or environmental heat across the city. The higher temperature the heat source, the less energy is required to provide heating to end users. [6]

Figure 48 outlines potential waste and environmental heat sources.

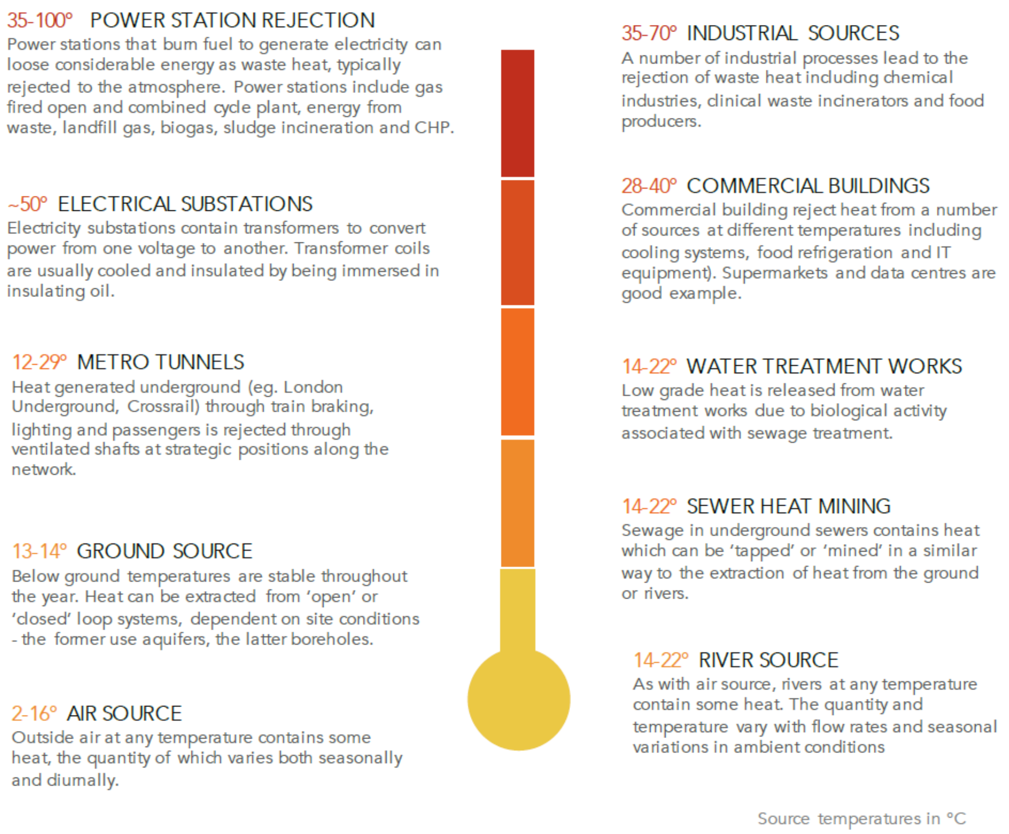


Figure 48: Potential heat sources for DH [6]

4.1.2. Heat losses

It's common that for the evaluation of district heating efficiency, the relative heat loss is used. The relative number is the rate of lost heat energy to heat output from a heating plant to the DH network. [35] Indeed, a significant amount of heat is lost during the heat path (from the heat generation to the consumption) along long distances pipes. Moreover, this heat loss is also observed in the residential dwelling level, as a significant length of pipework is present inside the dwelling. This phenomenon leads to heat over-generation to meet the heat demand, which obviously decreases the efficiency of the heat supply.

A study (published by BRE for the National Calculation Methodologies for Energy Rating of Dwellings (SAP)) was made in 11 different heat networks to evaluate this heat loss [36]. The result was that the distribution losses obtained were between 23 and 66% (Figure 49).

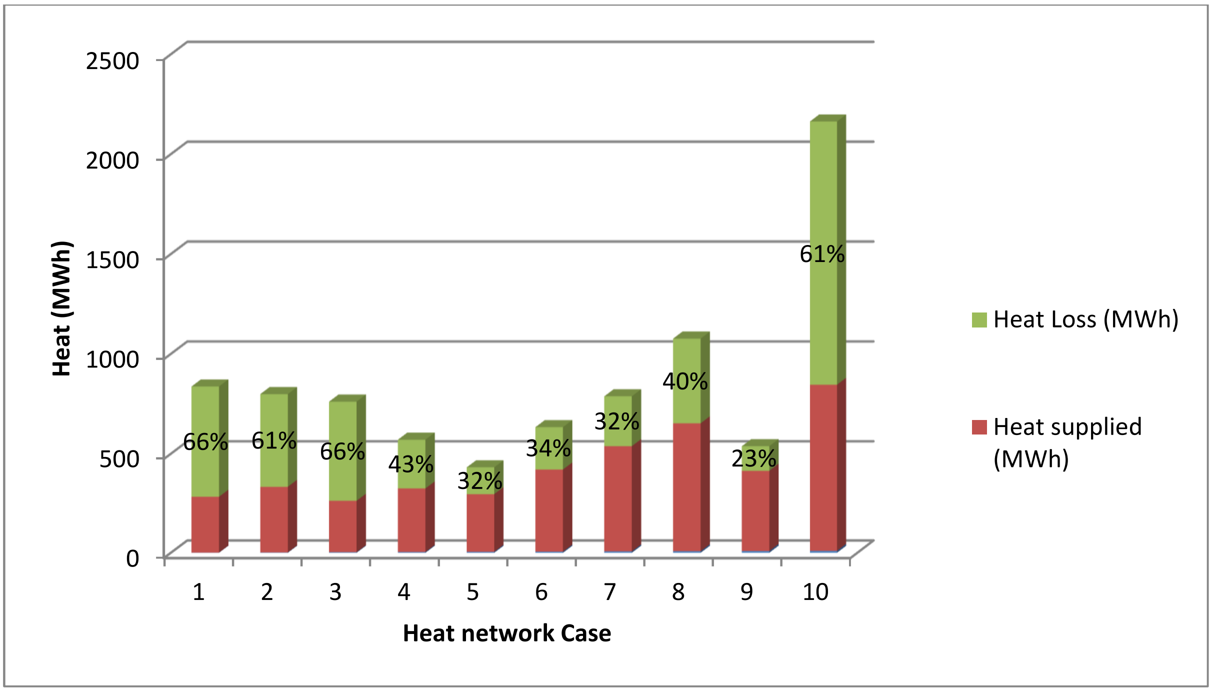


Figure 49: Proportion of heat loss in heat generation by case study (case study 11 was confidential) (made from data [36]).

The UK Standard Assessment Procedure (SAP, standard methodology used to assess the energy performance of UK buildings) has in its latest edition recognized these high heat losses therefore proposes a default distribution loss factor (DLF) of 2.0 (50% heat loss). If the network is designed and signed off in accordance with the CIBSE/ADE "Heat Network: Code of Practice for the UK", the default DLF is reduced to 1.5 (33% heat loss) [37].

In order to increase efficiency, it's important to know what contributes to heat losses. The following parameters affect the network heat loss [35]:

- Overall network heat transmission which depends on the insulation materials.

- Temperature level of network: Heat losses are driven by temperature gradient. Drop of temperature level in a DH network will bring about the reduction of heat loss due to a smaller temperature gradient between the DH heat media and external environment. The reducing temperature schedule in the network is one of the easiest possibilities to decrease the loss in case there are no hydraulic problems and consumer substations are able to work with lower parameters and deliver the needed amount of heat to the house heating system.
- Network geometrical dimensions. Heat loss depends on the heat transmissions are of the DH networks which in turn depends on the average diameter and length. A network with smaller average diameter and shorter length will have smaller heat loss.

A study was carried out to measure the effect of the network flow temperature on the heat loss [38]. The results clearly demonstrate that high temperature network (80°C) leads to high heat loss (Figure 50 and Figure 51). These figures show theoretical modeled values, real heat loss at 80°C are significantly higher (as shown in Figure 49). It's important to mention that, currently, for a typical UK multi-occupancy building, a centralized system with a water loop of 70-80°C is used (which leads to large heat losses). Figure 51 also shows the influence of the delta T between the flow and return temperature of a heat network. A large delta T obviously reduces the losses, but is not possible if the total load on the heat network is low. Both figures also demonstrate that a lower overall network temperature is a good way to reduce the losses significantly.

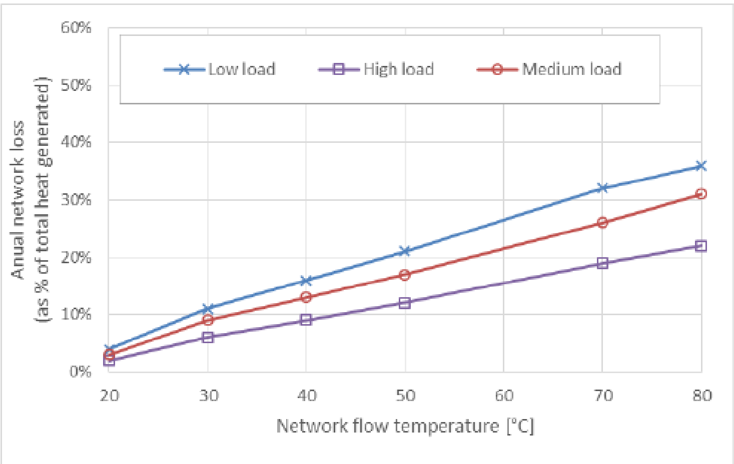


Figure 50: Annual theoretical distribution losses as % of total heat generated for various heating loads [38]

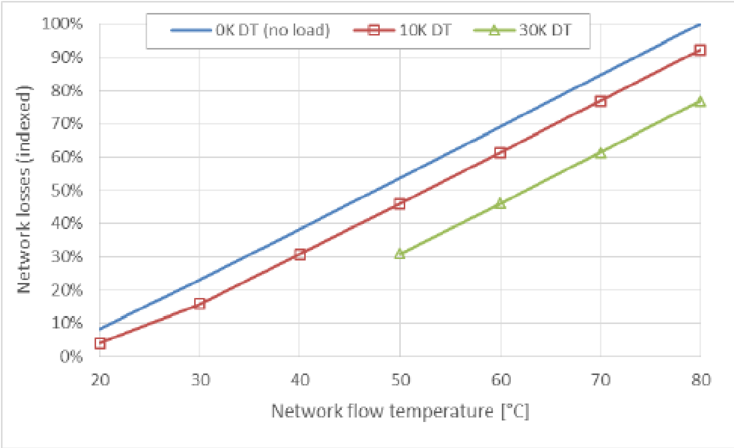


Figure 51: Comparison of network losses for varying flow temperatures and temperature differences (Indexed to 80°C flow temperature)

Another problem generated by heat losses is over-heating [38]. Over-heating has been highlighted as a real problem in corridors of apartment blocks for new and refurbished properties. It is particularly frequent during summer in the shared areas of an apartment block (corridors, stairs shafts…) but can also occur when heat demand is low. At this time, there is no need for heating but there is a constant need for hot water. This requires a constant feed of high temperature water through the heat network in order to service the hot water and leads to substantial over-heating.

Therefore, a reduction of the DH temperature has two positive effects on the energy efficiency of the heat supply. Firstly, when the DH temperatures are reduced, the heat losses from the pipe networks are also reduced. This can generate significant energy savings regarding to the high distribution losses of high temperature networks. Secondly, the over-heating problems can be overcome.

4.1.3. Heat pumps in low temperature networks will reduce heat losses

A good way to apply low temperature networks and make them more energy efficient is to implement heat pumps. Heat pumps have lower output temperature than the expected 70-80°C temperature in the network [38]. When looking at heating, this should not be an issue and the flow loop temperatures could be reduced to more favorable temperatures for heat pumps if the heat emitters have been sized up properly for low temperature applications. The use of heat pump could be applied in several different ways:

- Heat pump as a heat generator for the centralized heating loop with under-floor heating or fan coil convectors for heating.
- Individual heat pump in each home working from a very low temperature loop
- A combination of the above

A heat pump can also be used as a secondary heating device for heating and hot water in each apartment. This solution is particularly elegant for working with very low temperature heat network. It can be used to raise the temperature from a very low temperature network (at say 25°C) to a useable temperature inside the home. This combines all the advantages of a low temperature loop with the efficiency of a heat pump.

A very low temperature at 25°C can easily integrate with waste heat unlike the current heat networks which require high temperatures. This can work well with low grade energy available widely in cities, even using waste heat from sewers as a potential (see 4.1.1).

Therefore, there is a large potential to lower the district heating temperature by using heat pumps.

4.1.4. The 5th generation DH

The first generation of district heating systems used steam as the heat carrier. These systems were first introduced in USA in the 1880s. Almost all district heating systems established until 1930 used this technology, both in USA and Europe. Typical components were steam pipes in concrete ducts, steam traps, and compensators. The primary motivation in society for the introduction of these systems was to replace individual boilers in apartment buildings to reduce the risk of boiler explosions and to raise comfort [39].

The second generation of systems used pressurized hot water as the heat carrier, with supply temperatures mostly over 100°C. These systems emerged in the 1930s and dominated all new systems until the 1970s. Typical components were water pipes in concrete ducts, large tube-and-shell heat exchangers, and material-intensive, large, and heavy valves.

The third generation of systems was introduced in the 1980s and took a major share of all extensions in the 1980s and beyond. Pressurized water is still the heat carrier, but the supply temperatures are often below 100°C. Typical components are prefabricated, pre-insulated pipes directly buried into the ground, compact substations using plate stainless steel heat exchangers, and material lean components. The primary motivation is security of supply in relation to the two oil crises leading to a focus on energy efficiency related to CHP and replacing oil with various local and/or cheaper fuels such as coal, biomass and waste. Moreover, solar and geothermal heat has been used as a supplement in a few places.

In order to implement a sustainable energy system based on renewable energy and to include substantial reductions in the space heating demand, the 4th generation DH was born. Compared to the previous generations, the temperature levels have been reduced with supply temperatures in the range of 70 °C and lower. Potential heat sources are multiple:

- waste heat from industry
- CHP plants burning waste
- biomass power plants

- geothermal and solar thermal energy
- large scale heat pumps
- and other sustainable energy sources

4th generation district heating systems are expected to provide flexibility for balancing wind and solar power generation. Therefore, large scale heat pumps are regarded as a key technology for smart energy systems with high shares of renewable energy up to 100% and advanced 4th generation district heating systems. The 4th generation concept involves the development of institutional and organizational frameworks with appropriate cost and incentive structures. [39]

In order to be able to fulfill its role in future sustainable energy systems, DH will need to have the following abilities:

1. The ability to operate existing, renovated and new buildings with low-temperature DH for space heating and DHW.
2. The ability to distribute heat in networks with low grid losses.
3. The ability to recycle heat from low-temperature sources and integrate renewable heat sources such as solar and geothermal heat.
4. The ability to be an integrated part of smart energy systems and thereby helping to solve the task of integrating fluctuating renewable energy sources and energy conservation into the smart energy system.
5. The ability to ensure suitable planning, cost and incentive structures in relation to the operation as well as to strategic investments related to the transformation into future sustainable energy systems

Finally, the trend to lower distribution temperatures reaches its logical conclusion with 5th generation networks. This 5th generation heat network distributes heat at near ambient temperature in order to minimize heat losses and reduces the need for extensive insulation. Each building (or even each dwelling) on the network uses a heat pump in its own plant room to extract heat from the ambient circuit when it needs heat, and uses the same heat pump in reverse to reject heat when it needs cooling. This allows waste heat from cooling to be recycled to a place which needs heating. It is much more efficient for cooling to be provided by heat pumps rejecting heat into an ambient temperature circuit, than by forcing roof mounted chillers to waste heat into hot air. A low temperature circuit allows the opportunity to gather heat from any source of waste heat (from surplus heat from industrial processes to surplus heat from cold stores). [40] [41] [42]

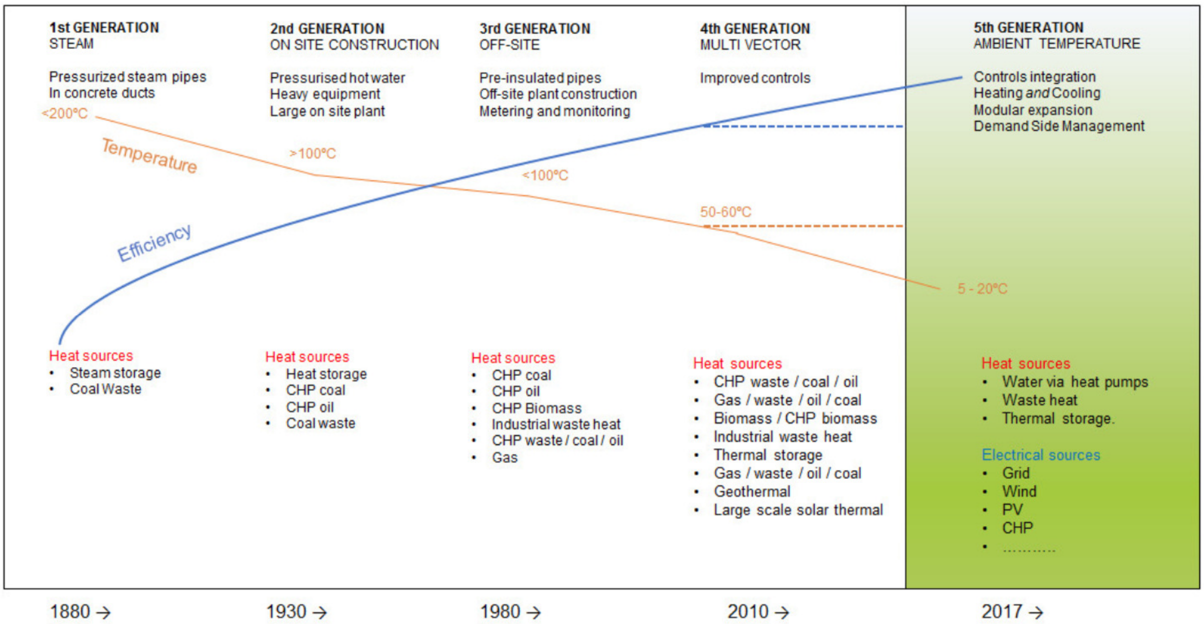


Figure 52: District heating generations [41]

4.2.Impact of heat pump deployment

The previous sections have established that heat pumps in District heating are expected to play an important role in the delivery of low carbon heat in UK. A study was made (by London Greater Authority) on the implications heat pumps would have in terms of carbon savings, capital costs and running costs to a 'baseline' approach relying on a connection to a District Heating network with gas-fired boilers and CHP, the following information was taken from this report [6].

4.2.1. Carbon savings

In order to estimate the quantitative impact of heat pumps on energy demand and carbon savings, an energy demand scenario has been assessed. It uses benchmarked predicted energy consumption data (taken from CIBSE Guide F for the commercial buildings and from PHPP modeling for the residential buildings, Table 3) in order to assess the impact of heat pumps against a realistic energy demand. This is to estimate the potential actual carbon reduction benefits of heat pumps in operation.

Several case studies of common development types in London were investigated (Table 4). These include residential buildings, a large school building, office buildings and 'district combinations', i.e. a residential led group of 15 buildings and a mixed-use group of 15 buildings. The following case study development types have been modeled with the described heat pump systems. This is to assess a range of applications types and variations of heat pump designs. This has allowed the energy saving and carbon reduction benefits of the technology to be assessed and compared for each case to a 'business as usual' scenario based on gas-fired CHP.

It's important to mention that GLA took an electricity carbon factor of 302gCO_2/kWh for their calculations. This value was taken to match with other GLA reports. This carbon value varies as a function of the sources, e.g. SAP10 proposed a factor of 233 gCO_2/kWh [37]. Therefore, if this value was taken, the heat pumps carbon emissions would be lower than what is found in this scenario. Moreover, the electricity carbon factor will decrease in the future due to the electricity generation decarbonisation (For exemple, a scenario conducted for the National Infrasctructure Commission assumes 30gCO_2/kWh by 2050 while National Grid's Future Energy projections outlines a 20gCO_2/kWh [43]) . Therefore, heat pumps carbon emissions will also decrease.

Table 3: Benchmark data used for energy assessment [6]

	Benchmark Source / CIBSE Guide F Reference	Space Heating Demand (kWh/m²)	Hot Water Demand (kWh/m²)	Electricity Demand (kWh/m²)
Residential	PHPP Modelling	30	30	40
Primary school	Education, Primary (good practice)	50	10	40
Hotel	Hotels, Holiday (good practice)	90	15	20
Office	Type 4 Office (good practice)	80	10	100

Table 4: Case studies and modelled systems [6]

Case study	Modelled heat pump system
1. Residential Block: 70 units	Centralised air source heat pump with VRF distribution and secondary cascading heat pumps in each unit delivering space heating and hot water.
2. Residential Block: 100 units	Closed loop boreholes providing ground temperature water to be distributed to all units (at 10°C). Individual heat pumps in each dwelling providing space heating (at 35°C via underfloor heating) and hot water (at 65°C) with thermal storage.
3. Primary School (6,500m²)	Air source heat pump generating space heating (at 35°C via underfloor heating) and hot water (at 65°C) with thermal storage.
4. 100-bed Hotel (3,000m²)	Centralised air source heat pump VRF system providing space heating (and cooling) to all areas and AHU heating/cooling coils. Hot water generated by a dedicated air source heat pump.
5. Office Building (7,000m²)	Centralised air source heat pump with hot water loop (35°C - 40°C) providing space heating via fan coil units. Hot water generated using direct electric point-of-use heaters (toilets and kitchenettes only).
6. Office Building (50,000m²)	Ground source heat pump with hybrid electric heat recovery providing space heating via a hot water distribution loop (35°C - 40°C) and local fan coil unit terminals. Hot water generated using direct electric point-of-use heaters (toilets and kitchenettes only).
7. District (Residential)	Energy centre with closed-loop boreholes coupled to a 2-stage high temperature heat pump generating 70°C to 80°C to a thermal store. Hot water distribution to all units.
8. District (Mixed-use)	Energy centre with closed-loop boreholes couple to single stage heat pump generating 50°C to a thermal store. Space heating taken directly from local heat interface units. Hot water generated by local indoor water-to-water heat pump unit (40°C to 65°C increase) feeding off the primary loop.

The results of this analysis are shown in Table 5 and Figure 53.

Communal heating using gas boilers provide a reference scenario based on boilers operating at 91% efficiency with 10% distribution losses within the building. An additional 20% loss is assumed for the district heating based communal boiler systems, which increases the carbon factor of heat from 264 to 330 gCO2/kWh.

Communal heating using gas-CHP provides the baseline scenario, which clearly highlights the erosion of carbon benefits previously associated with gas-fired CHP as a result of the reduced electricity carbon emissions factor. The carbon content of heat for this system is higher than equivalent systems using heat provided completely by gas boilers. It is assumed the CHP system operates with a thermal efficiency of 48% and an electrical efficiency of 32%.

Heat pump systems provide the lowest carbon heat for all case studies, though significant differences exist between the various types of heat pump. The lowest carbon heat is achieved by the residential block using ground source heat pumps coupled to a communal ground loop. This system benefits from very small distribution losses due to the ambient flow temperature and relatively high efficiencies of 380% for space heating at 35˚C and 290% for DHW at 60˚C offered by ground source heat pumps.

The district heat based systems generally have higher carbon heat as a result of reduced efficiencies from the higher flow temperatures assumed for this system, and additional distribution losses. This is despite assuming the use of specialist two-stage heat pumps that can achieve relatively high efficiencies of 250-290% even at flow temperatures that would be considered high for a normal heat pump.

Direct electric systems provide the highest carbon heat.

Table 5: Results of predicted actual carbon saving assessment - Total annual carbon emissions (assuming a carbon factor of 302gCO_2/kWh for electricity) [6]

	Communal heating with gas boilers (kgCO_2/yr)	Communal heating gas CHP-led (kgCO_2/yr)	Heat pump System (kgCO_2/yr)	Direct electric Resistance (kgCO_2/yr)
1. 70-unit residential block	164,000	168,000	137,000	178,000
2. 100-unit high rise residential block	235,000	240,000	190,000	254,000
3. 6,500 sqm primary school	212,000	219,000	200,000	238,000
4. 100-bedroom hotel	293,000	300,000	251,000	320,000
5. 7,000 sqm office	369,000	375,000	364,000	393,000
6. 50,000 sqm office	3,958,000	4,007,000	3,913,000	
7. District (Residential)	4,274,000	4,373,000	3,619,000	
8. District (Mixed-use)	3,648,000	3,724,000	3,388,000	

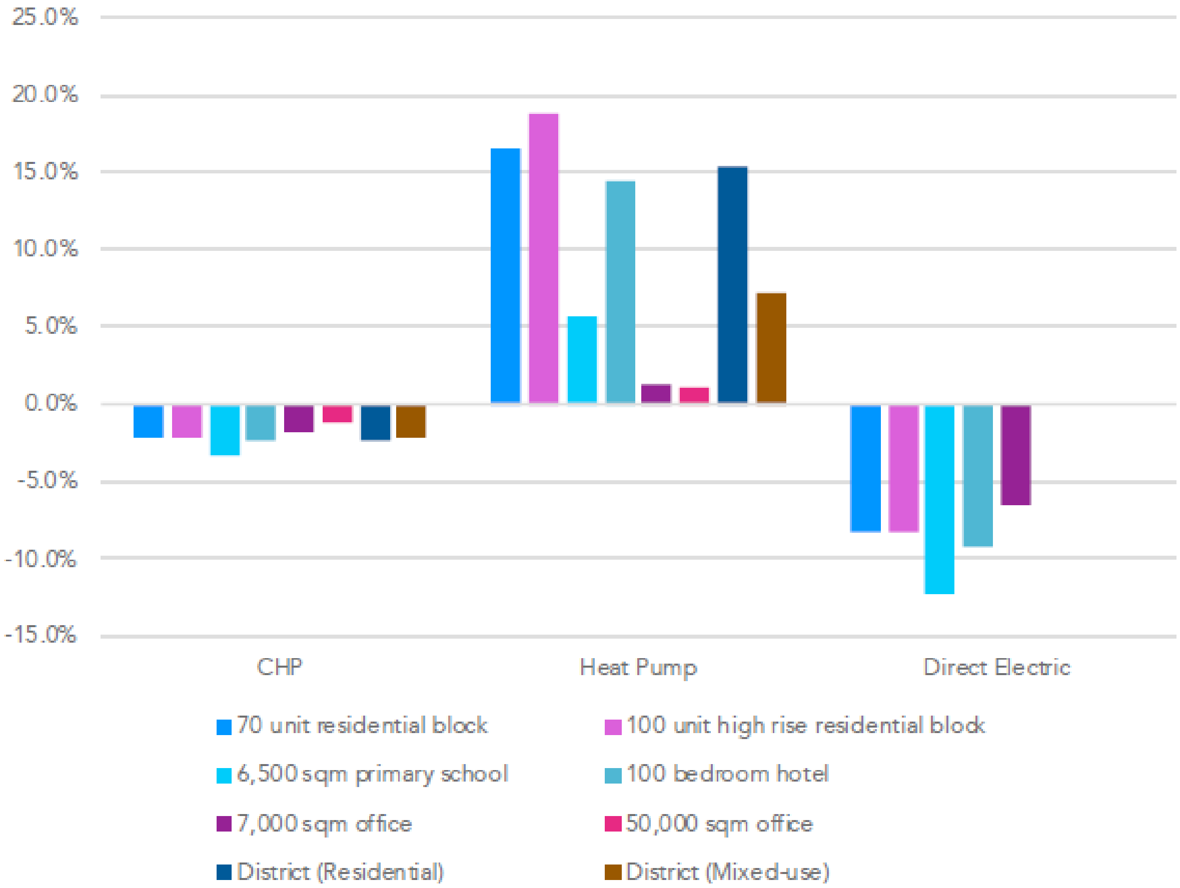


Figure 53: Summary of estimated carbon emission savings compared to a gas boiler scenario [6]

Heat pumps are able to provide the greatest energy efficiency and carbon saving benefits when the overall heating/hot water system is designed around the characteristics of heat pumps. For example, it is not ideal to centrally install a large heat pump system and distribute high temperature water throughout a building or district network, as may be the case for a conventional gas boiler or CHP installation. This is because heat pumps operate least efficiently at high output temperatures, there is generally little or no efficiency advantage of using large capacity heat pumps compared to small capacity heat pumps and pipework heat distribution losses are high when distributing water at a high temperature. For the same reasons, heat pumps can be very efficient when connected to a low carbon heat source (e.g. waste heat) and supplying a 4th generation district heating system at ultra-low temperatures.

4.2.2. Capital cost

Assessing the impact of heat pumps on capital costs for new developments is challenging: firstly due to the variety of new building types and scales in London, but most importantly due to the variety of heat pump systems which can be applied to each building type and to the wide range of costs of these systems. The idea of this study is to give views on the capital costs of heat pump systems compared to a 'business as usual' London Plan compliant baseline varied substantially. To achieve this comparison, a qualitative assessment of a large number of systems on capital costs has been considered and a quantitative assessment of a smaller number of systems has been undertaken. It compares the Mechanical and Electrical capital costs of heat pump systems against a baseline relying on a connection to a District Heating system with gas-fired CHP to assess the impact of the change in terms of:

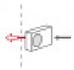
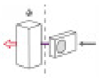
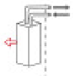
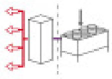
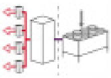
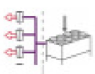
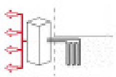
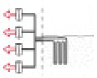
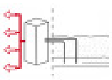
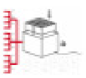
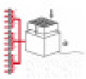
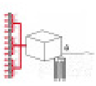
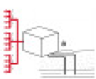
1. **Infrastructure**
   The baseline capital costs include the district heating pipes to the edge of the site. It is assumed that all other district heating costs (e.g. energy centre) are not paid for by the developer. This approach has been adopted as is the case for the majority of new buildings in London.
2. **Building**
   The baseline capital costs include the costs of the heat substation on the ground floor and the heating distribution to each unit.
3. **Dwelling**
   The baseline capital costs include the costs of the heat interface unit in each apartment and of the heating emitters (e.g. radiators).

As an example, for a communal ground loop connected to individual heat pumps (Ground source Medium G-2), the ground loop would introduce significant additional 'infrastructure costs' but also savings in terms of 'building costs' as no central plant room would be required. However, it would also lead to additional 'dwelling costs' due to the replacement of the heat interface unit with the individual water-to-water heat pump and its hot water cylinder. Another example would be a 4th generation District Heating network with air source heat pumps and a communal heat pump in each building connected to heat interface units. 'Infrastructure costs' would be similar for the developer (i.e. DH pipes to the edge of the site). 'Building costs' would be slightly higher due to the replacement of the heat substation by a building scale water-to-water heat pump. 'Dwelling costs' would be equivalent.

The scale of additional costs is indicated by 1 to 5 '+' and the scale of savings by 1 to 5 '-'. It indicates that costs comparisons are very dependent on the heat pump system. Please refer to Table 6 on the following page. Generally, individual heat pump systems are likely to be more expensive than communal systems as they add a significant cost at the dwelling level. This review does not include the impact of the Renewables Heat Incentive (RHI) which could add a positive effect on cost.

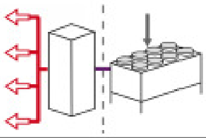
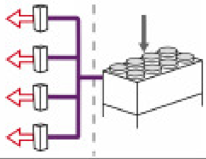
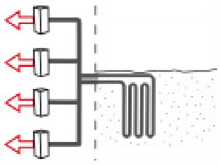
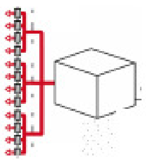
In summary, for the small systems there is clearly an additional cost at the dwelling level. For the large scale systems, costs are comparable except there is a low additional cost at the building level for two of the heat pump scenarios (Large A2, Large G1/2). For the medium systems, there is a range of a scale of additional costs between the three levels (infrastructure, building, dwelling).

Table 6: Qualitative appraisal of additional costs and cost savings for the developer of a medium density apartment block [6]

Type	Ref	Example	Capital cost implications for developer		
			Infrastructure	Building	Dwelling
AIR SOURCE Small-A1		Monobloc	- -	- - -	+ + + +
AIR SOURCE Small-A3		Hybrid	-	- - -	+ + + + +
AIR SOURCE Small-A4		Compact unit Heat Pump + MVHR	- -	- - -	+ + + + +
AIR SOURCE Medium-A1		Communal air source heat pump to heat interface units (HIUs)	- -	+ +	=
AIR SOURCE Medium-A2		Communal air source heat pump to heat pumps	- -	+	+ + +
AIR SOURCE Medium-A3		Communal VRF system air source heat pump to individual heat pumps	- -	+	+ +
GROUND SOURCE Medium-G1		Communal closed-loop ground source heat pump to heat interface units (HIUs)	++	+	=
GROUND SOURCE Medium-G2		Communal ground loop connected to individual heat pumps	++	-	+ +
WATER SOURCE Medium-W1		Communal water source heat pump to heat interface units (HIUs)	+	+ +	=
AIR SOURCE Large-A1		DH network with primary air source heat pumps	=	=	=
AIR SOURCE Large-A2		4th generation DH network with air source heat pumps and heat pump in each building	=	+	=
GROUND SOURCE Large-G1/2		4th generation DH network with ground source heat pumps and heat pump in each building	=	+	=
WATER SOURCE Large-W1/2		DH network with primary water source heat pumps	=	=	=

A more detailed analysis was also undertaken for four types of heat pump systems (Table 7).

Table 7: Overview of heat pump systems considered [6]

Scenario	Description		Description	
HP 1	Building level air source heat pump system with water distribution to HIUs		Communal air source heat pump to heat interface units (HIUs)	Heat is generated by a medium-scale / communal air source heat pump. A water-based system is used to distribute heat to each unit via a Heat Interface Unit (HIU).
HP 2	Building level air source heat pump system with refrigerant distribution to FCUs and separate system for DHW		Communal air source heat pump to heat pumps (e.g. VRF)	A refrigerant-based system is used to distribute heat to each unit where secondary heat pumps extract heat from it.
HP 3	Communal ground loop with individual heat pumps		Communal ground loop connected to individual heat pumps	A ground loop is supplying water to individual water-to-water heat pumps in each unit.
HP 4	Connection to Waste Heat Network with building level heat pump system		4th generation DH network waste source heat pump and secondary heat pumps in each building	Heat is generated by a large-scale waste source heat pump system potentially used in conjunction with other systems (e.g. central gas boilers). Low temperature heat is distributed to secondary heat pumps in the building.

The analysis summarised in Table 8 indicates that the heat pump solutions are likely to cost between 0.4% and 2.9% more than the baseline. Although additional costs would vary substantially depending on the building and context, they are likely to be comprised in the range £930/unit (HP1)-£7,080/unit (HP3). HP1 represents the most common and economic solution, although not the most efficient.

This excludes any potential costs associated with electrical infrastructure costs as this it depends on the local context (e.g. requirement for a network upgrade or not) and the scale of the additional requirement (e.g. whether it triggers the requirement for a much larger substation).

It is however important to note that these cost estimates are in the higher ranges. The costs of HP3 could be significantly reduced with scale and if design and procurement are optimized (as it is the case for the eight tower blocks in Enfield – please refer to associated case studies). Costs of heat pumps are also generally expected to reduce over time as demand increases and the supply chain develops.

Table 8: Overview of key impact on capital costs for the developer [6]

Scenario	Description	Additional costs (£)	Additional costs (£/m² GIFA)	Additional costs (£)	Additional costs (Proportion of total construction costs)
Baseline	Connection to District Heating Network with CHP	Ref	Ref	Ref	Ref
Ref 1	Communal gas boilers	- £50,000	- £7/m²	- £590/unit	- 0.2%
Ref 2	Direct electric heating	- £582,000	- £79/m²	- £6,850/unit	- 2.8%
HP 1	Building level air source heat pump system with water distribution to HIUs	+ £79,000	+ £11/m²	+ £930/unit	+ 0.4%
HP 2	Building level air source heat pump system with refrigerant distribution to FCUs and separate system for DHW	+ £203,000	+ £27/m²	+ £2,380/unit	+ 1.0%
HP 3	Communal ground loop with individual heat pumps	+£602,000	+£82/m²	+£7,080/unit	+ 2.9%
HP 4	Connection to Waste Heat Network with building level heat pump system	+£432,000	+£59/m²	+£5,080/unit	+ 2.1%

The Department of Energy and Climate Change (DECC – now BEIS) commissioned Delta EE to undertake research into the potential cost reductions for air source heat pumps and ground source heat pumps between the market as it was in 2014 and a mass market scenario. These reports were published in 2016. The reports concluded that costs could reduce by 15-20%. This would be comprised of a 30-50% potential cost reduction in non-equipment costs and a 5-10% cost reduction in equipment costs. The cost reductions would be due to the larger installer base with larger companies, a consolidated supply chain, better sales channels and cheaper installation costs. The cost reduction associated with the equipment itself would be smaller as heat pumps can already be considered a mature technology at the European level.

4.2.3. Running cost

The assessment of running costs is challenging though as it is based on assumptions which are highly variable and also the subject of debate. For this analysis, this scenario was taken: residents living in an energy efficient new build 2-bedroom apartment of 70 sqm using approximately 4,200 kWh per year for heat (i.e. space heating and hot water), equivalent to 60 kWh/m2/year.

The main aim of this analysis is to investigate the impact of a change towards heat pump based solutions. Three scales of systems have therefore been considered and seven heating systems in total.

Small/individual scale:

- individual gas boiler
- direct electric
- individual air source heat pump

Communal/building scale:

- communal gas boiler
- communal air source heat pump
- communal ground loop individual heat pumps

District/large scale:

- district heating with gas-fired boilers and CHP
- district heating with heat pumps

When looking only at the energy cost component (i.e. the direct costs related to metered energy use for space heating and hot water) a simplistic comparison of predicted future heating bills between systems may seem the right approach but it can be misleading. The reason for this is that, depending on the scale of the system, some costs are embedded in the heating bills. It is therefore very important to be clear about what the heating cost comparison includes (Figure 54).

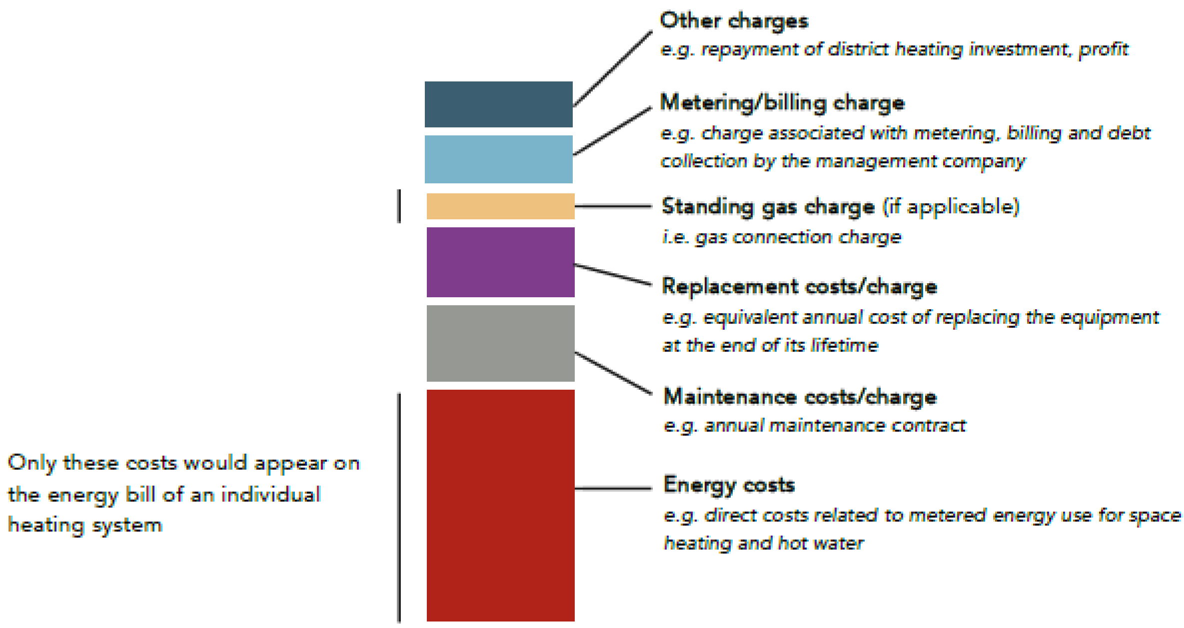


Figure 54: Key components of heating costs [6]

Figure 55 indicates that typically heat pumps are likely to lead to a small increase in annual heating costs compared to the cheapest non-heat pump solution (communal gas boiler, however, a communal ground loop with individual heat pumps is the cheapest overall and is very efficient. It is important to note that:

1. The costs associated with a communal air source heat pump system ('Communal ASHP below') will be lower if electricity is purchased at a cheaper rate.
2. The costs of metering and billing are an important component of all communal and district scale systems and should be reduced to a minimum to maintain low heating costs.
3. At the district scale, 'other charges' can be significant and our analysis suggests that they should be kept to a maximum of £100/year for an average 2-bed apartment in order for heating costs to remain competitive.

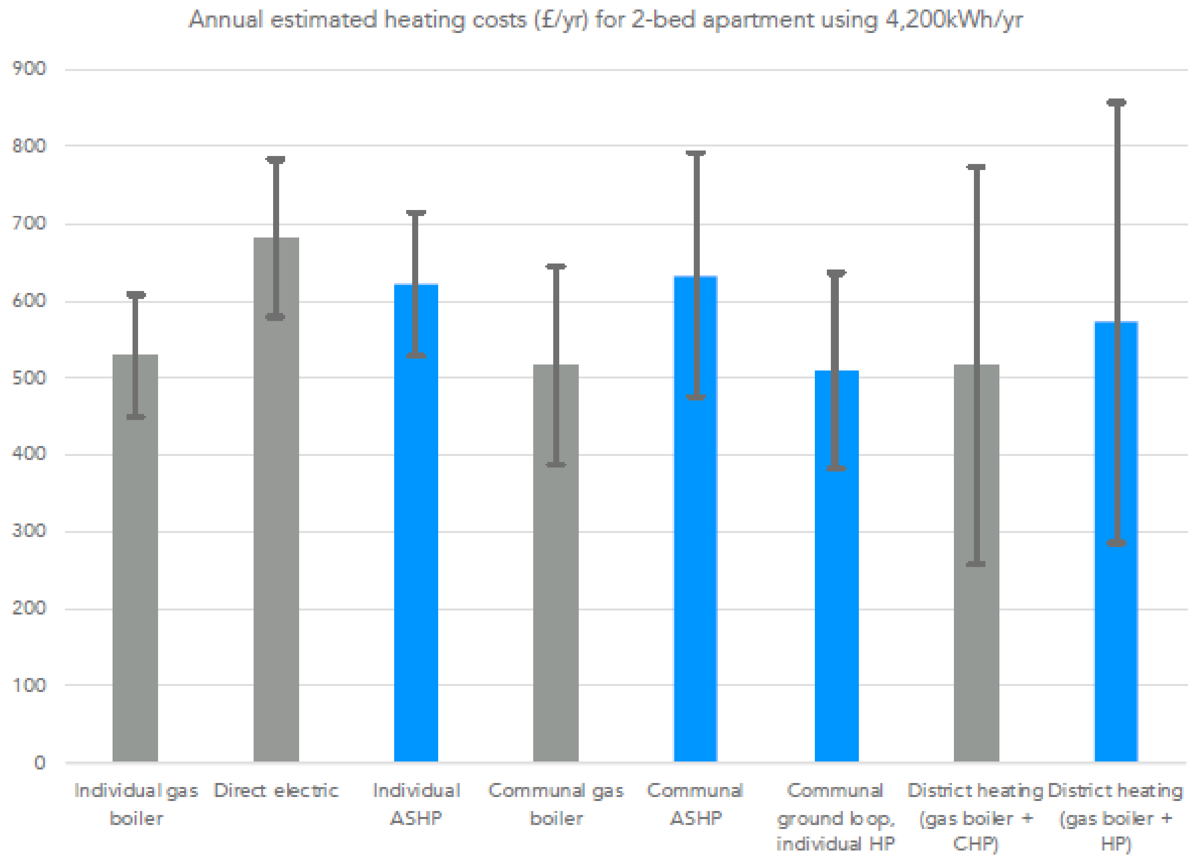


Figure 55: Comparison of predicted heating costs for the resident(s) of a 2-bed energy efficient apartment [6]

The Renewable Heat Incentive (RHI) can have a significant impact on heating costs. Assuming that 100% of the RHI savings are beneficial to the residents directly (e.g. individual air source heat pump) or passed on to residents in communal and district scale heat pump systems (for which commercial RHI tariff rates have been assumed), Figure 56 illustrates its likely impact on heating costs.

As it can be seen, the RHI would have a positive to very positive impact on residents' heating costs. With the RHI, individual air source heat pumps and the communal ground loop with individual heat pump systems would become the two most economic systems for residents. Heating costs of individual air source heat pump systems would become the lowest (circa £350/yr). If passed on to the residents, the benefit of the RHI would be to bring the annual heating costs to £380/yr (communal ground loop with individual heat pumps) or £570/yr (communal air source heat pump system). [6]

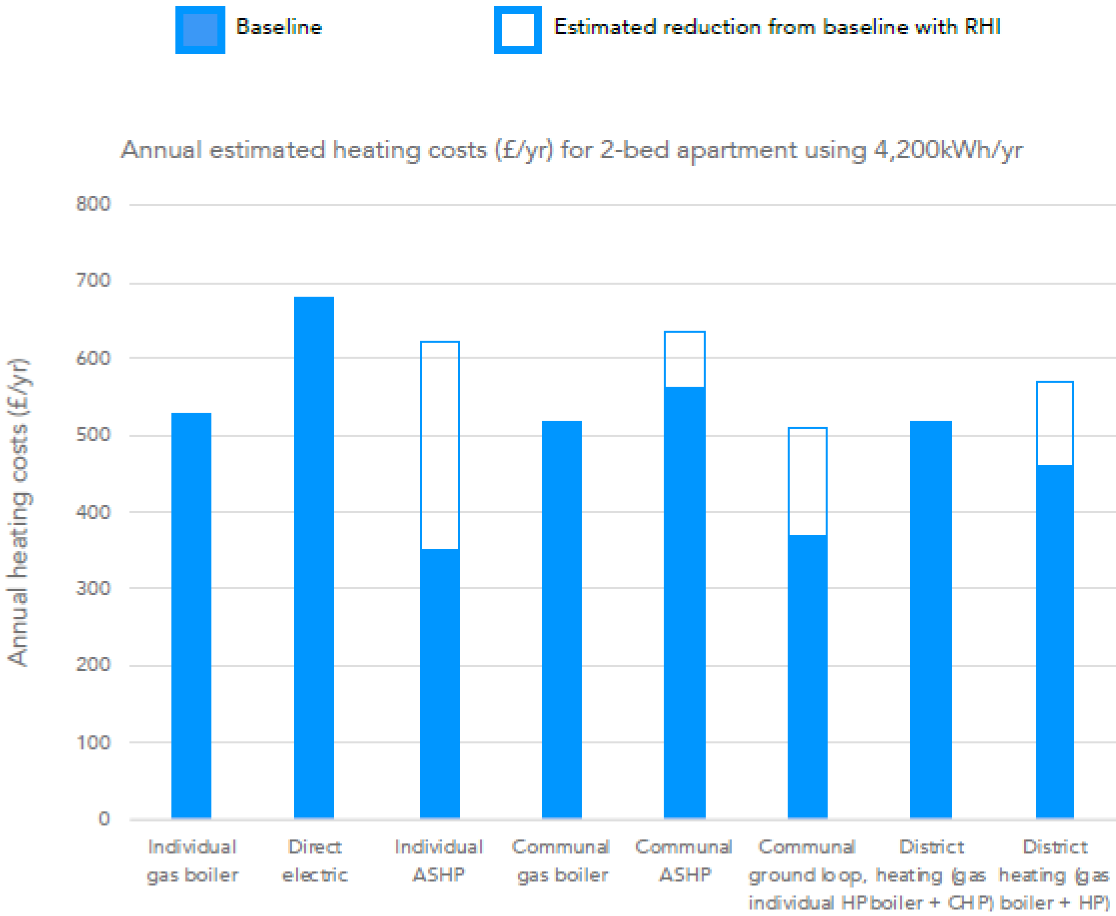


Figure 56: Impact of RHI on likely heating costs for a 2-bed energy efficient apartment [6]

4.3. Description of overall energy/CO_2 emissions reduction potential by HRE

Heat Road Map Europe project (HRE) developed low-carbon heating and cooling strategies for UK [13]. The main aim of these strategies is to demonstrate and understand how to cost-effectively use energy efficiency, be decarbonised, and design a pathway for decarbonised heating and cooling that fits within a broader decarbonised energy system. This means that the heating and cooling system is decarbonised in a way that enables the electricity sector to further decarbonise, and that does not stand in the way of further decarbonisation of the transport and industry sectors by using unnecessary amounts of bioenergy. This part of the report gives a short summary of the HRE analysis for UK and the information was taken from their report [13].

They made 3 scenarios:

- The Baseline 2015 scenario (BL 2015), which is a representation of the current energy system.
- The Conventionally Decarbonised 2050 scenario (CD 2050), which represents the development of the energy system under a framework that encourages renewables, but does not radically change the heating and cooling sector.

- The Heat Roadmap United Kingdom 2050 scenario (HRE 2050), which represents a redesigned heating and cooling system, considering different types of energy efficiency and better integration with the other energy sectors.

4.3.1. Heating and cooling demand in 2050

Figure 57 show the heating and cooling demands for the different scenarios.

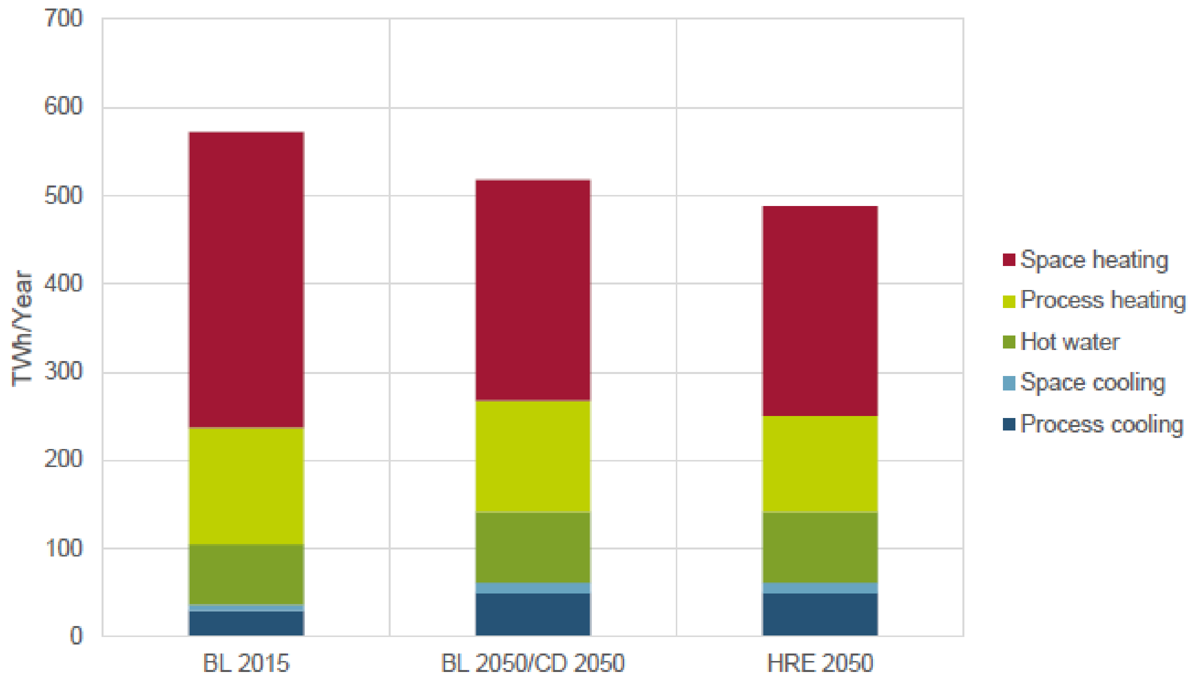


Figure 57: Delivered heating and cooling demands in the different scenarios [13]

4.3.1.1. *Space heating*

Space heating is, in all scenarios, the largest demand in the thermal sector. However, policy regarding the energy performance of buildings has been extremely ambitious at the UK's national level, so if current policy is fully implemented, this has an extremely large impact in terms of space heating, which decreases by 84 TWh in the 2050 Baseline. In HRE, a further 4% reduction is recommended, in order to achieve both efficiency on the demand and the supply side of the heating and cooling sector. To achieve over a 28% reduction, both renovation rates and renovation depths have to be increased and the efficacy of the existing policies constantly monitored and reviewed. Without this, decarbonisation becomes both technically more limited (especially in rural areas) and is likely to come at a higher cost.

4.3.1.2. *Process heating and hot water demands*

Process heating represents the second largest demand, the overwhelming majority of which is used by the industry sector in the United Kingdom. Since current policy has focussed mostly on space heating demands, under current policy savings in terms of process heating and hot water demands are not expected, and absolute demand for hot water and process heating will rise by around 2%.

In terms of the potential for savings in process heating, additional measures are necessary since all possible considered savings beyond the current policy projections are socio-economically feasible and desirable. In HRE scenario, that means that there should be savings of around 13%, in order to ensure the most cost-effective decarbonisation of the heating and cooling sector.

Hot water demands represent around 16% of the thermal energy demand in United Kingdom, meaning that while significant for the residential sector they don't represent a large part of the sector overall. Since demands are much more driven by behaviour and population, the ability to apply savings in this sector is relatively low and an overall growth of around 17% is expected between now and 2050 in the HRE scenario.

4.3.1.3. Cooling

Cooling, both in terms of space and process cooling, is the fastest growing part of the heating and cooling sector, but is not expected to represent more than 13% of the heating and cooling sector in the UK in 2050. Space cooling is expected to almost double towards 2050 (from 6,7 to 12 TWh), mostly in the service sector (which includes among others offices, hospitals, schools, and commercial buildings). In terms of space cooling in the residential sector a thirteen-fold increase is expected, but in absolute terms less than 8% of the 2050 demand is expected to be in the residential sector. At the same time, process cooling in industry is also expected to increase by about 14%, representing around 4% of the total heating and cooling demand in HRE. This means that while the growth for demand is very high (especially compared to space heating, where extremely substantial reductions in demand are considered for 2050), the heating and cooling sector overall is still dominated by space and process heating.

In addition, cooling is also typically produced very efficiently, so the potential for savings is not very high. However, further work is needed, especially to further explore how heat savings interact with increased cooling demands.

4.3.2. Heating and cooling supply in the energy system

4.3.2.1. Integrated energy system approach

One of the main objectives in HRE is to consider the effects of a deeper interconnection of the heating and cooling sector with the other parts of the energy system, creating synergies that result in a better use of the resources that are available, a lower level of cost and fuel use, and deeper decarbonisation (Figure 58). The synergy between the heating and cooling sectors and the industry (including the electrofuel production industry) is considered primarily from the perspective of being able to recover the excess heat that is lost within the conversion processes in thermal networks. This heat, which would otherwise be lost, can then be used to replace the use of other resources for the production of heating and cooling.

The heating and cooling sector in HRE is also connected more deeply with the electricity sector through the use of combined heat and power and heat pumps. The use of cogeneration, which responds to electricity demands but creates heat as a by-product, reduces the need for resource use in the heating and cooling sector in a similar way to the recovery of excess heat from industry. In addition, combined heat and power units are operationally more responsive than large condensing plants, so can respond better to the temporal fluctuations in variable renewable energy sources, allowing for more effective use of wind and solar power. Heat pumps can further contribute to this effect, providing heat in a highly efficient manner when electricity is abundant, potentially converting it into storage, and in this way reducing critical excess electricity and resulting in a better integration of variable renewable energy sources.

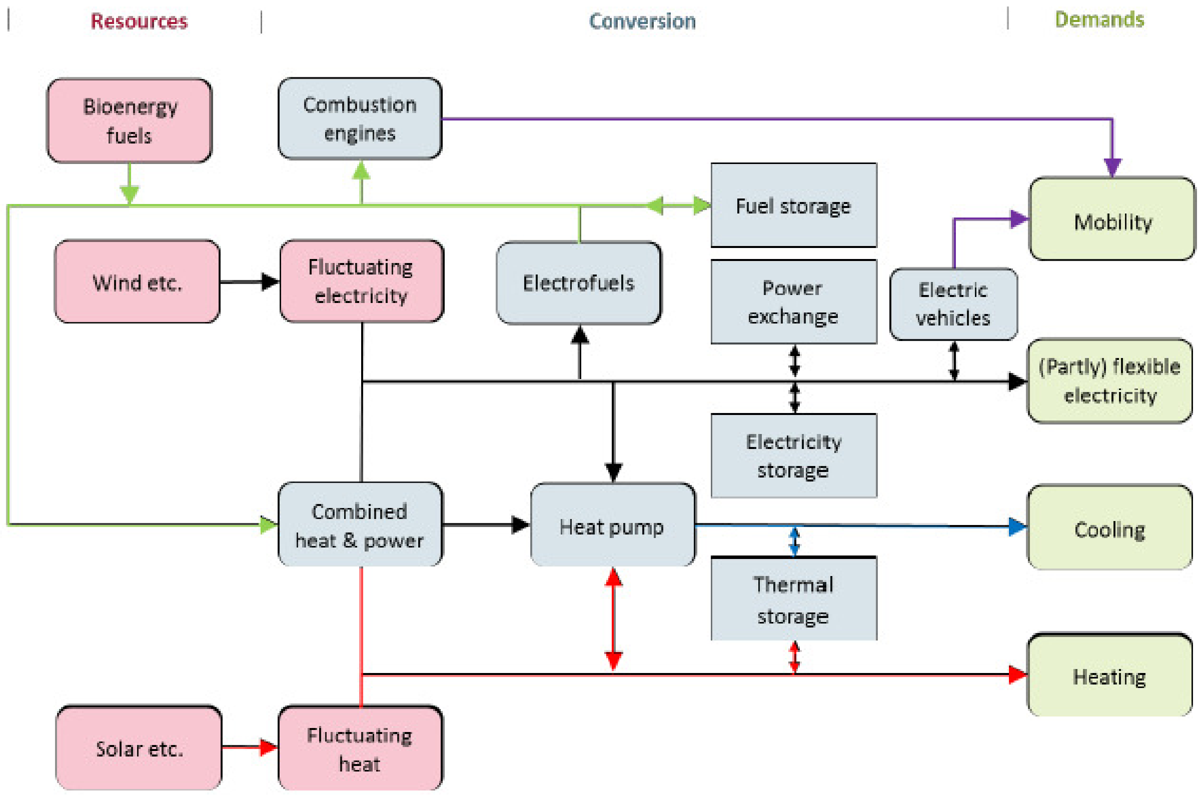


Figure 58: Illustration of the interconnected sectors, heating and cooling included, of a Smart energy system [13]

4.3.2.2. District heating in urban areas

In the HRE, district heating should be expanded to cover around 35% of the heating market in the UK , compared to 2% in 2015. The district heating sector is designed so that it uses no fossil fuels directly, in order to fully decarbonise the sector. Not using the excess heat sources from industry and cogeneration (which may still include some fossil fuels, even in a deeply decarbonised energy system) ignores the potential to recover energy already used in industry and power generation, limiting the overall efficiency of the system and possibility of coupling the electricity and heating sector. The main sources for heat are large scale heat pumps and cogeneration (supplying around 28% and 37%, respectively), with large shares for excess heat from various industrial activities (Figure 59).

Geothermal and large scale solar thermal are also used, with (biomass) heat only boilers producing less than 2% of the district heating supply.

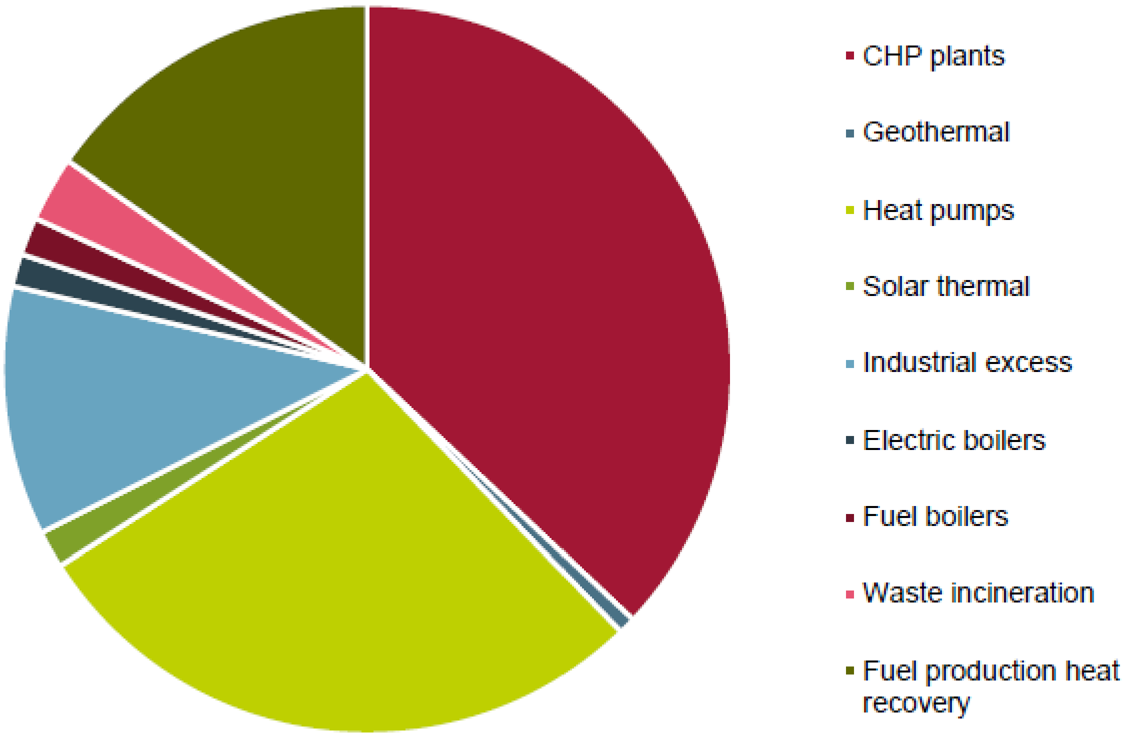


Figure 59: District heating source shares in HRE 2050 [13]

The HRE scenario shows a district heating sector looking towards 2050 which has a large variety of heat sources; uses both renewable, highly efficient, and excess sources of heat; and creates a strong link to the electricity sector, allowing for not only the decarbonisation of the district heating sector itself but also further integration of renewable electricity into the wider energy system. As the supply and supply sources for district heating become more efficient and varied, the marginal costs of supplying heat fall, creating much more competition within the baseloads of district heating system markets, since the majority of these technologies are more socio-economically viable with high operating hours. For this reason, a better understanding of the exact shares of particularly excess heat and solar thermal energy would benefit from an approach that can both consider the spatial allocation of these sources, but also represent a better distinction between large, multi-source district heating systems and smaller district heating networks which are not likely to have more than two or three main heat sources.

4.3.2.3. Excess heat recovery

One of the main ways in which HRE creates synergies between the heating and cooling and other energy sectors, is by using excess heat from industrial processes for the district heating system. In

HRE, the potential to operationally excess heat from industry is bounded geographically, temporally, and by temperature. The level of district heating in HRE has been designed assuming excess heat can be used only to cover the baseload and that which exists currently must be spatially present within a 50 kilometre zone of the prospective district heating system, and be within temperature. These boundaries are intended to create the distinction between the theoretical excess heat potential (i.e. all heat which is lost in industrial processes) and the accessible heat potential, which is a more realistic consideration of how heat can be used in district heating systems. Because excess heat is effectively the cheapest form of heat, that is in some ways limiting. Further research is needed to understand the role of non-baseload excess heat, especially in smaller district heating networks.

4.3.2.4. Renewable heat sources

The potential for renewables in the district heating supply mix is mostly geographically determined. For large scale solar thermal and geothermal this is especially the case, since their potential is likely to be highest in smaller, more decentralised district heating systems where no excess heat is available.

The potential in the United Kingdom for geothermal using this methodology is rather limited, representing only around 1% of the district heating supply. Operationally, it is used as a baseload supply (with some being redirected into storage during the summer), with very little temporal changes throughout the year. In addition, all the available geothermal potential that exists is economically viable, indicating that if the potential is there, the option of geothermal may be relevant even in larger systems where other types of baseload heat supply may be present. This means that where possible, geothermal energy in district heating presents a good solution to increase the share of renewables, reduce CO_2, and lower the fuel consumption in a cost-effective manner.

4.3.2.5. Large scale heat pumps and cogeneration

Large scale heat pumps play a very large role in the supply of the district heating supply in HRE. In total, they supply over 28% of the total district heating demand. This is because they can provide heat in a highly efficient manner, and provide a valuable link with the electricity sector through their use of (variable) renewable resources. Operationally, this means that they mostly function flexibly, in hours of the year when wind and solar electricity is abundant, and integrating it into the heating and cooling sector. This also allows for filling of the large thermal storages, allowing for even further use of the variable renewables. Based on this, large scale heat pumps have the potential to be an important technology in the heating and cooling sector in the long run, both in terms of scale and in terms of enabling variable renewable electricity utilisation. The deployment of large scale heat pumps needs to become a key element of the (re-)development of district heating systems in the United Kingdom.

The second link with the electricity sector is represented in the use of cogeneration, which produces around 37% of the redesigned district heating supply in the United Kingdom. This is both more than the heat, which is being produced in CHPs in 2015, and more than it would be in a conventionally decarbonised scenario. This increase in HRE is mainly due to the vast expansion of district heating in the United Kingdom. While the heat from cogeneration is considered a by-product, the fuels used in CHPs in HRE are mainly biomass and natural gas, producing about 50% each.

While district heating remains economically viable without cogeneration, the overall energy system is more expensive, has significantly more difficulties integrating variable intermittent renewable electricity sources, requires more electric capacity and requires either more fossil fuels or an unsustainable level of biomass. Based on this, the role of cogeneration in future district heating systems needs to be understood as more deeply engrained in the electricity sector than it currently is.

4.3.2.6. *Individual heating supply*

In the HRE scenario, heat pumps provide almost all the remaining heating demand in the United Kingdom, covering almost 56% of the heating sector. This is primarily in the rural and highly suburban areas. Especially compared to 2015, this means both a reduction in the amount of individual heat that is required, and an almost full replacement of the individual boilers, which are currently mostly fuelled by gas (Figure 16). This allows for a much higher level of efficiency, and a deeper level of decarbonisation through a deeper interconnection with the electricity sector.

The electricity that is used for heat pumps generally reflects the supply mix of the electricity sector, and includes a high level of variable renewables; shares of biomass combustion (in both cogeneration and condensing power plants), and a small amount of remaining fossil fuels. However, heat pumps are the primary way of supplying highly efficient and decarbonised heating in areas where district heating networks are not cost-effective, and contribute both to the overall efficiency and the decarbonisation of the energy system in HRE.

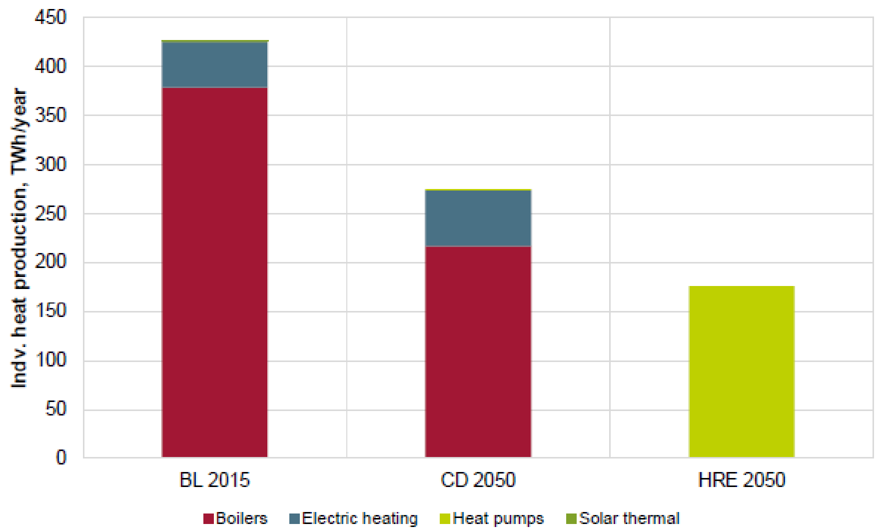


Figure 60: heat sources for individual heat production in the UK for the three scenarios [13]

4.3.2.7. *Cooling supply*

Cooling is considered in HRE in a similar way as heating; through spatial analysis of the demands and resources, and scenario development considering both district and individual supply options.

District cooling is implemented in 20% of the urban areas in the United Kingdom, resulting in an overall market share of less than 4% of the cooling market. However, the spatial analysis and energy system modelling that lead to this result are not as methodologically robust as those for the heating market. This is likely to be an underestimation, since the spatial dimensions of top-down cooling network modelling is not as well developed as for district heating infrastructures. In terms of operational simulation, district cooling is supplied equally through sorption cooling (using excess heat from the district heating system) and centralised chillers. The potential to explore the role of using direct sea- and lake water (where geographically available) and higher levels of cold water thermal storage requires further investigation to be able to fully understand the potential and role that district solutions for cooling could play.

The individual cooling demand is supplied using mostly (small) split units, large split units, and chillers of varying sizes. Cooling is one of the fastest growing of the thermal sectors, but supply options can be highly efficient, with COPs ambitiously expected to be around 6.6 in 2050. This is also the case in HRE, where less than 10 TWh of electricity is used for cooling. This high efficiency, combined with the relatively smaller demands than for the heating sector, is the main reason that even as the cooling sector expands, the impact on the wider energy system is relatively limited.

4.3.2.8. Electricity production

In terms of electricity production, the majority of electricity in the HRE scenario is produced by onshore wind and condensing power plants, producing about a third each (Figure 61). Offshore wind produces about 13%, while photovoltaic produces an additional 9%. Wave and tidal produce about 9%, while combined heat and power plants produce an additional 3%. Geothermal, dammed hydro and run of the river all produce less than 1% of the electricity demand in the United Kingdom.

The overall electricity production in both the conventionally decarbonised (CD 2050) and HRE are much higher, since there is a very high level of electrification in the transport and industry sectors, and power is being used for electro fuel production. However, the overall need for electricity production in HRE compared to a CD system is reduced by about 1%, simply because electricity demand for heating and cooling is replaced by district solutions, which can integrate more types of energy sources. Of this decrease in electricity production, the majority is in cogeneration (despite the increase in district heating), with only a minor decrease in the amount of variable renewable energy produced. Proportionally, this means that the variable electricity which is being produced in the HRE scenario is being integrated at a higher level, indicating a higher level of flexibility within the system.

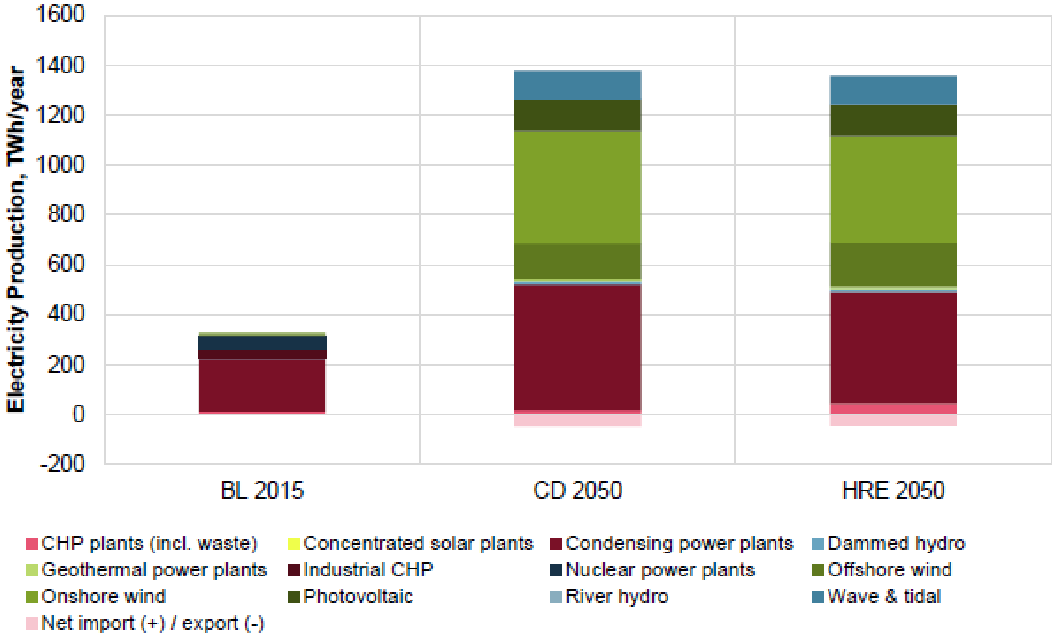


Figure 61: Energy conversion technologies for electricity production in the three scenarios [13]

4.3.3. Final HRE results

4.3.3.1. Decarbonisation

HRE reduces energy-related emissions by 58% compared to conventional decarbonisation, and the overall emissions by 90% compared to 1990 levels (Figure 62). This level of decarbonisation is especially remarkable since in the HRE scenario the transport and non-heating/cooling industry sectors were taken as given from a conventionally decarbonised scenario, and changes were made primarily in the heating and cooling, and to a lesser degree the electricity sector. With further integration of the sectors, higher levels of decarbonisation can be expected.

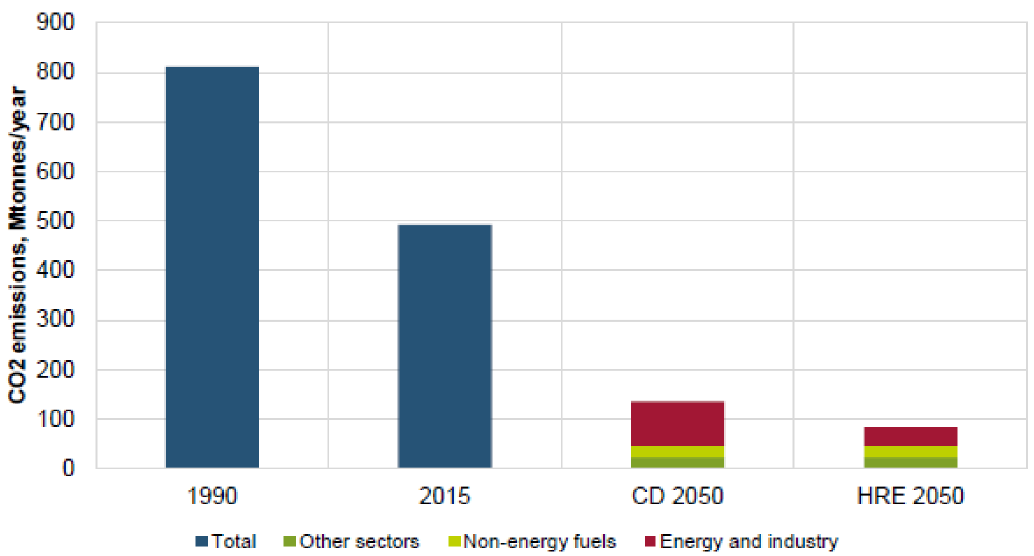


Figure 62: CO_2 emissions for the UK in 1990, in 2015, in CD 2050 and in HRE 2050 [13]

4.3.3.2. Efficiency

In terms of primary energy supply, the HRE uses approximately 12% less energy than a conventionally decarbonised energy system. This is mostly due to the vast reduction of natural gas and minor reduction of biomass, since the amounts of the main renewables (wind, solar and wave & tidal for the United Kingdom) are relatively comparable (see Figure 11). While most of this gas was being used in the electricity sector, its use can be displaced through higher levels of efficiency in the heating and cooling sector.

This primary energy reduction is partially brought through heat savings measures, and partially by efficiency in the demand side through the integration of excess heat sources, use of efficient supply technologies, and the better integration of the heating and cooling sector with the electricity sector.

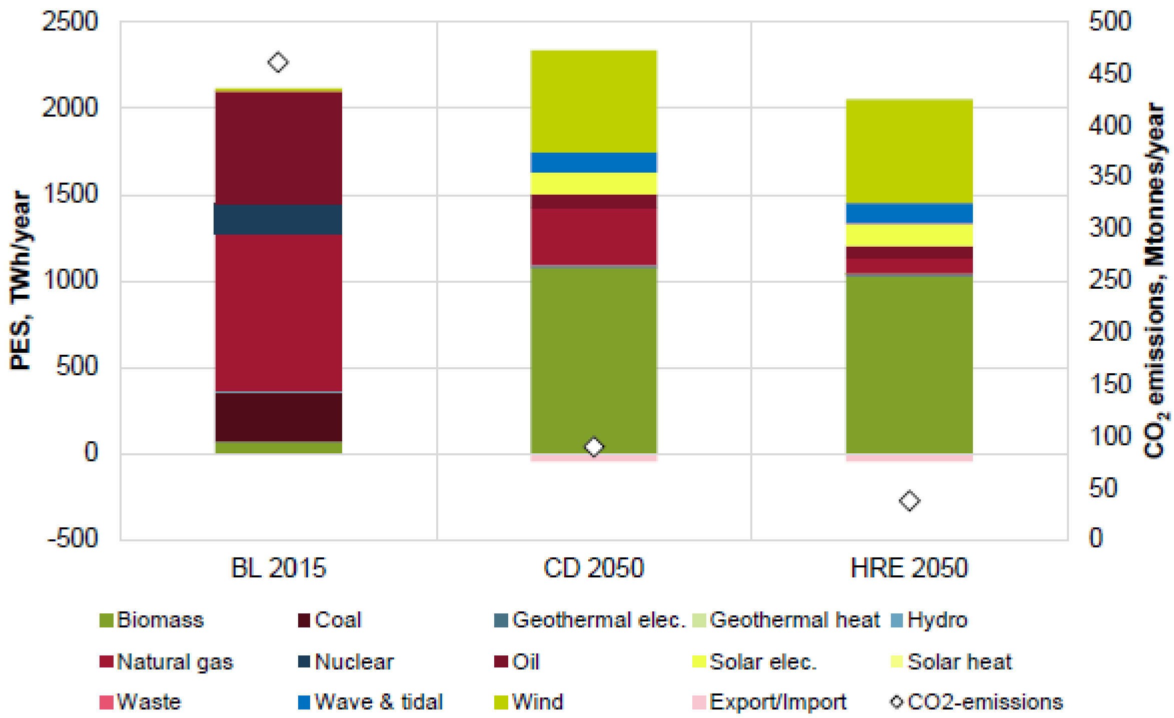


Figure 63: Primary energy supply and sources with respective CO_2 emissions for the three scenarios [13]

4.3.3.3. Economy

The HRE 2050 scenario achieves a deeper level of decarbonisation and a higher efficiency at a reduced cost, compared to a conventionally decarbonised scenario. The annual cost of achieving the energy system simulated in HRE is around 5% lower than the CD system, equalling cost savings of around €8 billion annually (Figure 64). While investments increase slightly, this cost reduction is made through a shift away from using fuels and in that a significant reduction of fuel costs.

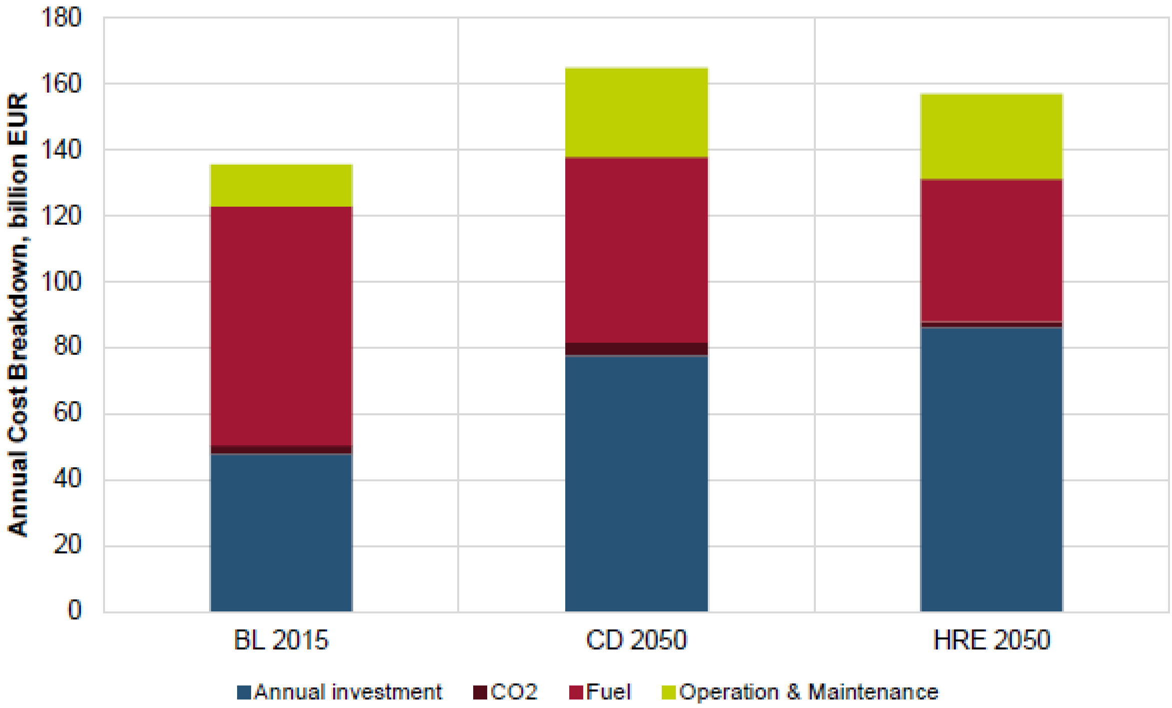


Figure 64: Annual socio-economic costs for the heating, cooling, electricity, industry and transport sector for the UK [13]

There are some changes in terms of investment that are required in a HRE scenario, compared to today and a CD energy system. The overwhelming category of investments needed in the United Kingdom is in heat demand reduction measures, which make up two thirds of the investments required in the heating sector and more than for the entire electricity sector.

In terms of the investment in the energy system outside of the built environment, the highest levels of new investment are needed in the electricity sector, in order to facilitate the transition towards variable renewables and the partial electrification of other sectors (Figure 65). There are however also some changes to the investments necessary in the heating and cooling sector.

After the heat savings measures, the most relevant new and growing investments for the United Kingdom are individual heat pumps, heat pumps for district heating, and investments in district heating infrastructure. Of these, the investment in individual heat pumps is most significant, representing about 15% of the investments necessary in the heating and cooling sector. This directly mirrors the declining investment in individual boilers.

The redesign of the district energy systems requires investments, but overall the investments in the distribution and transmission infrastructure only represent 5% of the investments necessary in the heating sector. In total (including supply technologies, substations, transmission and distribution) the district heating system only comprises 10% of the investments that are necessary in the heating and cooling sector. These investments are collective infrastructures, which have high up-front costs and require a policy support in order to ensure collaborative business and procurement models, but finally only represent a small fraction of the annualised investments needed in the heating and cooling sector.

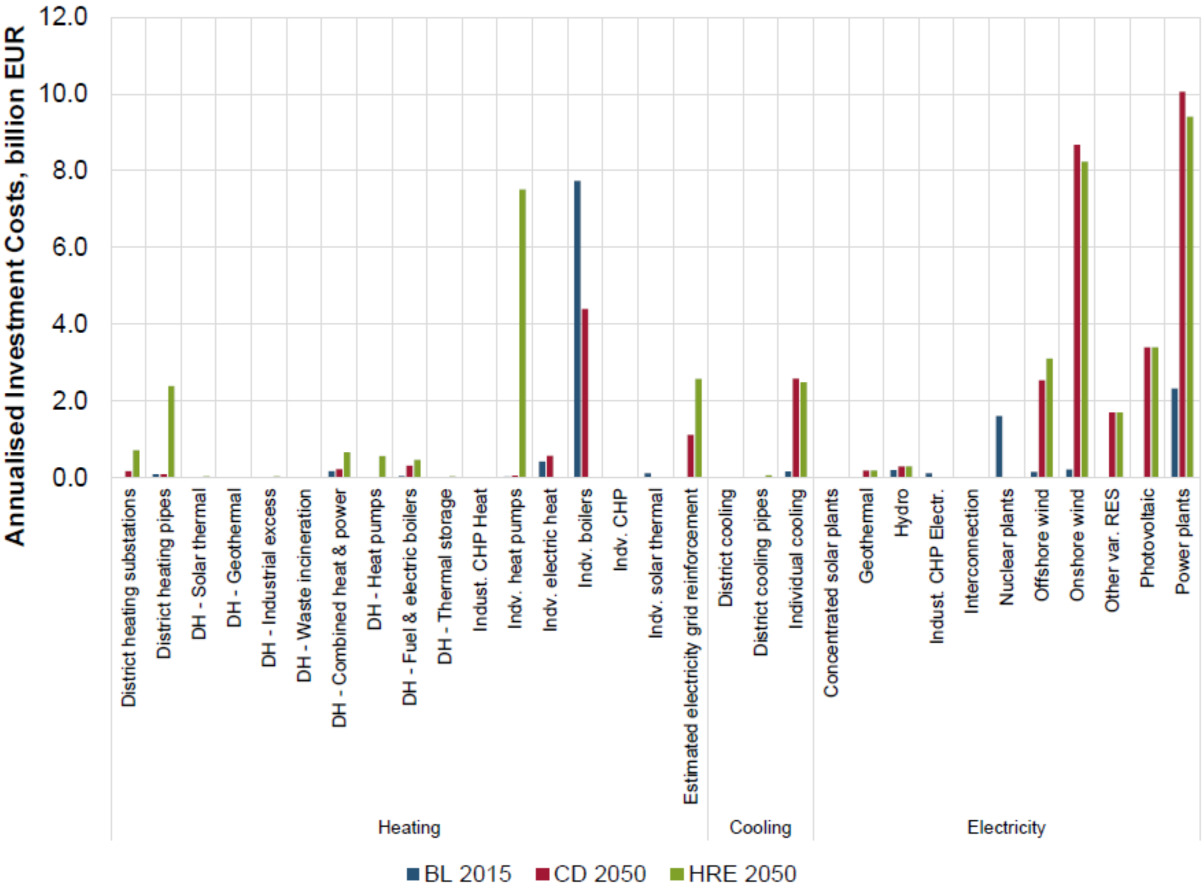


Figure 65: Annualised socio-economic investment costs and categories in the UK, excluding the investment costs necessary for energy savings [13]

4.3.4. Summary of differences between the CD and HRE

Regarding the annualised investment costs for both scenarios, the main differences are in the heating sector (Figure 65). While HRE invest in individual heat pumps, the conventionally decarbonised scenario still invests on boilers and individual direct electric heating. This is the reason why the individual heat supply is still provided by boilers and direct electric heating (in opposition to HRE which fully uses heat pumps, Figure 60). Furthermore, HRE strongly invests on DH which isn't the case for CD.

These investment differences lead to:

- Higher CO_2 emissions owing to the use of high carbon heating (Figure 62)
- Higher annual cost because of high fuel cost (Figure 64)
- Higher primary energy supply as gas is still mainly used (Figure 63).

Therefore, this shows that a heat supply fulfilled by district heating and heat pumps provides more efficiently a greener energy.

5) Description of thermal storage options

5.1.Definition

Thermal energy supply and demand will suffer from large losses in efficiency when the method of heat production must be either quickly increased or decreased. This can occur when a component in the system fails, or more likely, when there is a significant deviation in thermal demand from the anticipated thermal demand. When this happens, the control system can increase the supply quickly, switch on supplemental gas boilers or use heat from a thermal store. Thermal energy storage (TES) provides a way to shift heat production away from peak demand times and higher cost periods, leading to reduced peak loading, lower heating costs and less mechanical wear on equipment. TES has been shown to reduce overall primary energy usage by as much as 10%. This is due to heat load variation which can be minimized by the use of TES. [44]

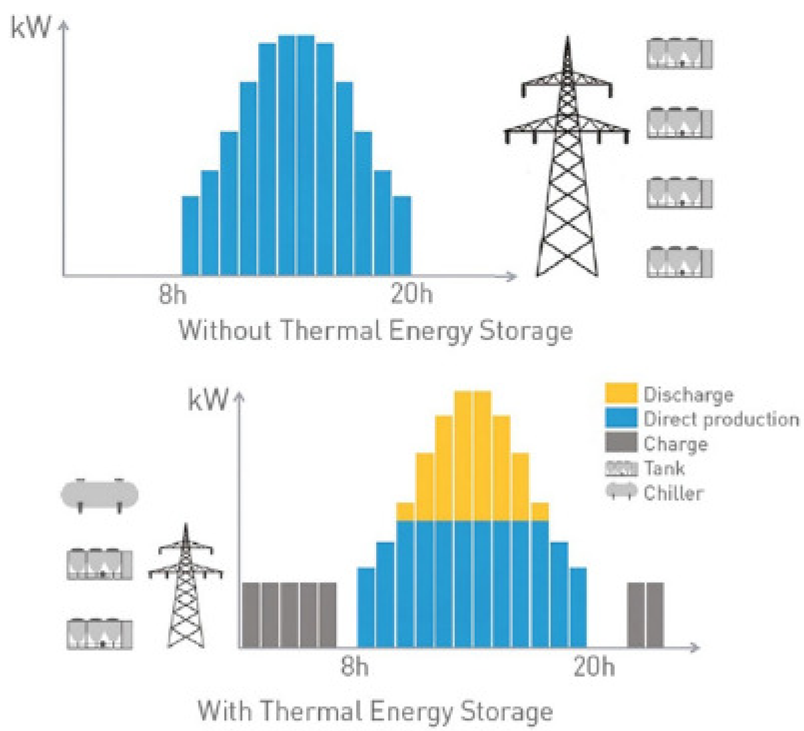


Figure 66: Diagrammatic example of thermal dispatch with thermal storage [44]

5.2.Three main categories of thermal energy storage

In 2016, BEIS released a report on TES, the following information was based on this report [45].

When characterising TES, one differentiates between three main categories:

1. Sensible heat storage
2. Latent heat storage
3. Thermochemical heat storage

5.2.1. Sensible heat storage

The concept is based on the principle of energy being stored (or extracted / exchanged) in a solid or liquid, which changes temperature, but not its phase and no chemical reaction takes place either. Typical materials used for sensible heat storage are liquids such as water, heat transfer oils and types of molten salts. Further material types include solids such as concrete, pebbles, granite, rocks, earth etc. For charging, heat from a higher temperature source is added to the store and in order to discharge, the heat is extracted to a lower temperature sink, subsequently decreasing the temperature in the store again.

5.2.1.1. Underground TES

Sensible heat storage is by far the most commercially advanced type of thermal energy storage, with the primary type being tank based systems storing hot water. These are used for both small scale residential, as well as larger commercial, industrial and district heating applications. In these contexts tank based systems usually provide intra-day / daily heat storage, however, tank based systems have also been developed for interseasonal thermal energy storage. Three other sensible heat storage technologies, which are primarily used to provide interseasonal heat storage, are Pit TES (PTES), Borehole TES (BTES) and Aquifer TES (ATES). These technologies (together with large underground water tanks) are commonly summarised as underground thermal energy storage. The four different types of sensible heat storage suitable for interseasonal heat storage are illustrated in Figure 67.

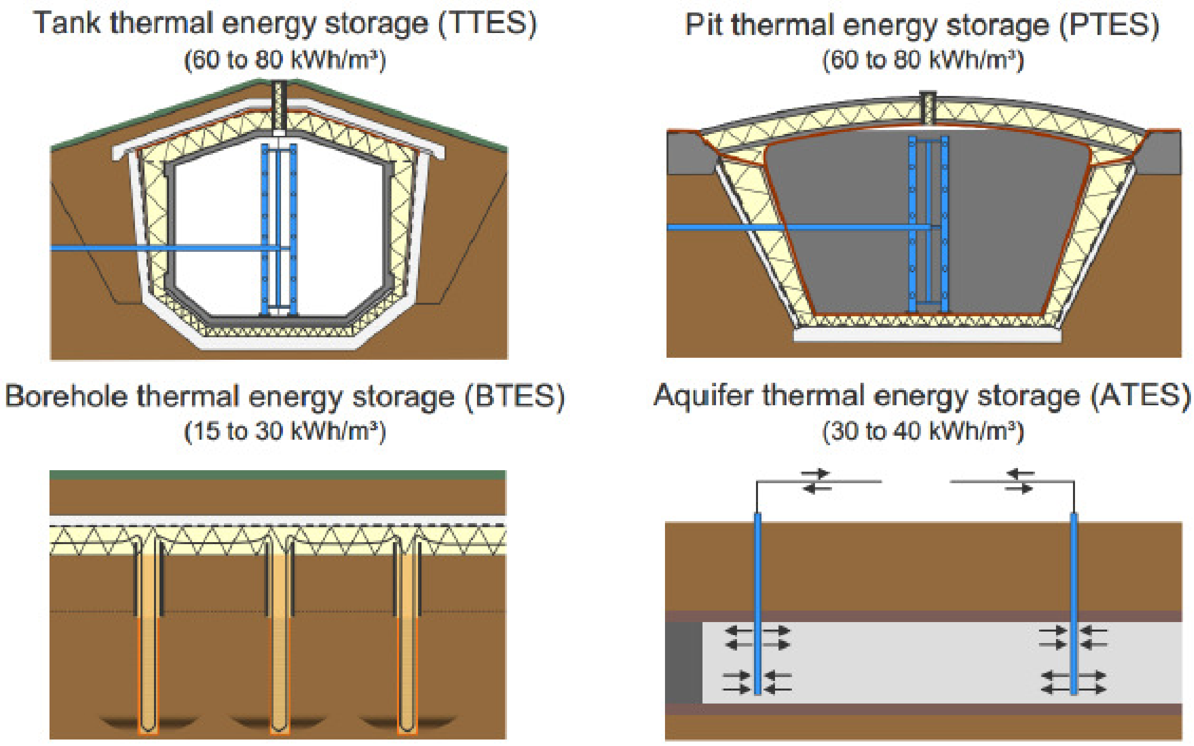


Figure 67: Illustration of different underground TES technologies with their respective energy capacity [45]

This kind of thermal storage has already been studied to be used in district heating. Obviously, the ability to store energy in order to use it in the most efficient way is a key for District heating. Underground TES has been assessed as seasonal solar TES (SSTES). As illustrate in Figure 68, the total amount of solar radiation incident on the roof of a typical home represents a large amount of energy that could help to generate heating. However, to use solar heating, long-term heat storage (provide by underground TES) is required to help balance differences between solar heat generation and demand requirements with respect to both disparities in time and magnitude. This long term heat storage is provided by underground TES (an example is illustrated in Figure 69 in which an ATES is used). [46] [47]

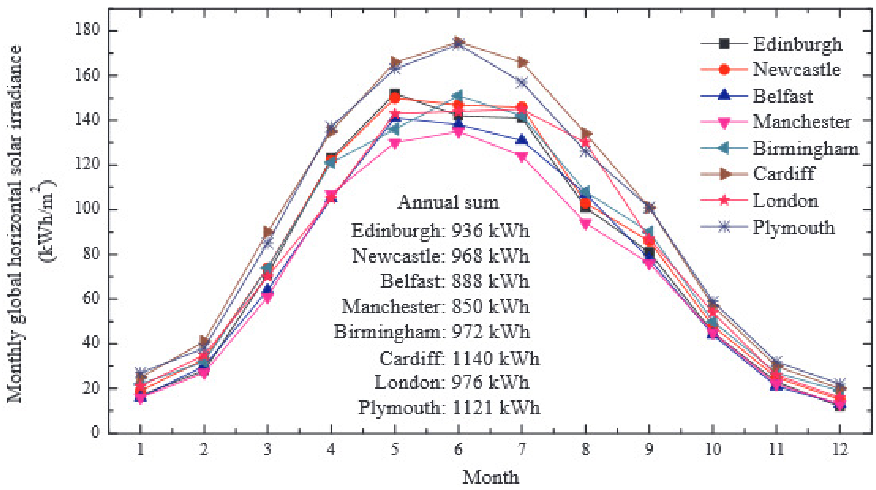


Figure 68: Solar irradiance in several UK cities [46]

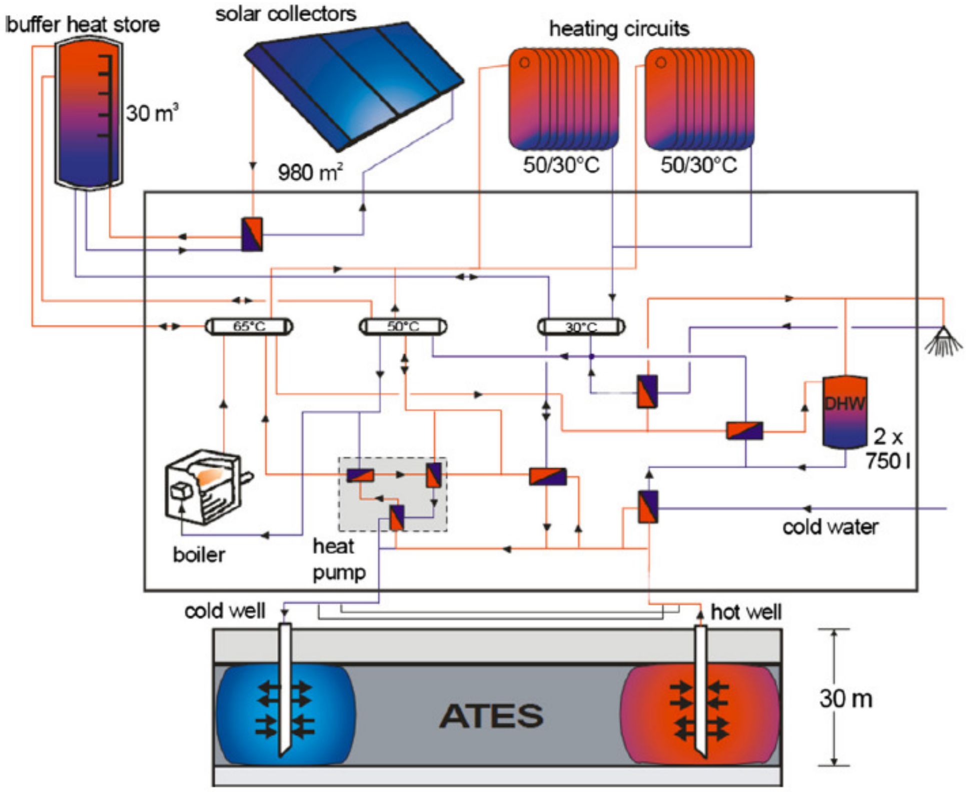


Figure 69: Scheme of a heat supply system using ATES as seasonal solar thermal energy storage [47]

5.2.1.2. Electric storage heaters

Another very common form of sensible heat storage is through electric storage heaters. These are a common heating technology used in the UK domestic sector. An estimated 1.8 million homes in Great Britain use storage heaters. Most homes with storage heaters will also have some direct electric panel heaters or bathroom heaters, along with a direct electric hot water tank. Electric storage heaters typically consist of ceramic blocks, which are heated to temperatures of up to 600˚C.

Storage heaters typically run at night, storing heat in a material with a high specific heat capacity. Storage heaters used to be 'static' – the heat would gradually be discharged from the storage medium through the day with no or little control. Additional direct electric input from a boost heater is then sometimes necessary in the evening period before the night time charging period.

Recent improvement in this field let to the introduction high heat retention storage system such as the Dimplex Quantum system [48] [49]. This technology core storage is based on high density bonded magnetite energy cells and the thermal insulation is fulfilled by microporous silica. According to the builder, this high heat retention storage leads to 22% energy saving and 27% cheaper run than a conventional storage heater system (it's recognised and calculated by the Government approved SAP2012). Figure 70 shows a comparison of Quantum and a static storage heater in terms of temperature profile. This shows how much electric storage systems have been assessed and could help reduce heat consumption.

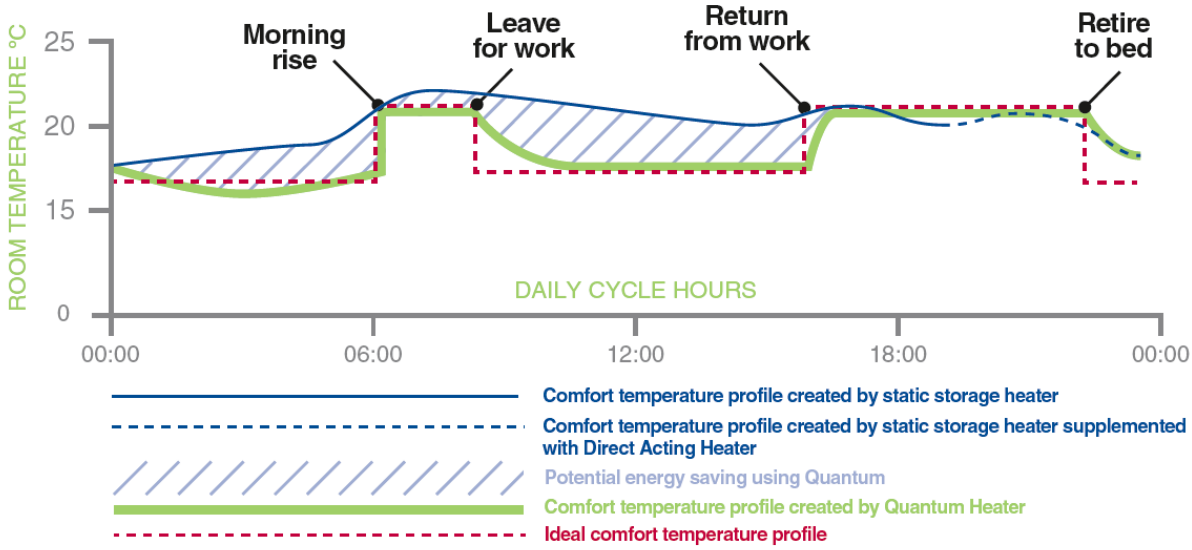


Figure 70: Comparison between Quantum and conventional static 24kWh Storage Heater [49]

5.2.1.3. Thermal mass of buildings

Another form of sensible heat storages, which is present in all enclosed structures, is thermal mass of buildings. The internal structure of buildings, and to a small extent the contents, warm up and cool down with a lag following input (or loss of) heat to the internal air. In all buildings this lag helps to balance minute-by-minute and hour-by-hour temperature fluctuations, and in buildings with high thermal mass (such as old stone-built houses) day-night temperature fluctuations can be significantly reduced.

Use of thermal mass to store heat and cold is an important component of architectural design, particularly in hot countries. Modern buildings should be designed to make optimal use of their thermal mass, but the interactions between insulation and thermal mass are not simple and some modern buildings have very low thermal mass, which can necessitate higher capacity heating or cooling systems to meet more ‘spikey’ demands. Some modern buildings, particularly schools and office buildings employing natural ventilation techniques, are designed with high thermal-mass materials in optimal locations to store daytime solar gain or night-time cold.

5.2.2. Latent heat storage

A latent heat store refers to the concept of storing energy in the form of heat in the material’s change of phase most commonly from solid to liquid, but the change of phase from liquid to gas is also usable.

The most explored latent heat concept uses phase change material (PCM), which melts at a specific temperature and pressure. Typically the heat is stored within a very narrow temperature range. This can give the technology an advantage for applications that use heat with small temperature differences, for example providing heat pumps with heat at a constant temperature (e.g. ice water storage). In this circumstance PCM can be advantageous over sensible heat stores in terms of potential energy storage density, required store volume and significantly lower storage losses. The very narrow temperature range of PCM stores is also a major shortfall compared to sensible heat storage, which is likely more economical for applications that allow for larger temperature differences.

A wide range of materials can potentially be used and they are largely explored in a research / academic context with few commercial products emerging. Some further advanced solutions use aqueous salt solutions and other examples include the use of ice-slurries for cooling purposes in commercial or industrial buildings. One of the key drawbacks of latent heat stores using PCM is the low thermal conductivity of many of the materials used. Therefore an effective heat transfer must be achieved, often increasing material costs for components such as heat exchangers.

5.2.3. Thermochemical heat storage (THS)

Thermochemical heat storage (THS) is the commercially least advanced thermal storage technology. THS refers to the use of reversible chemical reactions to store large quantities of heat in a compact volume. Using different chemical reactants (usually two liquids or a solid and a vapour), the material breaks down as heat is applied and the separated parts are then stored. As the components are then recombined heat is released. The energy storage density and capacity is dependent on the temperature, chemical and physical properties of the materials used.

THS offers some significant advantages: THS generally has a much higher energy density than other thermal storage technologies, as well as being able to store the separated reactants for a long period of time without causing high or any degradation of the energy stored. Thus THS is able to provide efficient interseasonal storage without any significant heat losses. However, there are a number of limiting factors in the residential space, depending on the material and technology used. Examples include uncertainty with regards to reliability, potential toxicity, safety concerns, system lifetime, relatively high cost and issues around recyclability. Therefore the most likely future applications of THS are within larger commercial or industrial solutions.

THS remains far from commercial realisation in the UK and elsewhere – exemplified by the fact that there are no demonstrator plants in the UK. Additionally the current test projects in other countries have been run by technology research institutes aiming to prove the capability and performance of THS, rather than aiming for commercialisation of systems. A significant amount of time and research will be required to further develop demonstration plants and projects. It is thus unlikely that THS will experience any significant market uptake within the next 10 years.

Table 9 sums up the different types of TES and adds the main advantages and disadvantages of each type.

Table 9: High level overview, description and comparison of different thermal energy storage technologies [45]

Category	Type of TES	Description	Key advantages	Disadvantages
Sensible heat storage	TTES	Tank systems usually storing hot water, but molten salts and heat transfer oils can also be used.	Established and proven Scalable Usable for wide range of applications Cost effective	Space requirements Smaller stores have higher heat loss rates and are not designed to store heat over long periods of time
	PTES	Shallow pits dug in the ground, which are then lined and filled with gravel and / or water for energy storage.	Potential very large storage capacity Interseasonal potential (e.g. solar heat storage)	Low energy density Not suitable for built-up areas Potential land cost constraints
	BTES	Regularly spaced vertical holes drilled into the ground, with heat exchangers inserted to transfer heat to and from the ground (closed loop system).	Interseasonal potential (e.g. solar heat storage) Relatively small excavation requirements	Relatively low efficiency Limited charging and discharging capacity
	ATES	Open-loop system utilising natural underground water-bearing permeable layers from which groundwater is extracted.	Efficient provision of heating and cooling Easily integrated into building design, thus small land footprint	Hydrogeological restrictions Balancing of heat input and extraction Limited to places where extraction is possible
Latent heat storage	PCM	Using organic or inorganic compounds to store energy in the form of heat in the material's change of phase (usually from solid to liquid, but also from liquid to gas).	High energy density Low volume of store Constant temperature during charging and discharging.	Relatively immature technology in the domestic segment Limited availability of suitable PCM materials with desired melting points
Thermo-chemical heat storage	THS	Reversible chemical reaction to store large quantities of heat in a compact volume.	Very high energy density Long term storage without degradation	Very far away from market commercialisation Lack of real world proof of potential performance

5.3. Market review and future development

5.3.1. Current market overview

Overall, there are two primary TES technologies that have experience of widespread uptake in the UK:

- Electric storage heaters (approximately 1.8 million homes in the UK use electric heating system, of which the large majority will be electric storage heaters).
- Tank based systems:
    - Residential systems (around 11 million systems in homes; approximately 400,000 sold per year)
    - Larger systems (>500 litres), selling low thousands of units each year for large residential or commercial applications. There are tens of systems in the district heating segment, where tanks are usually of a size between low hundreds to thousands of m^3.

Other systems have seen much more modest uptake. There is a high degree of uncertainty with regards to PTES, BTES and ATES projects, because there has been very little discussion in the literature and the projects realised are very much niche applications. Across these three technologies, the key barrier explaining the small current market is the high upfront cost and related cost sensitivity shown by building / project developers. The low uptake of PTES and BTES can also be broadly linked to the low uptake of large solar thermal in the UK – especially PTES, commonly used for the interseasonal storage of solar heat. Table 10 gives the current status of TES technologies in the UK by application.

Table 10: Current status of TES technologies in the UK by application [45]

Type of TES / common timeframe in UK	Current market status in the UK		
	Domestic	Non-domestic	District Heating
Tank thermal energy storage (TTES) **Intra-day**	Widespread use in the domestic sector for hot water storage (installed base of ~11 million homes)[12]	Widespread use for commercial and industrial applications	Widespread use for district heating applications
Pit thermal energy storage (PTES) **Interseasonal**	No use in domestic sector	One project identified in the UK	No projects identified in the UK (projects in Denmark)
Borehole thermal energy storage (BTES) **Interseasonal**	Very few installations in the UK (low 10s)	Low number of installations carried out (approximately low 10s) by a number of UK based businesses	No projects carried out in the UK (examples from Denmark and Germany).
Aquifer thermal energy storage (ATES) **Interseasonal**	No use in domestic sector (for single family buildings)	Low number of projects (<10) in the UK for commercial buildings / apartment blocks	No projects in UK (some applications e.g. in the Netherlands)
Phase change materials (PCM) **Intra-day**	Some industry R&D for domestic PCM products. Primarily trial projects, with one product in the UK close to market	Limited R&D activity for specific applications, with different concepts explored across Europe.	Limited R&D activity for specific applications
Thermochemical heat storage (THS) **Intra-day / Interseasonal**	Early stage research (primarily in academia) – unlikely to be used in domestic sector	Early stage research (primarily in academia)	Early stage research (primarily in academia)

5.3.2. Factors affecting future adoption of TES

To drive the UK TES market further two factors need to be present: a stronger understanding of and confidence in the various technologies beyond hot water tanks and storage heaters; and price signals that enable TES to deliver value to customers.

The crucial cap is economics and upfront costs of different TES technologies – there are few price signals to drive the market (e.g. dynamic electricity pricing). TES would benefit if these signals become more widespread and stronger. This may occur where more intermittent electricity generation is seen in the market.

As seen in previous section, it can be expected that the number of district heating schemes will grow further and the majority of new schemes will most likely use water based TTES.

Large scale solar thermal plants drive the integration and deployment of interseasonal, underground TES, as seen in countries such as Denmark and Germany. However, based on the limited uptake of solar heating in UK district heating schemes, there may potentially be limited demand for interseasonal heat storage using PTES or BTES in the UK over the coming years.

5.3.3. Future scenarios for TES market development

BEIS also made scenario about the future marker development of TES. This scenario assumes a more positive outlook for TES in the UK based on strong drivers from the decarbonisation of heat, primarily through its electrification and favourable frameworks for providing flexibility to the network. In the residential and small commercial sector sales of hot water cylinders would increase and new products such as PCM would emerge. Additionally interseasonal TES would receive a stronger push with trial projects looking to exploit the potentials for solar thermal integration as efforts to decarbonise heat further develop.

5.3.3.1. Electricity price signals

This growth scenario assumes the emergence of strong time-of-use prices for end-customers. Different types of customers would be rewarded for shifting demand away from peak electricity demand periods – or for generating during times of peak electricity demand. TES together with intelligent controls and effective system integration enable production of heat from electricity, or CHP, to exploit these price signals.

5.3.3.2. Renewable heat drivers

The widespread uptake of renewable heating technologies and especially the electrification of heat using heat pumps would provide a very favourable outlook for the deployment of TES. The ability to decouple production from consumption of heat through thermal storage would make the integration of electric heating into existing electricity networks easier.

Stricter building regulations requiring more energy efficient technologies to be used in new builds and existing buildings would increase the uptake of renewable heating technologies. Furthermore, it would also encourage the installation of underground TES such as BTES or ATES for improving performance of heating and cooling in large buildings.

Lastly this potential scenario outlines the possibly increasing uptake of large hot water storage for community and district heating schemes, as such schemes increase in popularity and receive continuous support as part of decarbonisation strategies (assumption for growth scenario). This was also echoed amongst the industry expressing plans for increasing district heating installations in the UK. It will be likely that in order to improve system performance the majority of these new schemes will be paired with TTES. There may also be more interest around using solar input for district heating in the UK acting as a strong driver for interseasonal TES.

5.3.3.3. Deployment until 2025

Table 11 gives the potential uptake of different TES applications under the scenario.

Table 11: Potential uptake of different TES applications under scenario [45]

Application type	Intra-day storage	Interseasonal storage
District Heating	Strong growth of DH using heat pumps and/or CHP; TTES in all new installations and majority of DH retrofitting TTES. Potential for limited trials integrating PCM with hot water stores (Hybrid tank / PCM).	Trials and early adoption of underground TES technologies for district heating applications with solar thermal.
Non-domestic	Growing market for TTES based on renewable heating uptake and CHP. Development of more novel TTES applications using other materials than water. Potential emergence of suitable PCM products likely as part of trial projects.	Growing uptake of ATES and BTES for individual commercial buildings as technologies such as GSHP and solar achieve greater uptake. Emergence and improvement of early pilots for THS applications in the industrial sector.
Domestic	Growing market for TTES based on electric heating uptake (and possibly micro-CHP) and electricity price signals for flexibility. Uptake of PCM products for time shifting renewable heating and mitigating space constraints in properties.	Different types of BTES becoming more established based on coupling with renewable heating technologies.

6) Bibliography

[1] Wikipedia, "Global warming," [Online]. Available: https://en.wikipedia.org/wiki/Global_warming. [Accessed 25 April 2019].

[2] IPCC, "Climate Change 2014: Synthesis Report, Summary for Policymakers," 2015.

[3] Futurearth, "Global Carbon Budget 2018," 5 December 2018.

[4] Wikipedia, "Kyoto Protocol," [Online]. Available: https://en.wikipedia.org/wiki/Kyoto_Protocol. [Accessed 29 April 2019].

[5] Wikipedia, "Paris Agreement," [Online]. Available: https://en.wikipedia.org/wiki/Paris_Agreement. [Accessed 2019 April 25].

[6] Greater London Authority, "Low Carbon Heat: Heat pumps in London," London, 2018.

[7] Commitee on Climate Change, "Reducing UK emissions: 2018 Progress Report to Parliament," 2018.

[8] Department for Energy & Climate Change, "Investing in the UK's heat infrastucture: Heat Networks," November 2015.

[9] Department for Business, Energy & Industrial Strategy, "2018 UK Greenhouse gas emissions, provisional figures," 28 March 2019.

[10] Department for Business, Energy & Industrial Strategy, "Provisional UK greenhouse gas emissions national statistics 2018," 2019.

[11] DECC, "UK energy in brief," July 2018.

[12] Department for Business, Energy & Industrial Strategy, "Energy Consumption in the UK: data table," 2018.

[13] S. L. R. S. M. B. V. C. M. P. U. R. G. L. P. U. Paardekooper, "Heat Roadmap United Kingdom: Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps," 2018.

[14] Heat Roadmap Europe, "2015 Final Heating & Cooling Demand in the United Kingdom: Country presentation," October 2017.

[15] B. V. M. (. coordinator), "Heat Roadmap Europe," 2019. [Online]. Available: Heatroadmap.eu. [Accessed 10 April 2019].

[16] EU commission, DG ENER, Unit A4, “Energy datasheets: EU-28 countries,” Energy statistics, 06 July 2016.

[17] I. C. Jason Palmer, “United Kingdom Housing energy fact file,” 2013.

[18] Department for Business, Energy & Industrial Strategy, “Public attitudes trackers,” September 2018.

[19] Heat Roadmap Europe, “Pan-European Thermal Atlas 4.3,” 2019. [Online]. Available: https://heatroadmap.eu/peta4/. [Accessed 12 April 2019].

[20] Department for Business, Energy & Industrial Strategy, “Energy consumption in the UK,” July 2018.

[21] Z. Wang, “Heat pumps with district heating for the UK's domestic heating: individual versus district level,” *Energy Procedia,* vol. 149, pp. 354-362, 2018.

[22] OFGEM, “Typical Domestic Consumption Values,” 2017. [Online]. Available: https://www.ofgem.gov.uk/gas/retail-market/monitoring-data-and-statistics/typical-domestic-consumption-values. [Accessed 11 April 2019].

[23] Energy Trends, “Experimental statistics on heat networks,” March 2018.

[24] Department for Business, Energy & Industrial Strategy, “Heat Network Statistics,” 31 May 2018.

[25] The Association for Decentralised Energy, “Market Report: Heat Networks in the UK,” January 2018.

[26] Department for Business, Energy & Industrial Strategy, “Digest of United Kingdom Energy Statistics 2018,” July 2018.

[27] Department for Business, Energy & Industrial Strategy, “Energy trends - Section 5 Electricity,” March 2019.

[28] Department for Business, Energy & Industrial Strategy, “Energy trends - Section 6 Renewables,” March 2019.

[29] E. &. I. S. Department of Business, “Energy trends - Section 4 Gas,” March 2019.

[30] ERVIA, "A look at the Irish Gas Market," 2018.

[31] Department for Business, Energy & Industrial Strategy, "Quaterly Energy Prices - Quarter 4 2018," 28 March 2019.

[32] Element Energy and E4tech, "Cost analysis of future heat infrastructure options," March 2018.

[33] Element Energy and E4tech, "Technical annex: Energy and fuel bills today and in 2050," July 2018.

[34] Aurora Energy Research, "Power sector modelling: System cost impact of renewables," 24 May 2018.

[35] E. L. A. V. Vladislav Masatin, "Evaluation factor for district heating network heat loss with respect to network geometry," *Energy Procedia,* vol. 95, pp. 279-285, 2016.

[36] Building Research Establishment, "Distribution loss factors for heat networks supplying dwellings in SAP," June 2016.

[37] Andrew McManus, AES Sustainability Consultants, "Initial impact assessment of the changes to the SAP procedureto be incorporated in SAP 10," September 2018.

[38] M. B. Xavier Boissieux, "Low carbon solution for heating and cooling in Multi Family Buildings," in *12th IEA Heat pump Conference 2017*, 2017.

[39] H. Lund, "4th Generation District Heating: Integrating smart thermal grids into future sustainabale energy systems," *Energy,* vol. 68, pp. 1-11, 2014.

[40] Wikipedia, "District heating," [Online]. Available: https://en.wikipedia.org/wiki/District_heating. [Accessed 01 May 2019].

[41] ICAX, "FifthGeneration District Heating & Cooling Networks," [Online]. Available: https://www.icax.co.uk/Fifth_Generation_District_Heating_Networks.html. [Accessed 01 May 2019].

[42] S. Buffa, "5th generation district heating and cooling systems: A review of existing cases in Europe," *Renewable and Sustainable Energy Reviews,* vol. 104, pp. 504-522, 2019.

[43] Department for Business, Energy & Industrial Strategy, "Clean Growth - Transforming Heating: Overview of Current Evidence," December 2018.

[44] N. M. B. a. Z. Y. Michael-Allan Millar, "District Heating Challenges for the UK," *Energies,* vol. 12, 2019.

[45] Department for Business, Energy & Industrial Strategy, "Evidence Gathering: Thermal Energy Storage (TES) Technologies," 2016.

[46] Z. Ma, "Feasibility study of seasonal solar thermal energy storage in domesticdwellings in the UK," *Solar Energy,* vol. 162, pp. 489-499, 2018.

[47] J. e. a. Xu, "A review of available technologies for seasonal thermal energy storage," *Solar Energy,* 2013.

[48] Dimplex, "Introducing the Quantum heating system: The heater that adapts to its environment," 2014. [Online]. Available: https://www.glendimplexireland.com/pdf/20276446_Quantum_Main_Brochure_Sep14_v4.pdf.

[49] Dimplex, "Quantum - electric point," 2014. [Online]. Available: https://www.electricpoint.com/dimplex-quantum-qm125-1-25kw-storage-heater-low-energy-intelligent-white.html.

7) Annexe

The following figures give maps of heat demand, cold demand and heat excess respectively.

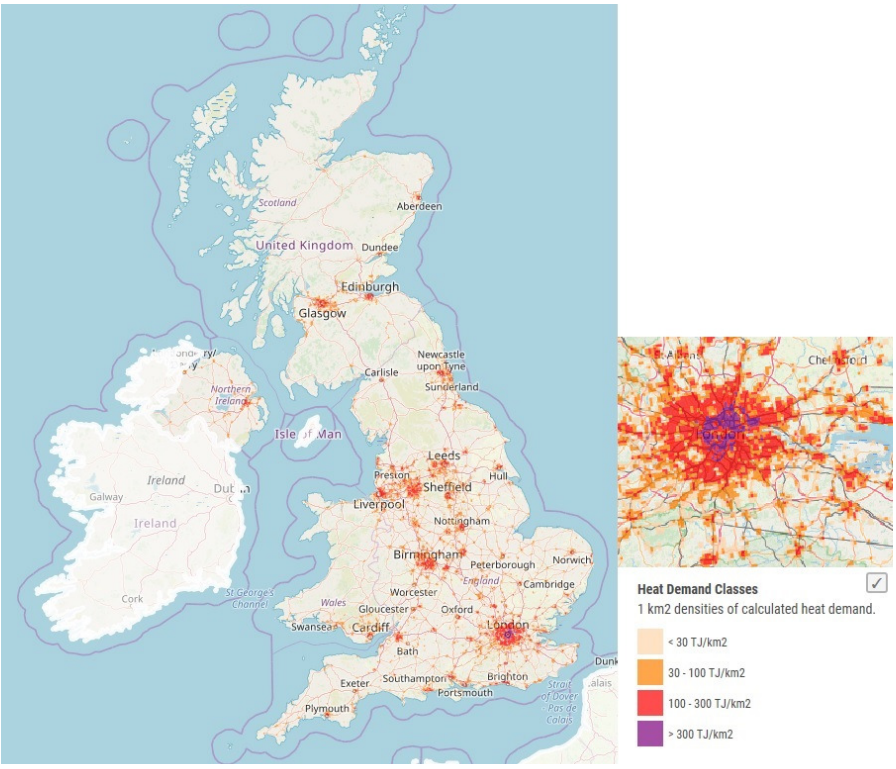


Figure 71: Heat demand in UK

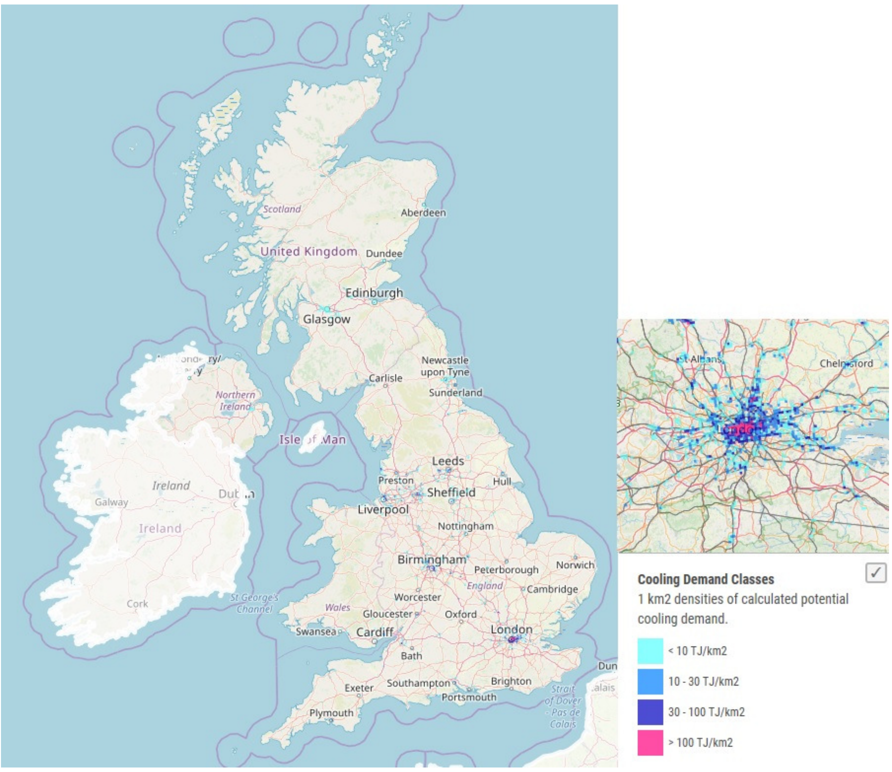


Figure 72: Cold demand in UK

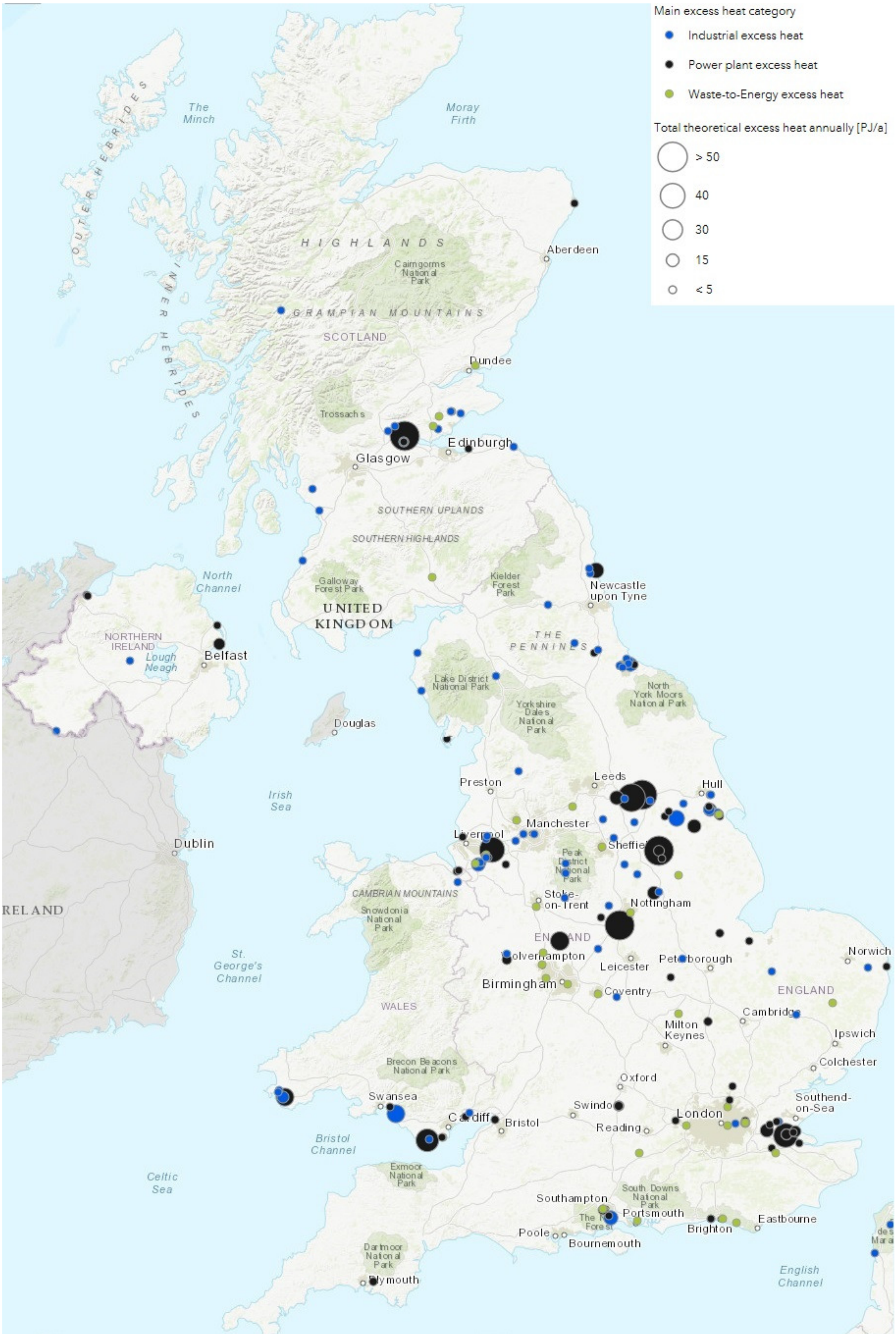


Figure 73: Excess heat in UK