International Comparisons of Heating, Cooling and Heat Decarbonisation Policies

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Executive Summary

Internationally, the buildings sector has been slow to embark along the path to decarbonisation. The IEA's 2017 edition of *Energy Technology Perspectives* notes that buildings are off track to meeting international goals, to a greater degree than many other areas across the economy. Decarbonising buildings is highly challenging, first, because many of the technologies to deliver low carbon heating – heat pumps, biomass boilers, hydrogen networks – have higher capital cost than incumbent technologies without delivering a higher level of service from the perspective of the customer. Second, changing heating technologies can be disruptive. The existing housing stock remains a major share of the heat demand to 2050 in OECD countries, and thus technological change requires the retrofit of households, offices and warehouses. Delivering low carbon heat may also entail the development of new infrastructure and a need to plan for service interruptions. To overcome these challenges, there is a need to learn lessons from case studies of best practice around the globe.

The Department for Business, Energy and Industrial Strategy (BEIS) commissioned Vivid Economics to summarise the evidence base on how other countries provide heating and cooling and what the UK can learn from them. The focus of this report is heating and cooling in buildings, viewed broadly across residential and non-residential sectors with an emphasis on OECD countries. Within this context, two specific research questions are posed:

- What **challenges** are shared by the UK and with other countries in the area of heat decarbonisation and where is there less commonality?
- What **learning and innovation** opportunities exist outside of the UK, both in countries where there are clear points of comparisons as well as contrasts?

This Rapid Evidence Assessment (REA) addresses these questions in three phases. The first phase is a broad review of international evidence on heating and cooling, identifying strengths and weaknesses. An important output of this phase of the work is a detailed excel database, which catalogues both quantitative evidence sources as well as key documents from journals, governments, research institutes and other credible institutions. This database provides an assessment of the quality and relevance of each of these sources and a summary of their contents. Phase two provides a detailed breakdown of the demand and supply of heating in OECD countries as far as the evidence in phase 1 permits. Tables of fuel sources by country, over time, and the technology mix that delivers heat to buildings are provided. Phase two also provides a catalogue of the key policy interventions that have been implemented in OECD countries. Phase two concludes by constructing a set of simplified heating "archetypes", which link the natural endowments of countries to the fuels and technologies that are used in each. This archetypes analysis is important as it both explains the current fuel mixes, and gives a sense for countries which may have similar or contrasting challenges to the UK. Based on an assessment of areas where the evidence is strong (Phase 1) and areas which could provide transferable and instructive lessons for the UK (Phase 2), a shortlist of countries (Germany, Sweden, Japan, the Netherlands and France) is selected for '*deep dive'* analyses. This third phase involving 'deep dives' provides much more granularity on the policies and strategies that have been implemented, as well as their effectiveness, efficiency and transferability to the UK context.

Decarbonisation challenges

A key challenge of decarbonisation is moving away from relatively low-cost sources of energy that form the natural endowment of a nation. To understand the challenges associated with changing heating fuels/technologies, it is important to understand the drivers of the current fuel mix, which tends to follow natural energy endowment. Countries with hydro tend to opt for electric heating, those with large gas reserves tend to have developed a gas grid and those with access to biomass have tended to develop district heating based on biomass. Moving away from the natural endowment may entail increasing cost, or developing new infrastructure. There may also be substantial lock-in costs associated with existing infrastructure, such as the costs of decommissioning the gas grid, that are challenging to overcome.

Progress in moving away from gas heating delivered via a gas network has not been achieved to a large degree despite substantial efforts – suggesting this is a particularly challenging aspect of heat decarbonisation. This is important for the UK, which has the highest penetration of on-gas-grid heating in the OECD. An important example is Germany, where despite over a decade of policy effort, almost all new heating purchases for existing buildings remain fossil fuel. Possible reasons for the lack of progress regarding gas grid transitions include the low cost of gas fuel and boilers, the high level of service provided by gas boilers, the disruption associated with retrofits and the lock-in costs associated with existing infrastructure.

In contrast, new build homes and the off-gas-grid sector have seen a relatively successful transition to low carbon in a number of countries. Substantial transitions are underway in multiple countries with regards to the heating mix of new builds, which have typically been supported by regulation. In Germany, the majority of heat pumps have been installed in new builds whilst, in areas off the gas grid, transitions towards district heating, biomass and heat pumps are taking place. In Sweden, the share of oil fired boilers has fallen significantly in off-grid homes as they have moved towards biofuel based alternatives and heat pumps.

Policy learning and innovation

Effective transitions have been supported by a package of policies which span regulation, information, standards, research and development and long-term targets. The key ingredients of success in shifting to low carbon sources have been sustained policy support over time and the implementation of packages of policies which address the investment case, as well as a range of barriers (technical, information, innovation) and the interaction with other areas of policy (building codes, development of new infrastructure). The use of subsidies or grants is important in some jurisdictions, although this has been phased out in countries such as Sweden, where economics and customer preferences have supported a shift towards low carbon technologies. Supporting evidence for the benefits of a policy package is found in the detailed case studies:

- **Germany's heating transition is based on a combination of targets, subsidies and building codes**. These are beginning to have an effect in the new build sector, where heat pumps are installed in almost a quarter of new homes. Germany has been successful in transitioning away from oil, towards heat pumps, particularly in new builds, and district heating. However there has been little movement away from established natural gas heating in many existing buildings. Energy efficiency policies are also important. Heat consumption in residential buildings decreased by 20% from 2000 to 2012.

- **Sweden has also used a mix of policies to drive a transition from electric resistive and oil-fired heating towards heat pumps and district heating.** Historically, this included a range of subsidies and tax incentives, which have been gradually phased out. Quality standards helped to ensure that heat pump systems achieve high levels of performance and building codes have contributed to the increasing dominance of air-to-air heat pumps over ground source heat pumps since 2005. District heating was also encouraged by strong planning rules and investment subsidies. Sweden also has the highest carbon tax in Europe, which was introduced in 1991 and has more than tripled since then. In addition to the carbon tax, there is an energy tax on natural gas for heating and tax on heating oil. Taxes on oil combined with the promotion of biomass have led to oil boilers being substituted by wood fuel alternatives or heat pumps.
- **Japan is promoting hydrogen through subsidies, tax incentives and R&D finance support as well as energy efficiency policies to meet its renewable heat objectives.** The Top Runner Programme covers energy efficiency standards for heating and cooling appliances. The Hydrogen Society initiative is being supported by public and private R&D finance, in close collaboration with large commercial firms. The Ministry of Economy, Trade and Industry (METI), assisted by Japan's New Energy and Industrial Technology Development Organization (NEDO), has played a critical role in devising the road map and facilitating the successful collaboration between key market participants, R&D institutes and policy makers.
- **The Netherlands has centred its heating policy on subsidy programs, energy efficiency standards and a suite of accompanying instruments.** Both the SDE+ and ISDE encourage subsidise a switch towards renewable heating sources for both industry and households. Energy efficiency standards for new build housing have been progressively strengthened and all new houses from 2020 onwards will be close to carbon neutral. Hydrogen may play a role in the longer-term, with government backed research and development leading to several pioneering hydrogen and CCS, and renewable power-to-gas hydrogen, demonstration plants.
- **France is pursuing its ambition to double the share of renewables in heating to 38% by 2030 through subsidies for commercial and residential heat, alongside a number of other policy instruments.** The CITE tax credit and the zero percent Eco-loan programme support residential renovations and installations, while the Fonds Chaleur supports commercial installations. The 2012 Regulation Thermique also helps limit continued deployment of direct electric heating in new builds, while a carbon tax may help limit switching from direct electric to natural gas.

Market forces have also been a driver in some of these transitions, but have worked in combination with policy. Early deployment of heat pumps and heat networks in leading countries (e.g. Sweden, Denmark) took place as a response to the oil crises in the 1970s, as prices rose. However, in the decades that followed, a combination of planning, regulation, taxation and incentives brought around a transformation of heat provision. In Norway, rising electricity prices in the late 1990s encouraged a move towards heat pumps and district heating, but it was supported by policies to facilitate take up. In other cases, such as Germany, the transitions have been almost entirely policy led.

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1 Introduction

Decarbonising heating and cooling is crucial to meeting carbon reduction targets. The UK has a legally binding commitment to reducing its greenhouse gas emissions to 80% below 1990 levels by 2050. Heat is a vital part of the overall emissions budget, comprising around one third of total UK greenhouse gas emissions[1], making it a priority sector for emissions reduction. This report focuses on heating in buildings only.

The UK has a set of circumstances that may make a heating and cooling transition challenging. The availability of North Sea gas has resulted in the gradual development of an infrastructure where a large number of households and industry are on a gas grid. The cost of gas heating in the UK is low due to low taxes on gas as well as low capital costs of gas boilers. As a result, approximately 85% of UK households use gas for heating and customer surveys show high levels of satisfaction with gas central heating systems and a lack of willingness to consider alternatives[2]. The UK housing stock is also among the least energy efficient in Europe, which is a barrier to the uptake of some low carbon technologies which provide heat at lower flow temperatures.

The aim of this study is to build the evidence base on how other countries provide heating and cooling and what lessons the UK can learn from these. A review of the international literature suggests fresh ways of thinking that could be applicable to the UK. Other countries have some similar or contrasting characteristics to the UK, and many have taken part in an energy transition to some extent. Recently in Germany, which has 20 million gas customers (the UK has around 23 million, although a larger proportion), there have been policies to replace the gas grid with heat pumps and district heating, particularly in new builds. In Sweden and Norway, annual sales of heat pumps are over 20 times the UK. In most countries, transitions have occurred over a multi-decadal timeframe. Outside of Europe, in New Zealand, a rapid uptake of heat pumps in a short period – the size of the market tripled in 5 years – suggests that these transitions are not only possible but could proceed relatively quickly (and, in this example, cater towards the cooling demand simultaneously).

The study addresses two key overarching questions:

- What challenges are shared by the UK and with other countries in the area of heat decarbonisation and where is there less commonality?
- What can the UK learn or adopt from innovation outside of the UK, both in countries where there are clear points of comparisons as well as contrasts?

The study also addresses more detailed research questions that fall under the themes of heating and cooling demand, supply, technology and policy. Details of these research questions are set out in section 4.

The structure of the report is as follows:

[1] *(BEIS 2012)*

[2] *(Hanna, Parrish, and Gross 2016)*

— section 2 lays out the methodology for evidence screening and selecting priority cases. Annex 1 provides further detail on this;
— section 3 answers the research questions. Annex 2 summarises country-level descriptions of heating and cooling sectors;
— section 4 presents the summaries of the five case studies – Germany, Sweden, Japan, the Netherlands and France. Annex 3 has the detailed case studies;
— section 5 synthesises the conclusions.

2 Methodology

This work involved a broad review of evidence on heating and cooling sectors across OECD countries and detailed case studies on countries that appeared to offer the greatest potential for learning. Following an initial review of the literature, to streamline the study, it was agreed to predominantly focus on eight countries that were found to have a good amount of robust and reliable evidence and a range of characteristics enabling the comparison of similarities and differences in their heating and cooling profiles. These countries are: Canada, Germany, Japan, the Netherlands, New Zealand, Norway, Sweden and the US. Further details on the methodology can be found in Annex 1.

The rapid evidence review included three main steps:
— a broad systematic search of the academic literature;
— a targeted quantitative search based on research questions (see Section 4) provided by BEIS along four categories – demand, supply, technology and policy; and
— a quantitative data search.

Once this was accomplished, collected data was then judged on the basis of quality. Quality was assessed on two dimensions: source reliability and relevance to the project. The outcome of the evidence assessment was aggregated into two supplementary spreadsheets made available to BEIS. The first sheet lists 250 academic sources and the second sheet the top 50 targeted sources.

The key conclusions from the top 50 targeted sources are:
— **demand**: strongest evidence is present in Europe, the US and New Zealand, data gaps in Japan;
— **supply**: there is good evidence regarding the fuel mix overall, but lack of highly granular spatial data outside of Europe, and poor evidence on gas grid decommissioning;
— **technology**: there is good evidence on the technology mix for Europe, the US, Canada, and New Zealand;
— **policy**: there is good evidence on decarbonisation strategy across countries and on future policy innovation.

Annex 1 contains additional information about project approach, methodology for evidence review and key results of the evidence review.

As a result of the evidence assessment, countries were grouped into archetypes and research questions were answered in detail for each. Sections 3 and 4 present the archetypes and answers to research questions respectively. Three countries were then selected for detailed case studies, shown in section 5.

3 Archetypes

The eight countries (excluding the UK) taken forward as the main focus of the evidence review were assessed for four attributes that might influence a country's heating and cooling provision: resource endowment, markets, infrastructure and climatic conditions. The implication of this exercise is that countries face similar challenges and opportunities in the decarbonisation of heating and cooling if their attributes are similar. Resource endowment is selected as the key attribute and is used to group countries into archetypes.

This section provides an initial assessment of eight countries (Canada, Germany, Japan, the Netherlands, New Zealand, Norway, Sweden and the US) in relation to four attributes:

- **resource endowment**: countries with access to natural gas, hydro, biomass or coal may have well developed supply chains and infrastructure to use these fuels. This may impact energy prices and the economics of heating and cooling;
- **markets**: countries that have historically had a greater degree of state provision or market intervention by state may have been able to facilitate technologies that need coordination such as district heating. The differential between electricity and gas prices is also a significant driver of fuel mix (see Table 2);
- **infrastructure**: technologies which require new infrastructure such as district heating may be better suited in countries that are highly urbanised, as heat distribution costs fall in dense areas. Countries with existing gas infrastructure may face barriers to reducing its use, such as customer familiarity and the costs of decommissioning. An efficient building stock may also support the use of certain technologies like heat pumps; and
- **climate region**: in particular whether the country is in a temperate region similar to the UK.

Table 1 presents a summary of these attributes for the eight countries.

Resource endowment is identified as the key attribute for grouping countries into archetypes. The archetypes provide information on the barriers and opportunities in countries with similar endowments. The other three attributes are taken into account while selecting priority cases for further study to assess similarity and contrast to the UK (see section 5).

Table 1. **Summary table on attributes for heating/cooling in buildings**

Country	Buildings heating and cooling cons. as a% of total energy cons.	CO_2 em from res. sector as a% of total energy em	Fuel (% of total energy used for heating in buildings)	Natural endowment	% of households connected to gas grid	Climate region (HDD)	Avg. annual heat pump sales per 1000 households	% of citizens served by District Heating	Key policies
Canada	24%	13%	Gas (52%), electricity (25%)	Very high oil and gas reserves. high hydro and biomass	50%	Temperate in south, subarctic and arctic in north (6,561)	..	<1%	- Financial incentives - Policies vary at the federal and provincial levels
Germany	39%	24%	Gas (43%), oil (26%), electricity (10%)	Very low oil and gas reserves	54%	Temperate, marine (3,017)	1.7	12%	- Grants and low interest loans for building renovations and industrial heat and renewable district heating - Building standard RH obligations for new-build (and existing buildings in one state)
Japan	8% (Residential space heating only)	18%	*[shares for total res energy demand]* Electricity (53%), oil (26%), gas (20%),	Very low oil and gas reserves, moderate hydro	54%	Temperate along coast, colder interior with increased precipitation and colder summers (2,814)	8.1	..	- Energy efficiency standards for buildings and appliances (including space heaters) - Government financed heat pump efficiency R&D - Loans, tax incentives, grants, subsidies for building energy efficiency (including heat)
Netherlands	24% (heating only)	17%	Gas (83%), electricity (7%)	High gas reserves	94%	Temperate and marine with cool summers and moderate winters (2,711)	1.1	4%	- Subsidy support for renewable heat - Emphasis on continued innovation

Country	Buildings heating and cooling cons. as a% of total energy cons.	CO_2 em from res. sector as a% of total energy em	Fuel (% of total energy used for heating in buildings)	Natural endowment	% of households connected to gas grid	Climate region (HDD)	Avg. annual heat pump sales per 1000 households	% of citizens served by District Heating	Key policies
France	26%	19%	Gas (42%), oil (21%), electricity (15%), biofuels and waste (12%)	Very low oil and gas reserves, moderate hydro	41%	Temperate, warmer in south east (2,340)	4.9	6%	- Subsidies for residential and commercial renewable heat - Regulation effectively eliminating direct electric heating in new builds - Carbon tax on fossil fuels
New Zealand	14%	7%	Electricity (63%), gas (23%)	High hydro	Low	Temperate with sharp regional contrasts (3,354)	53	<1%	- Subsidies for heat pumps - Due to high level of electric heat generation, focus has been on renewable electricity
Norway	11% (Residential space heating only)	3%	Electricity (85%)	Very high gas and oil reserves, high hydro	Low	Temperate along coast, colder interior with increased precipitation and colder summers (5,413)	34	<10%	- Subsidies for heat pumps - Subsidies for DH infrastructure - Energy performance labelling - Ban on oil boilers from 2020
Sweden	21%	7%	Electricity (38%), district heating (50%), biofuels and waste (5%)	Very low oil and gas reserves. high biomass and hydro	1%	Temperate in south, subarctic in north (5,183)	23	52%	- High energy tax on heating fuels - Support for district heating expansion - Heat pump electricity tariffs
UK	34%	26%	Gas (78%), electricity (12%)	Moderate oil and gas reserves	85%	Temperate and marine (3,017)	0.7	2%	- Renewable Heat Incentive – generation-based tariffs for large-scale and small-scale installations - Some support for district heating

Country	Buildings heating and cooling cons. as a% of total energy cons.	CO_2 em from res. sector as a% of total energy em	Fuel (% of total energy used for heating in buildings)	Natural endowment	% of households connected to gas grid	Climate region (HDD)	Avg. annual heat pump sales per 1000 households	% of citizens served by District Heating	Key policies
US	15% (buildings space and water heating only)	21%	Electricity (42%), gas (50%)	High oil and gas reserves. Moderate hydro.	56%	Mostly temperate; tropical, arctic and semi-arid in some regions (4,494)	1.8	<1%	- Federal tax credits for various renewable technologies - State level tax incentives and rebates

Note: *..=not available. Norway% of citizens served by DH is an approximation. 10% is the amount of heat produced from district heating as a percentage of total heat generation in Norway. HDD=heating degree days (2008-2009 average). HDD base for EU = 16C, non-EU =65F. HDD aggregate data not available for Canada, Japan and New Zealand, as a proxy HDD data from Toronto, Tokyo and Wellington is used respectively. US HDD data excludes Alaska and Hawaii.*

Source: *Norway DH from (Statistics Norway 2017), US and Japan heat pumps per 1000 calculated from: (Dawson 2014), fuel (% of total energy used in res.) from country national statistics, emissions from the residential sector from* (IEA 2016)*, natural endowments from (BP 2016), climate region data from (CIA, n.d.), HDD data from (EIA 2012), (Eurostat 2013), (The Weather Company 2017),% of households connected to gas gird, average annual heat pump sales and % of citizens served by DH from (Hanna, Parrish, and Gross 2016) and key policies from (Collier, 2018). Fuel shares and gas connections data for the UK from ECUK tables, 2017.*

Table 2. **Summary of fuel prices**

Country	Gas price p/KWh	Electricity p/KWh	Difference (p/kWh) electricity-gas
Canada	3	7	4
Germany	6	27	21
Netherlands	7	15	8
New Zealand	8	15	7
Norway	..	14	..
Sweden	10	18	8
UK	5	17	12
US	4	10	6

Notes: *For Canada data, 1GBP =1.63CAD, data is for 2014. For EU country data: 1GBP=1.1EUR, data is the 2016 average price. For US data, 1GBP=1.28USD, data is 2016 average price. NZ data is from 2013 in USD PPP,1GBP=1.28USD.*

Source: *Canada: (Natural Resources Canada 2014b) European countries: (Eurostat 2017), US : (EIA 2017), NZ: (Ministry of Business 2013)*

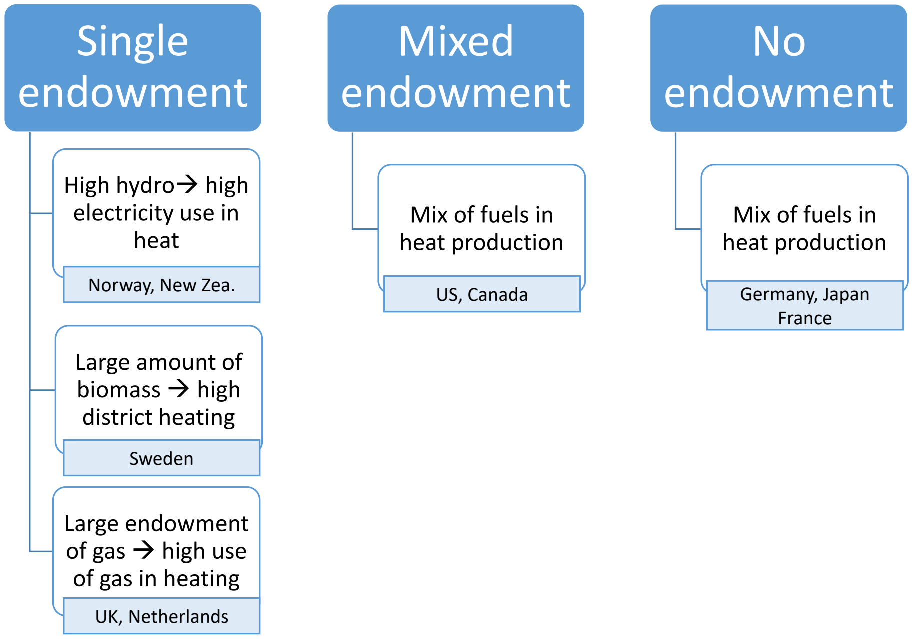
Three simplified archetypes are specified:

— **single endowment for heating:** these are countries with a single resource such as hydro (delivered via electricity), natural gas or biomass resources that can be used in heating. For example, Norway and New Zealand have large hydro resources, the UK and the Netherlands have extensive gas reserves, and Sweden has large biomass resources. Some countries have multiple resources, for example Norway has hydro as well as oil and gas, but only one is used for heating. This may be because some resources were discovered at a later stage, by which time the lock-in costs for the initial resource were high.

— **mixed endowment for heating:** this archetype includes countries that have multiple resources that can be used for heating. Examples include the US and Canada, which have gas reserves, coal, as well as hydro. Canada also has large biomass reserves.

— **no endowment for heating:** countries like Germany and Japan that do not have indigenous resources for heating fit into this archetype.

Figure 1. **Archetypes**



Source: *Vivid Economics*

The archetype analysis suggests that there is a strong relationship between endowment and fuel mix used for heating.

— **Single endowment countries use their endowment as the dominant heating source.** Countries with large amounts of hydro have a lot of electric heating. For example, in both Norway and New Zealand, over 70% of heating is supplied by electricity. Countries with large gas reserves have extensive gas grids and use gas as the key source for heating. Examples are the UK and the Netherlands where over 80% of heating is delivered from gas. High biomass countries like Sweden, have high district heating. Sweden uses biomass-powered district heating as the main source of energy for heating, although district heating in these countries was initially developed to use fossil fuels.

— **Both mixed endowment countries and no endowment countries end up with a diverse heating fuel mix**. The US and Canada use a mix of gas and electricity for heating. Germany and Japan largely import oil and gas for heating.

4 Research questions

This section provides answers to research questions for each of the eight countries. The research questions are split into four broad themes: demand, supply, technology and policy. Insights into the research questions have been summarized in sections 4.1 to 4.4. Detailed summaries by country are provided in the Annex.

The questions answered include:

Demand:

- What proportion of energy demand and CO2 emissions in each country is driven by heating and cooling (i.e., how much of a priority is energy demand from heat and cooling in terms of energy bills and carbon targets)?
- How is demand for heating and cooling segmented by sector (industry, residential, commercial & public), access to national gas / electricity grid, proximity to natural energy resources, urban/rural/suburban?

Supply:

- What energy sources (e.g., hydrogen, biogas, electricity) are used to meet demand (segmented as above) and how are they produced?
- How is energy distributed at a national and local level (segmentation as above)?
- How are energy system challenges driven by daily and seasonal heat demand peaks mitigated?

Technology:

- What technologies are used to provide heating and cooling (segmented as above) and what factors have driven this technology mix?

Policy:

- What low carbon heating and cooling policies and strategies have been deployed or proposed?
- What major innovation strategies are in place, or are currently being developed, which are relevant to decarbonising heating and cooling?

4.1 Demand

This section explores the heating and cooling demands for residential and commercial buildings in the selected countries, as well as other European countries.

4.1.1 Global context

Globally, heat accounts for more than half of final energy consumption. This includes heat consumption for space heating and water heating in buildings, for cooking and for operating industrial processes. Over two thirds of the world's heating consumption is in China, India, North America, Europe, Eurasia and Russia. Within Europe and North America, most of the heat demand occurs in buildings – 61% and 54% respectively[3].

Heat accounted for around 12 $GtCO_2$ or 40% of global annual energy related emissions in 2014[3]. Additionally, burning of fossil fuels or biomass for heat also contributes to local air pollution problems.

Space cooling is also a fast-growing energy service demand in buildings and accounts for around 2% of global energy consumption (including consumption in buildings, industry and transport)[3].

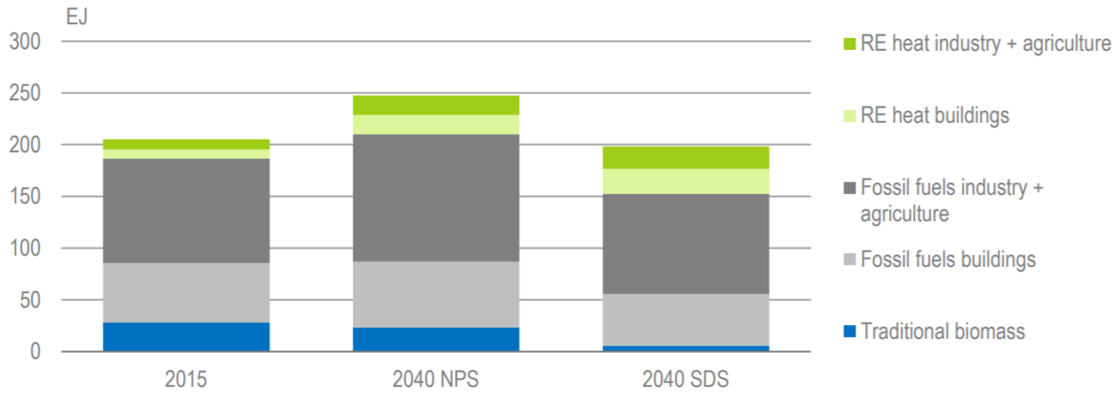
Heat demand varies between countries due to climatic regions, building efficiency and heating technologies. Countries with cold/temperate climates have high heat demands in general, although there are large variations per m^2 of floor space even within countries in the same climatic region due to energy efficiency of the building stock[3].

Demand for heat is expected to increase over the next few decades (see Figure 2). Heat demand would increase between now and 2040 under a scenario that takes into account policies currently in place or committed to (New Policies Scenario, NPS). Fossil fuel consumption for heat would also increase under this scenario. Heat demand would decrease slightly by 2040 under a scenario that describes an integrated path for achieving the Sustainable Development Goals most closely linked to energy (labelled 'SDS' in Figure 2).

Data on energy use for heat is variable. Most actual heat delivered is not measured by international databases except the limited amount of heat sold through district heating. Data limitations are particularly significant for biomass.

[3] (Collier, 2018)

Figure 2. **Global heat demand scenarios for 2040**



Note: *NPS is the New Policies Scenario broadly serving as the IEA baseline scenario. It takes account of broad policy commitments and plans that have been announced by countries, including national pledges to reduce greenhouse gas emissions and plans to phase out fossil fuel subsidies, even if the measures to implement these commitments have yet to be identified for announced. SDS is the Sustainable Development Scenario, which integrates the objectives of the three Sustainable Development Goals (SDGs) that are most closely related to energy – climate stabilisation, cleaner air and universal access to modern energy.*

Source: *(Collier, 2018)*

4.1.2 Heating and cooling demand across selected countries

This section provides a summary of insight into the heating and cooling demand research questions using the nine countries of focus (including the UK). A summary of heating and cooling demand across a range of OECD countries is also provided.

What proportion of energy demand and CO_2 emissions in each country is driven by heating and cooling?

Total heating and cooling demand from buildings is in the range of 13 – 39% of the total final energy demand in the selected countries (see Table 3). Germany has the highest relative heating and cooling demand at 35%, followed by the UK, the Netherlands and Canada. Cooling demand is small in most of the countries considered in this study.

Comprehensive data on emissions from building heating and cooling usage is not available. Table 4 shows data on CO_2 emissions from consumption of heat and electricity by the residential sector. Countries with high relative emissions include the UK, Germany and the US.

How is demand for heating and cooling segmented by sector (industry, residential, commercial and public), access to national gas / electricity grid, proximity to natural energy resources, urban/rural/suburban?

Residential buildings account for a large share of heating and cooling demand from buildings. Table 3 shows that except for New Zealand, where demand from commercial buildings is around 60% of total buildings' demand, in most countries, on average, residential buildings account for three-quarters of the total buildings' demand. Data on industrial demand was only available for a few countries and has been omitted.

Household demands for heating vary significantly across countries. Annual demand per household for space heating and hot water is highest in Canada at 28 MWh, and lowest in New Zealand at 6 MWh. The UK, Germany and the US have similar demands around 14 MWh, while Sweden, Norway and Netherlands have slightly lower demands. The reasons for these variations include differences in climate affecting the need for heating and cooling, energy efficiency of building stock, access to heating and cooling, and the average sizes of households.

Countries vary in the extent of national gas grid. The UK and the Netherlands have the majority of their households connected to the gas grid; the US, Germany, Japan and Canada have approximately half of their households connected to natural gas grids. All of these countries have large indigenous reserves of natural gas, except Germany and Japan which import most of it. New Zealand, Sweden and Norway have very low indigenous reserves as well as a low level of gas connections.

Comprehensive data on split of heat demand between urban, suburban and rural areas does not exist.

Table 3. **Heating and cooling demands for buildings**

		Heating + hot water (TWh)		Cooling (TWh)			
Country	**Building heating and cooling demand as a% of total energy consumption**	**Residential**	**Commercial**	**Residential**	**Commercial**	**No of hhlds (million)**	**Per hhld demand for space and water heating (MWh/hh)**
Canada	24%	360	175	5	16	13	28
France	26%	292	133	4	18	29	10
Germany	35%	574	277	2	18	41	14
Japan	8% (Residential space heating only)	280	..	..	..	..	..
Netherlands	23% (heating only)	75	75	..	..	..	10
New Zealand	14%	10	10	..	3	2	6
Norway	11% (Residential space heating only)	25	..	..	..	2	11
Sweden	21%	55	21	..	1	5	12
UK	34%	370	110	..	13	27	14
US	15%	1,767	840	..	..	125	14
Other European countries (space heating demand only)							
Austria	26%	57	22	..	1	4	15
Belgium	8%	..	35	..	1	5	
Croatia	21%	11	4	1	-	1	8
Czech Republic	24%	48	22	..	1	5	10

Denmark	35%	36	15	..	..	2	15
Estonia	8%	..	3	..	..	1	
Finland	22%	55	7	..	1	3	21
Greece	8%	..	..	3	12	4	..
Hungary	13%	..	24	..	1	4	..
Ireland	8%	..	10	..	..	2	..
Italy	27%	206	112	16	34	26	9
Latvia	10%	..	4	..	..	1	..
Lithuania	16%	7	4	..	..	1	5
Poland	23%	120	54	-	3	14	8
Portugal	6%	..	8	1	2	4	
Slovakia	21%	8	15	..	..	2	4
Spain	10%	..	41	12	39	18	
Switzerland	23%	51	..	..	..		

Note: *.. = not available. All heating demands include space heating and hot water, except Norway and Japan, where data is only available for domestic space heating. Data on cooling demands was not available for Japan, Netherlands and the US. For Japan, commercial sector heating demand data is also not available.*

Source: *Residential heat demands from (Euroheat 2015), commercial heating and cooling demands from* (Stratego 2015b)

Table 4. **Carbon emissions from electricity and heat consumption in the residential sector $MtCO_2$**

Variable	Total	Residential	Residential as a proportion of total
Canada	555	73	13%
France	286	55	19%
Germany	723	171	24%
Japan	1,189	218	18%
Netherlands	148	26	17%
New Zealand	31	2	7%
Norway	35	1	3%
Sweden	37	3	7%
UK	408	108	26%
US	5,176	1,100	21%

Source: IEA, 2015

4.2 Supply

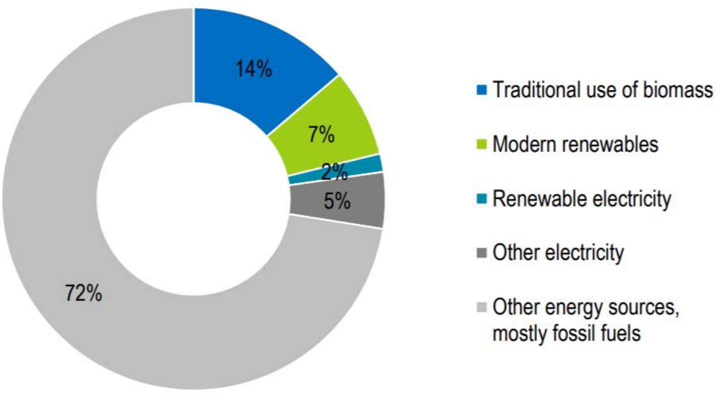
This section presents the energy sources used to meet heating demands, in both residential and commercial buildings. The split between the residential and commercial buildings is not available[4]. The section also discusses how energy system challenges driven by daily and seasonal demand peaks are mitigated.

4.2.1 Global context

Direct combustion of energy sources such as oil, coal, natural gas or biomass supply 86% of world heating needs. Only 9% of world heating demand is met by renewables excluding traditional biomass (see Figure 3). Often, the supply source of heat depends on uniquely local factors and circumstances contingent upon climate, distribution networks, resource endowments and heating policies.

Space cooling, and most cooling demand in general, is met by electricity.

Figure 3. **Total global energy consumption for heat (2015)**



Note: *'Other energy sources' includes oil, coal and natural gas*

Source: *(Collier, 2018)*

4.2.2 Heating and cooling supply across selected countries

This section provides a summary of insight into the heating and cooling supply research questions using the nine countries of focus (including the UK). A summary of heating and cooling supply across a range of OECD countries is also provided.

What energy sources (for example, hydrogen, biogas, electricity) are used to meet demand and how are they produced?

[4] for example Stratego 2015a provides fuel split for space heating and hot water in residential and service sector buildings

Heat is primarily produced by fossil fuels in most countries. Around 80% of heat demand for buildings in the UK and the Netherlands is met by gas. Gas also plays a large role in meeting heat demand in Canada, the US and Germany. In these countries, gas is either produced domestically or imported (see section 4.1 above).

The use of electricity for heat is high in countries with abundant indigenous resources for power generation. Norway and New Zealand have the highest proportion of electricity in their heating fuel mix (see Figure 4). In both countries, electricity is generated predominantly from domestic hydro resources. The US and Canada also produce over 25% of heat from electricity. Sweden uses a moderate amount of electricity in heat production.

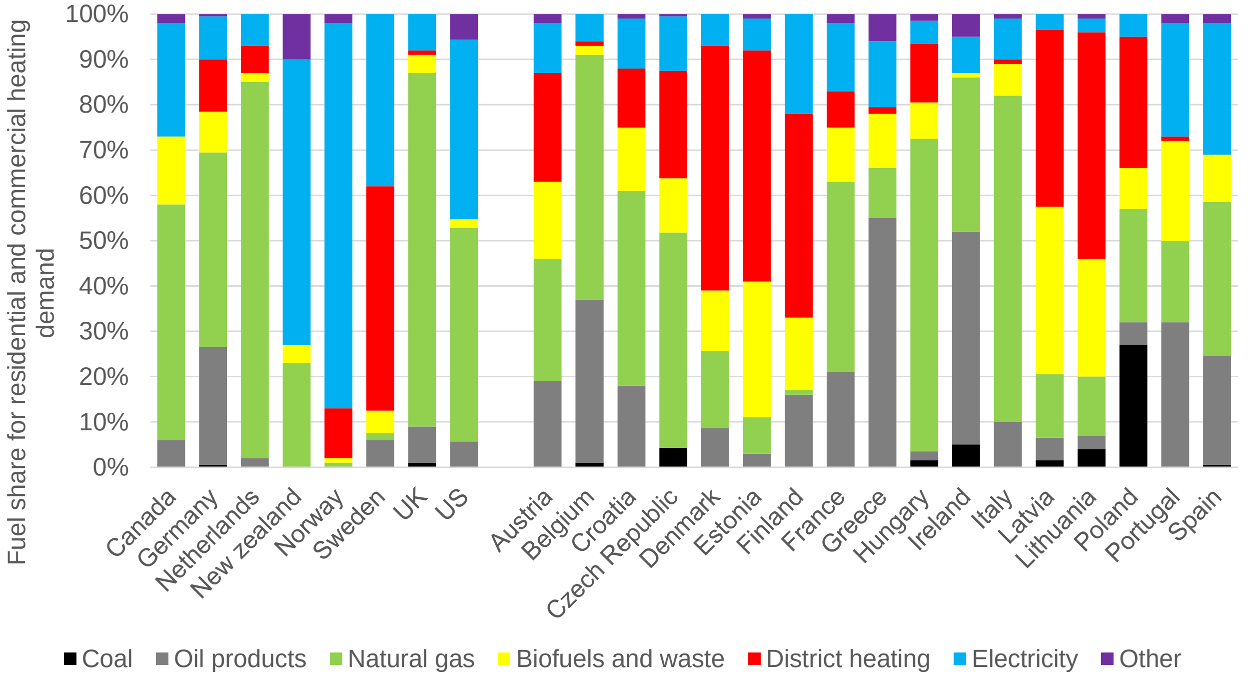
Countries with large shares of domestic biomass have transitioned towards biomass powered district heating. District heating is Sweden's dominant source of energy for heating and largely utilises biomass from forests. In Norway, district heating supplies over 10% of heat demand and is produced using a mix of biomass and waste heat. However in most countries, district heating was initially constructed to run on fuels such as coal and fuel oil, and has more recently transitioned towards gas, municipal waste, waste heat and wood.

How are energy system challenges driven by daily and seasonal heat demand peaks managed?

District heating and Combined Heat and Power (CHP) generation can be an important source of peak shaving and energy storage. Heat demand peaks create challenges by putting pressure on the power system. The use of district heating instead of electricity for heating in the Nordic countries reduces the need for electricity, but especially the peak in demands, as electricity demand also peaks in the coldest winter days. When district heating is produced with CHP, electricity can also be produced which is helpful particularly during the peak demand. When the demand for electricity is low, electricity production can be bypassed in the CHP plants, or district heat can be produced with heat-only boilers or heat pumps in the system. District heating systems also allow the heat to be stored in the district heating networks and separate heat storages, which is not possible with electricity[5]. Information on how other countries manage these peaks in demand was not easily available, and therefore based on the literature and data reviewed, it was not possible to compare countries.

[5] (Nordic Council of Ministers 2017)

Figure 4. **Fuel shares for residential and commercial heating**



Note: *Data for Japan and Slovakia is not available. For US, data is only for residential fuel shares. Other includes winds, solar, geothermal and peat.*

Source: *EU data from (Stratego 2015b), Canada data from (Natural Resources Canada 2014a), New Zealand data from* (Energy Efficiency and Conservation 2015a),*Norway data from (Nordic Council of Ministers 2017) and US data from* (EIA 2015a).

4.3 Technology

This section describes the technologies used to provide heating and cooling in buildings (split not available for residential and commercial buildings) and discusses the factors driving this technology mix.

4.3.1 Global context

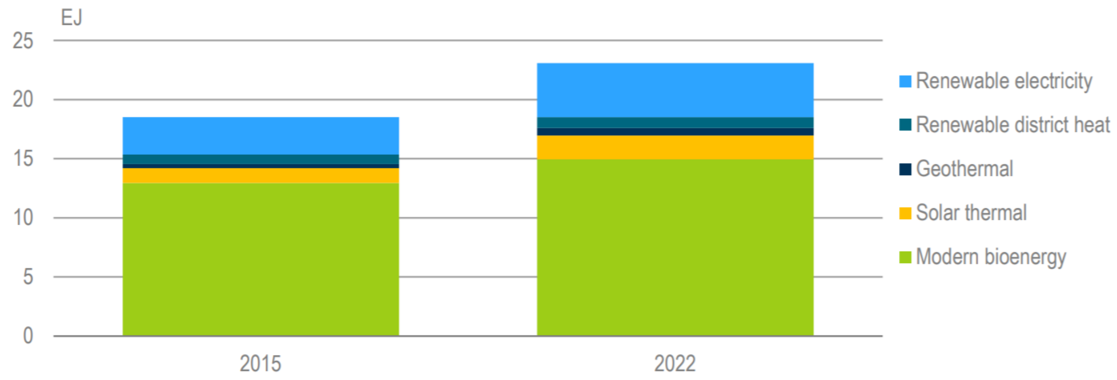
Improvements in building energy efficiency can be deployed to decrease demand and heat waste, and to make the buildings compatible with new technologies. This can be accomplished by better insulation of buildings, smarter building energy management and more efficient heating appliances. Heat demand however cannot be completely eliminated and in some cases substantial reductions in heat demand may be difficult or expensive. Therefore, low carbon heating technologies are required to decarbonise heat.

Multiple strategies exist to make heat generation more energy efficient or to decarbonise heating systems completely. In dense urban areas, district heating (and cooling) provide the infrastructure for flexible heating supply that can be based on a number of sources including biomass, waste heat and heat pumps. The electrification of heat generation, provided the electricity is sourced from renewable sources, offers another avenue to decarbonisation. It is particularly efficient when heat pumps are used. Direct renewable heat options use solar thermal, biomass or biogas boiler, biomass or biogas CHP systems and biogas injection into gas grid.

Currently, biomass based technologies dominate renewable energy consumption but the use of other technologies is expected to grow (see Figure 5). The use of electricity for heat especially through heat pumps is expected to increase. Along with growing share of renewables in electricity generation, this would mean an increase in the share of renewable electricity in heat consumption. Solar thermal and geothermal are also expected to grow, though from a small base[6]. Still under development, hydrogen, if generated via low carbon methods, is a novel technological solution to decarbonising heat.

[6] (Collier, 2018)

Figure 5. **Total final, global consumption of renewable heat by source 2015 and 2022 (including industry)**



Source: *(Collier, 2018)*

4.3.2 Heating and cooling technologies across selected countries

What technologies are used to provide heating and cooling and what factors have driven this technology mix?

Share of heat pumps is high in Sweden, New Zealand, Norway and new builds in Germany.

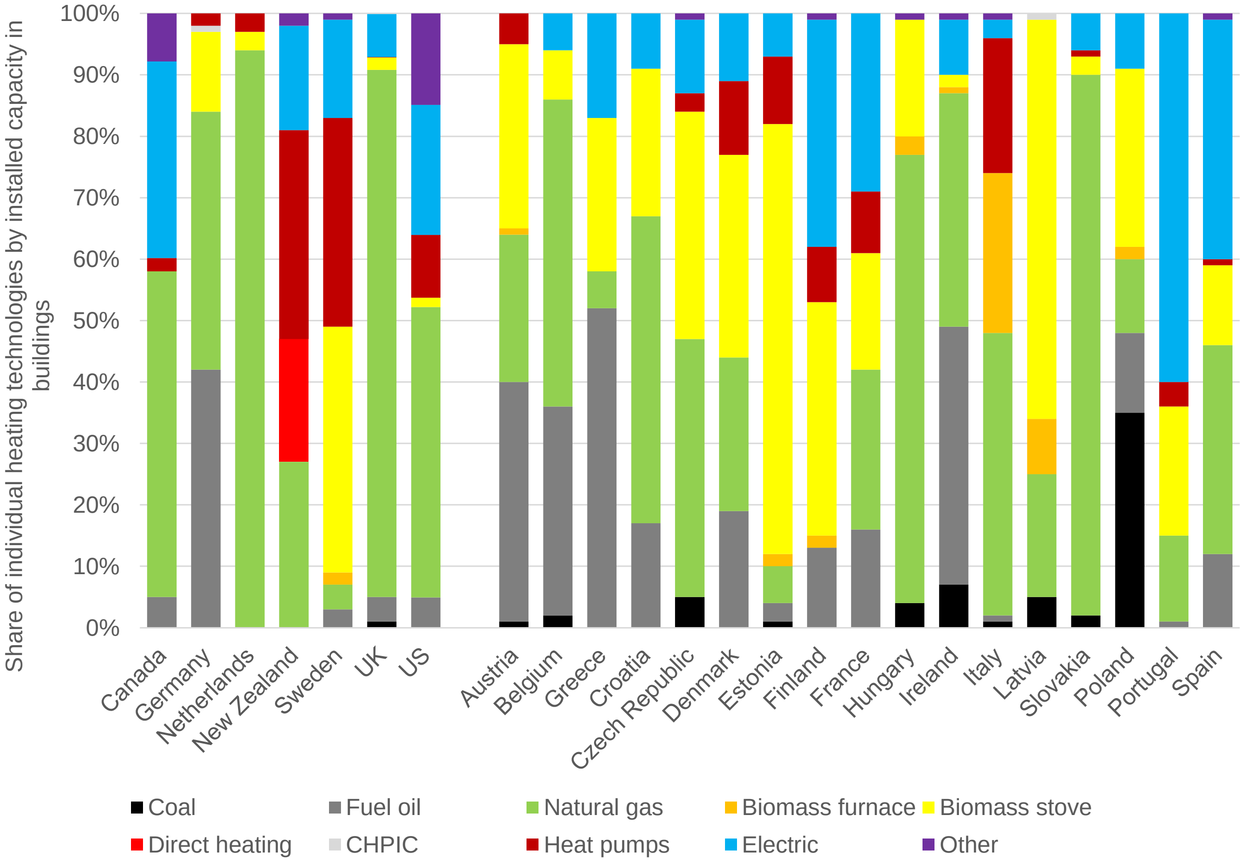
- Sweden has heat pumps in about a fifth of dwellings. Oil use is taxed heavily in Sweden whereas the use of biomass and heat pumps has been promoted through subsidies, which led to oil boilers being substituted by heat pumps and/or mainly biofuel based alternatives like biomass boilers.
- In New Zealand, the share of heat pumps in residential buildings has increased significantly in the last ten years, replacing fossil fuel based heating. This has been a result of heating programmes that encourage take up through subsidies. Over 60% of households in New Zealand use heat pumps for cooling rather than heating.
- The heat pump market in Norway has also seen strong growth in the last 10 years, mainly due to policies implemented in response to hydro capacity constraints, increasingly high electricity costs for end-users and subsidies for heat pumps. A large proportion of buildings transitioning to heat pumps were previously using direct electric heating, therefore transition to heat pumps reduced electricity demand.
- Share of heat pumps in new homes in Germany has increased from less than 1% in 2000 to 23% in 2016 as a result of building standards, financial support and changes in VAT rates.

Biomass based technologies are popular in Sweden and New Zealand.

- In Sweden, biomass has been supported by two investment subsidy programmes. This has led to the use of wood fuel alternatives in homes as well as use of biomass in district heating.
- Wood burners have been historically popular in New Zealand

Conventional technologies like gas and oil boilers dominate in countries with high gas and oil usage in heating.

Figure 6. **Share of individual technologies by installed capacity in buildings**



Note: *Data not available for Japan, Lithuania and Norway. For US, data is available on actual number of units installed and residential buildings only.*

Source: *EU data from (European Commission DG Energy 2016), Canada data from (Natural Resources Canada 2017), New Zealand data from* (Energy Efficiency and Conservation 2015b)*, and US data from* (EIA 2015b).

4.4 Policy

This section presents an analysis of policies deployed in countries to promote low carbon heating and cooling.

4.4.1 Global context

Global analysis indicates that there are several best practice policy elements that are needed to deliver long-term heat decarbonisation successfully. A recent IEA report[7] looks at the renewable heat policies of nine countries. The study suggests that these best practice elements include:

- **A long-term ambition for renewable heat in buildings.**
- **An effective delivery plan** taking a systems approach, integrating renewable heat with energy efficiency policies and facilitating action at the local level.
- **Public investment in district heating infrastructure to facilitate renewable heat integration**.
- **Addressing economic barriers via taxation and support mechanisms**. Renewable heat support policies in buildings have focused on grants and support of renewables in district heating.
- **Addressing non-economic barriers** through building codes and installer certifications for example.

Assessing the effectiveness of individual policies is difficult however, as countries have used a package of policies and relevant information to assess effectiveness of individual policies is not available. Detailed statistics on heat demand or renewable heat deployment are not published by most countries. In the absence of this data, making comparisons between policies is difficult[9].

4.4.2 Heating and cooling policies across selected countries

What low carbon heating and cooling policies and strategies have been deployed or proposed?

Strong government intervention appears to be a common feature of low carbon transitions. Policy has addressed multiple market failures/barriers in the heat sector.

- **natural monopoly**: the development of district heating requires centralised planning and the capacity to collaborate between energy utilities, localities and states. District heating in Sweden, for example, developed prior to liberalisation and was planned and organised by local governments.
- **information provision**: technical and informational barriers regarding new low carbon technologies have been addressed through information provisions and awareness raising campaigns. In Germany, establishment of the German heat pump association (IWP), the publication of technical manuals and guidance and the information campaigns by the IWP played a role in steady growth of heat pump sales in the 1990s. The heat pump market in Sweden has also been supported through technical standards and information campaigns.
- **innovation**: governments have supported R&D in technologies and provided support for innovative renewable technologies. German's Market Incentive Programme for renewable heat provides bonus supports for innovative renewable heating technologies or combination of different technologies.

[7] *(Collier, 2018)*

— **financial barriers**: technology uptake has been encouraged by financial support in the form of subsidies and grants.

A variety of policy instruments have been used to address different failures.

— **credible long-term commitment:** countries with a successful transition have a credible long-term commitment to heating infrastructure transition, often initiated for security of supply reasons and more recently to meet ambitious decarbonisation goals. Sweden has an ambition to phase out fossil fuels by 2020, and is well on the way to achieving this. Germany's energy transition has stringent targets for the buildings sector. Long-term and sustained policy support over a multi-decadal timeframe have been pivotal for successful transitions.

— **taxes:** energy or carbon taxes have been successful in some countries in a switch away from oil and gas towards use of renewable technologies. Sweden has taxes on natural gas and oil used in heating which have substantially risen over time (e.g. from $44 per metric ton of CO_2 in 1991 to $168 per metric ton of CO_2 in 2014). In district heating, high taxes have led to a transition away from heating oil to biomass.

— **codes:** building codes that require a certain percentage of heat to be supplied from renewables have encouraged the take up of low carbon technologies. Building codes in Sweden have resulted in it having the most efficient stock in the EU and have contributed to the increasing dominance of air-to-air heat pumps over GSHPs since 2005. This is because these building regulations have mandated higher energy efficiency levels and lower heating demands in new buildings. Such new buildings with tighter building envelopes frequently require controlled ventilation. In Germany, building codes for new builds have made heat pumps the second most popular heat source after gas. The 'Investment aid for Energy measures in households' programme in Norway also supports energy efficiency measures, measures aimed at decreasing energy consumption or conversion from heating sources based on fossil fuels or electricity to a renewable source (see Table 5 below).

— **technical standards:** have supported the heat pumps market in particular (for example, see the Germany case study in Section 5.1/Annex 3).

— **grants/subsidies:** have been provided for individual technologies as well as district heating investments. These include Germany's Market Incentive Programme for renewable heat, Japan's subsidies and loans for renewable heat, Netherland's Sustainable Energy Investment Subsidy programme, New Zealand's Warm Up New Zealand programme, Norway's subsidies and financial incentives for heat pumps and district heating, and Sweden's subsidies to replace oil and direct electric. Table 5 below provides details on these policies. However, where policies have been credible and coherent, such as Sweden and Norway, grants/subsidies have been phased out as the technologies became competitive.

It is also notable that in most cases a combination of all or most of the above policies has been in place, and it is the policy package rather than individual policies that appear to have resulted in a successful transition due to synergies between policy goals[8]. For example strong building codes or support for district heating are in part a response to cold climate, seeking to ensure that citizens have acceptable levels of comfort at affordable prices. Additionally, they have also made decarbonisation easier to achieve over time. While district heating permits the fuel source for heat to be decarbonized, such as transition from fossil fuel to biomass in Sweden, efficient building stock makes heat pumps feasible.

[8] (Hanna, Parrish, and Gross 2016)

Market forces have also been a driver in some of these transitions but in combination with policy[9]. Early deployment of heat pumps and heat networks in leading countries took place as a response to the oil crises in the 1970s, partly as prices rose but also as a result of policies. However, in the decades that followed, a combination of planning, regulation, taxation and incentives brought around a transformation of heat provision. In Norway, rising electricity prices in the late 1990s encouraged a move towards heat pumps and district heating, but it was supported by policies to facilitate take up.

Information on levels of public engagement, and on the impact of public engagement initiatives, was not available in the evidence sources that were reviewed. Although the public engagement was raised during our stakeholder interviews for this work, no evaluations of public engagement policies were available. This could potentially be an important aspect of policy uptake, as familiarity of customers with potential heating technologies and knowledge of incentives was referenced by interviewees as a key ingredient of the success of new technologies.

[9] (Hanna, Parrish, and Gross 2016)

Table 5. **Key policies**

Country	Policies	Policy details
Canada	- Capital grants and subsidies, soft loans and tax incentives - Policies vary at the federal and provincial levels	- **ecoENERGY for Renewable Heat Program**: CAD 36 million program between 2007 and 2011 to encourage solar thermal equipment for heating and cooling and water heating - **Renewable Energy Deployment Initiative (extension)**: CAD 25 million between 2003 and 2006 to promote solar hot water and space heating systems, biomass combustion systems and ground source heat pumps
Germany	- Grants and low interest loans for building renovations and industrial heat - Building standard renewable heat obligations for new-build (and existing buildings in one state)	- **Energy Efficiency Ordinance**: launched in 2001 regulates maximum level of primary energy consumption of all new and existing buildings - **Market Incentive Programme for renewable heat** (2008-2017): offers grants for small-scale renewable heat systems including heat pumps, and low-interest loans for industry and district heating (currently €300 million per year available in grants or low-interest loans) - **Federal Renewable Energies Heat Law**: introduced in 2009, sets out requirements for a specific percentage of heat demand in new buildings to be supplied by renewable heat - **Energiewende** in the buildings sector has stringent targets for energy efficiency, refurbishment, and loans for renewable heat technologies
Japan	- Energy efficiency standards for buildings and appliances (including space heaters) - Government financed heat pump efficiency R&D - Loans, tax incentives, grants, subsidies for building energy efficiency (including heat)	- **The Rational Use of Energy Act**, 1979: sets energy efficiency standards for residential and commercial buildings - **The Top Runner Programme**, 1998: covers energy efficiency standards for household appliances, equipment, vehicles and building materials - **The Improvement of Energy Consumption Performance of Buildings Act**, 2015: introduced mandatory efficiency standards for large new buildings and new residential buildings (starting 2020). The policy provides financial incentives and performance labelling - **Subsidies and loans for renewable heat:** Loans schemes for SMEs are available for up to JPY 720 million (approximately £5 million) with a maturity of 15 years. This scheme has been paired with a national R&D project aimed at increasing heat pump efficiency. For homeowners, tax incentives were introduced in 2009 for energy efficient home renovation where 10% of renovation costs up to JPY 2.5 million (approximately £17,250) can be deducted from that year's income tax - **Hydrogen society initiative:** under the 4th Strategic Energy Plan. Includes R&D grants, demonstration projects, subsidies, studies and promotion
Netherlands	- Subsidy support for renewable heat - Emphasis on continued innovation	- **Feed-in Premium Programme SDE +:** a combined support scheme for renewable electricity, biogas, and renewable heating technologies. In 2016, a total of €3.4 billion (USD 3.1 billion) was available for renewable heat technologies and biogas. - **Sustainable Energy Investment Subsidy**: grants for the support of small renewable heating installations in homes and businesses (for example €650 for solar thermal and €1500 for ground source heat pumps) - **Energy Performance Certificate and Energy Labeling**: Measures include methodology for calculating the energy performance of buildings; application of performance standards on new and existing buildings; certification schemes for all buildings; regular inspection and assessment of boilers/heating and cooling installations. - **Energy Performance Standard for Buildings:** All new buildings are required in the building code to reach a performance standard. Renewables in buildings like solar thermal, PV, passive solar and heat pumps, contribute to reach a low energy coefficient

Country	Policies	Policy details
France	- Subsidies for residential and commercial renewable heat - Regulation effectively eliminating direct electric heating in new builds - Carbon tax on fossil fuels	- **Crédit d'Impôt pour la Transition Énergétique (CITE):** tax credit for residential renewable heat and energy efficiency investments, up to €8,000/€16,000 for individuals/couples, covering up to 30% of capital costs - **Eco-loan:** 0% interest loans up to €30,000 for residential energy-efficient renovations - **Livret de développement durable et solidaire (LDDS):** preferential rate loans for domestic energy savings projects - **Fonds Chaleur:** subsidies for commercial renewable heat investments, covering project development (40%-80% of costs) and project implementation (25%-80% of costs) - **2012 Régulation thermique:** requires all new buildings constructed after 1 January 2013 to achieve primary energy consumption below 50 kW/m^2 per year, de facto eliminating direct electric heating - **Carbon tax:** taxation on fossil fuels and specific natural gas tax; exemption for installations covered by EU ETS
New Zealand	- Subsidies for heat pumps - Due to high level of electric heat generation, focus has been on renewable electricity - Energy efficiency	- **EECA's Warm Up New Zealand programme** has supported heat pumps by providing funding for insulation retrofits and heater retrofits. Installation rates have been between 90,000 and 120,000 per annum in recent years. - **Energy Efficiency and Conservation Strategy** (since 2001): support for warm, dry and energy-efficient homes with improved air quality to avoid ill-health and lost productivity - **Innovation Fund for Solar Water Heating**: NZD 2.7 million in grants, plus operational costs - **Energywise Solar Water Heating Grants**: NZD 1000 per solar water heating installation
Norway	- Subsidies for heat pumps - Subsidies for district heating infrastructure - Energy performance labelling	- **Concessions for District Heating:** all district heating plants with a total heat capacity exceeding 10MW are obliged to have a district heating concession - **Investment aid for Energy measures in households through Enova SF**: Enova offers investment aid to households undertaking energy efficiency measures, measures aimed at decreasing energy consumption or conversion from heating sources based on fossil fuels or electricity to a renewable source - **Incentives for Non-Electric Heating Technologies**: financial incentives for new homes incorporating non-electric heating technologies. Loans are available for builders to incorporate technologies such as heat pumps, solar systems and biofuel boilers in new construction
Sweden	- High energy tax on heating fuels - Support for district heating expansion - Heat pump tariffs	- **Carbon tax**: Taxation on fossil fuels; exemption on renewable electricity and CHP plants which are part of EU ETS - **Consumer subsidies to replace oil and direct electric heating**: Up front grant: homeowners could receive up to 30% of material and labour costs up to a maximum level per household for replacing direct electric heating with a heat pump, district heating or biomass - **Investment subsidies for biomass CHP**: Investment subsidies for retrofitting of fossil-fired CHP plants and district heating plants (into CHP). - **Tradable electricity certificates for biomass CHP**: Market-based certificates for renewable electricity generated from biomass CHP
UK	- Generation-based tariffs for large-scale and small-scale installations - Some support for district heating	- **Renewable Heat Incentive**: long term support programme for renewable heat, with payments based on heat generated. - **Heat Networks Investment Project**: the £320m (USD 432 million) capital investment programme is expected to support up to 200 projects related to district heating by 2021 through grants and loans and other mechanisms
US	- Federal tax credits (solar thermal only) - State level RPS and rebates	- **Residential Energy Efficient Property Credit:** tax credit of 30% of qualified expenditures for using energy efficient systems - **California Solar Initiative:** budget of USD 2.2 million, ten-year programme to put solar on a million roofs in the state of California.

Source: (IEA/IRENA 2016)

What major innovation strategies are in place, or are currently being developed, which are relevant to decarbonising heating and cooling?

The Swedish Energy Agency has a programme of more than thirty years research and development, much of this is focused on heat pumps. This has resulted in many improvements including the efficiency of compressors, reliability and confidence in large scale water source heat pump projects for the commercial sector. The high uptake and high confidence of heat pumps in Sweden has been attributed in part to the longstanding R&D programme.[10]

Japan has had substantial experience in development of hydrogen. It has successfully developed a residential fuel cell CHP system and further developments are ongoing to expand the use of fuel cells in power and heat supply, to improve the efficiency of the fuel cells and to bring down their costs. Japan is also conducting research into renewable methods of producing hydrogen.

The Dutch government has emphasised the need for significant innovation to make further progress in heating and cooling. This includes the use of aquifers for heat storage, hybrid heat pumps and a better alignment between energy efficiency, residual heat and renewables[11]. The Netherlands' main source of gas, the Groningen gas field is expected to be depleted within 17 years. It is planning to move away from gas towards diverse mix of heat sources including district heating in dense urban areas and heat pumps in less densely populated and well insulated houses.

[10] (Swedish Energy Agency 2009)

[11] (De Vries 2017)

5 Policy evaluation of priority cases

This section provides case study summaries for Germany, Sweden, Japan, the Netherlands and France. The case studies focus on decarbonisation trends in the last 10-15 years, the policies and drivers facilitating transition, and applicability to the UK. Annex 3 offers detailed case studies for the three countries.

Priority cases were selected on the basis of four criteria deemed important for further study:

- **transition**: whether there has been a heating or cooling transition in the country;
- **evidence**: whether there is enough evidence to do a detailed study;
- **previous work**: whether these transitions have been explored before;
- **relevance:** whether the country is similar to the UK or in contrast to the UK.

Case studies are defined as having the most learning potential for the UK if they have attributes which are most similar or most dissimilar to the UK.

Germany, Sweden, Japan, the Netherlands and France were chosen as the priority case studies. The rationale for selecting each of these countries is as follows (Annex 2 provides more detail):

- **Germany** was selected as a result of its similar climate, high levels of gas connections and liberalised market structure. Germany's comparatively advanced process of transitioning to a decarbonised heating system also merited attention. Germany's heat system has been well studied in the past, however, not with respect to decarbonisation policy.
- **Sweden** was selected to highlight the lessons learned during Sweden's ongoing dual transition toward heat pumps and renewable district heating. Sweden offered first rate data availability as well.
- **Japan** was selected in order to explore Japan's efforts to build a hydrogen society. This and Japan's uniquely effective institutional structure set it apart from other potential case studies. Few previous studies have been conducted on Japan's heating and cooling and heat decarbonisation efforts despite moderate levels of information available from both the IEA and Japan's METI.
- **The Netherlands** was selected due to its similarities with the UK. It is heavily reliant on gas with little district heating, possesses liberalised gas and electricity markets and has a similar climate to the UK. It has been particularly successful in the use of energy efficiency programs and a good deal of data was available on both the range of policies in use today and potential scenarios in the future.
- **France** was selected due to its position as a country with no natural strong endowment in energy, but a substantial share of electricity in use for heating, alongside large shares of natural gas. France is also interesting in its use of subsidies to stimulate heat pump deployment, with one of the largest and fastest growing heat pump markets in Europe in recent years.

5.1 Germany

Introduction

Germany is in a temperate region similar to the UK, with a seasonal peak for energy for heating in winter. There are approximately 40.5 million dwellings in Germany and 44% of total final energy consumption in Germany is for heat. The housing stock in Germany has a lower average heating consumption than in the UK, ranging from 250 kWh/m^2/year for single family homes[12] built in 1918 to 53 kWh/m^2/year for single family homes built in 2010[13].

Germany has a relatively low resource endowment, and a mixed portfolio of heating provision, with 54% of households connected to the gas grid. Germany imports most of its gas supplies from Russia, Norway and other countries. District heating provides around 14% of primary heating energy and is growing, albeit slowly overall. In 2016, 13% of heat consumption was sourced from renewables. Germany does not have a large natural endowment in hydro, and has not traditionally relied on electric heating to a large degree. Germany has committed to the complete phase-out of nuclear power by 2022.

Germany has begun to undertake a heating transition that is based on a combination of targets, subsidies and complementary policies. These are beginning to have an effect in the new build sector, where heat pumps are installed in almost a quarter of households. Germany has been successful in transitioning away from oil, towards heat pumps, particularly in new builds, and district heating. However there has been little movement away from established natural gas heating in many existing buildings. Energy efficiency policies are also important. Heat consumption in residential buildings decreased by 20% from 2000 to 2012

Trends in the last 10-15 years

Germany is moving to phase out heating oil and expand the role of district heating and heat pumps as well as improving efficiency. Overall there has been a move from oil to gas in all homes and a pronounced growth in district heating and heat pumps in new builds.

In 2005, the share of oil heating installed in new homes was 14%, but this has declined to negligible levels now. In the existing housing stock, there has been a shift from oil to natural gas heating. In 1995, natural gas supplied 37% of existing homes, compared to 49% in 2015. The share of district heating in existing properties increased from 12% in 1995 to 14% in 2015. Heat pumps in existing homes were at 1.7% in 2015 compared to 0.2% in 2005. The proportion of new homes supplied by district heating grew from 7 to 22% between 2000

[12] Single-family dwellings are defined as 'housing units that are separated by a ground-to-roof wall, are not stacked vertically, have separate heating systems, and have separate utility meters.' Multi-family dwellings include 'all buildings containing at least two housing units which are adjacent vertically or horizontally. If built side-by-side, they (1) do not have a wall that extends from ground to roof, or (2) share a heating system, or (3) have interstructural public utilities such as water supply/sewage disposal.' (Moody's Analytics, 2017)

[13](Buildings Performance Institute Europe 2011)

and 2016. In 2000 the share of heat pumps was less than 1% of new homes, compared to 23% of new homes in 2016[14].

Policy and drivers

The Energy Efficiency Ordinance (EnEV) was launched in 2001 to implement the European Energy Performance of Buildings Directive. The EnEV regulates the maximum level of primary energy consumption of all new and existing buildings, including the building envelope and all equipment used within buildings, which use energy for heating and cooling. Energy efficiency interventions such as very high quality insulation or heat pumps can be installed to ensure that maximum values for primary energy demand are not exceeded. From 2016 onwards, enhanced energy efficiency standards apply which require new residential buildings to consume 25% less primary energy than pre-existing standards.

The **Market Incentive Programme (MAP) for renewable heat** launched in 2008 offers grants for small-scale renewable heat systems including heat pumps, and low-interest loans for industry and district heating. Investment grants are available for heat pumps with a minimum CfP and small solar thermal installations. The MAP provides a core subsidy and various additional subsidies, according to the type of heat pump and the project (See Annex 3 for details).

Heat pumps need to be certified with the **EHPA Quality Label**, which has minimum coefficient of performance (COP) requirements, in order to access the subsidy. Extra support is available for innovative renewable heating technologies or combinations of different technologies (for example, combining heat pumps with solar heating and water storage tanks). The KfW development bank provides soft loans for larger scale systems. KfW also supports the building or purchase of energy-efficient homes with a grant or loan if their energy consumption falls within the EnEV requirements (see above).

The **Federal Renewable Energies Heat Law (EEWarmeG)** was introduced in 2009 and aims to increase the share of renewable heating and cooling in total final energy demand to 14% by 2020. This requirement can also be met by connecting to district heating networks or installing extra energy efficiency measures.

The **Energiewende** in the buildings sector has ambitious targets for energy efficiency, refurbishment, and loans for renewable heat technologies. The Energiewende is an energy transition concept introduced by the German government in 2010, which sets out targets to reduce greenhouse gas emissions by 2020 and a pathway for decarbonisation through to 2050. The 2020 targets include: increased energy efficiency in all sectors; increased share of renewables in final energy consumption; and reducing CO_2 emissions by 40% in 2020 compared to 1990[15].

The Energiewende developed a modernisation programme for buildings which set minimum standards for energy performance in new and existing buildings, an obligation for new buildings to use renewable heat and,

[14] (GIW 2017)

[15] (Kemfert, Claudia, Opitz et al. 2015)

in 2012, changes to the tenancy law to tackle the split incentives barrier to refurbishment by dividing advantages and costs between landlords and tenants.

Investment subsidies for heat networks are available according to the length and diameter of pipes, which has stimulated interest in planning, and beginning work on district heating. Under the German CHP Act in 2013, single payments totalling €110 million were used to fund 1,017 district heating systems with a total length of 423 km.

Information provision and awareness raising campaigns have been implemented as a response to technical problems and lack of installation experience with heat pumps in the 1980s. More recently, utilities and energy agencies have led information campaigns to raise consumer awareness about heat pumps. For example, in the German region of North Rhine-Westphalia the marketing activities of the NRW Energy Agency and the RWE utility have been linked to sustainable heat pump market growth.

Applicability to the UK

There are several lessons for the UK from Germany's heat transition. Germany has a significant dependence on natural gas heating and high levels of household gas connections while selling over half a million heat pumps from 2005 to 2015. Since Germany possesses a substantial proportion of households connected to the gas grid (54%) it can provide an instructive comparison to the UK where 83% of households are connected to the gas grid. The case of Germany demonstrates persisting challenges with increasing the share of renewable heat in the existing building stock, where there has been a significant shift from oil to gas heating.

An important challenge for achieving a sustainable heat pump market in the UK is perceived inadequate technical performance and consumer perceptions and confidence arising from this, which together with low public awareness of heat pumps in general, may be significant constraints on rates of uptake. In Germany, consumer confidence problems experienced in the 1980s were addressed through a combination of technical standards, quality assurance and information campaigns.

Lessons from heat pump transition in Germany show demonstrable potential to increase the share of heat pumps in new builds supported by a combination of building regulations and upfront grants. In contrast, heat pumps are still at an early stage of market penetration in the retrofit sector where the share of natural gas heating has increased. As detailed above, the MAP offers greater support for heat pump installations in retrofits compared to new builds. In recent years however, the share of heat pump sales in retrofits has been decreasing despite an increase in the MAP incentive for retrofitted heat pumps in 2015.

District heating deployment in Germany can also be instructive in designing policy to expand district heating in the UK. A significant proportion of heating in Germany is supplied by natural gas (43% in 2013) and in larger cities natural gas is the main competitor to district heating: a 2009 incentive scheme (Programme for Rational Energy Use, Renewable Energy Sources and Energy Saving) in the German state of North Rhine-Westphalia aimed to stimulate the replacement of gas grids with district heating grids. Elsewhere, Frankfurt's climate protection policy has included the creation of an Energy Agency which searches for potential customers and suitable locations for CHP and district heating, and has frequently led to the construction of new CHP plants or connections to existing district heating networks[16].

16 (UNEP 2015)

5.2 Sweden

Introduction

Sweden is temperate in the south and subarctic in the north. Sweden has a significant endowment of biomass resources, and biomass is a dominant source for heating. Sweden also has a large natural endowment in cheap electricity from abundant hydro and nuclear power, which has historically been used for direct electric heating. Sweden produces no natural gas and has a negligible number of households connected to gas. Key technologies for supplying heating in buildings currently include district heating and heat pumps. Prior to the shift to district heating, biomass and heat pumps, Sweden relied on oil and direct electric heating to a large degree. There were approximately 4.8 million dwellings in Sweden in 2015. The housing stock in Sweden has a generally lower average heating consumption than in the UK, ranging from 196 kWh/m^2/year for single family homes built between 1922 and 1940 to 124 kWh/m^2/year for single family homes built from 2001 to 2005[17].

Sweden has the highest share of renewable heat production in the EU – renewables accounted for 69% of heat demand in 2015, compared to 47% in 2004. District heating supplies the majority of heating to buildings in the residential and service sectors (approximately 55% of heat supplied in 2014). In the last two decades, the use of individual heat pumps has expanded significantly and has emerged as the main competitor to district heating: heat pumps now supply almost a quarter of heating to residential and service sector buildings.

Decarbonisation trends in the last 10-15 years

Following the oil crises in the 1970s, Swedish energy policy in the domestic heat sector focused on replacing oil heating. Oil heating in the residential and service sector supplied over three quarters of heat to buildings in 1970, and its share has continued to decrease over the last 10-15 years, to very low levels today. In single family homes, oil heating declined from around 9TWh of total energy consumed in this household type in 2002 to 1TWh in 2015. The share of electric heating supplying residential and service sector buildings has also decreased markedly over the last two decades, from approximately 30% in 1990 to 12% by 2014.

The share of heat pumps supplying one or two family dwellings is 52% - equivalent to 1 million heat pumps. Heat pumps have mainly replaced oil boilers, direct electric heating and electric boilers[18].

In the 1970s district heating was predominantly supplied by fossil fuels and oil in particular, but has since experienced a significant diversification and decarbonisation of fuel sources. By 2015, 46% of district heating was supplied by biomass, 24% from waste incineration, with fossil fuels contributing just 7%. The use of biomass for district heating has increased by 8% per annum between 1990 and 2014.

Between 2002 and 2015, total energy consumption of heating and hot water in the residential and service sectors decreased by an average of 1% per year.

[17] (Buildings Performance Institute Europe 2011)

[18] (EHPA, 2016)

Policy and drivers

Sweden has used a **mix of policies to drive a transition from electric resistive and oil-fired heating** to heat pumps and district heating. Historically, this included a range of subsidies and tax incentives to encourage consumers to replace oil and electric systems (described below). Quality standards also helped to ensure that heat pump systems achieve high levels of performance. District heating schemes were also encouraged through strong planning rules.

Sweden has by far the highest carbon tax in Europe. The carbon tax was introduced in Sweden in 1991 at a standard rate of $44 per metric ton of CO_2. The carbon tax has more than tripled since this time, to $105/t$CO_2$ in 2003 and $168/t$CO_2$ in 2014. Data from Eurostat (2016) shows that Sweden has had the highest average annual natural gas price for any country in the EU over the last decade (averaging 28 euros per gigajoule for 'medium-sized households' from 2004 to 2015). In addition to the carbon tax, there is an energy tax on natural gas for heating (introduced in 1985) and tax on heating oil (since the 1950s). Taxes on oil combined with the promotion of biomass have led to oil boilers being substituted by wood fuel alternatives or heat pumps.

Heat production from CHP plants which are part of the EU ETS scheme has been exempt from the carbon tax since 2013. With respect to CHP and district heating, the carbon tax has resulted in a considerable decrease in the use of fossil fuels and increased use of biomass, which was also supported by two investment subsidy programmes for biomass CHP from 1991 to 2002. Tradable renewable energy certificates were introduced in 2003. These further supported the use of biomass in district heating and were often the decisive factor for investment in CHP.

Bans on landfill of combustible and biodegradable waste in 2002 and 2005 drove an increase in heat from waste incineration. Investment subsidies supported the use of industrial waste heat and the expansion of district heating into areas of one or two family homes.

Subsidies for households to switch from oil and direct electric heating to alternative heating systems were available from 2006 to 2010. These took the form of an up-front grant where homeowners could receive up to 30% of material and labour costs up to a maximum level per household for replacing oil and direct electric heating with a heat pump, district heating or biomass. The subsidy to replace direct electric heating in any type of home provided a higher maximum grant than the oil heating replacement subsidy, due to the additional costs of installing central heating, and led to 80% of the subsidies being awarded for a shift from electric heating to district heating. With respect to the subsidy for replacing oil heating in one or two family homes, heat pumps were the most popular replacement, accounting for 43% of the awarded subsidies and district heating for 20%.

The heat pump market in Sweden has also been supported through **technical standards**, for example the P-label quality mark for heat pumps introduced in 2005, and the Swan label (an eco-label for heat pumps) introduced in 2006, as well as installer certification training. In addition, there have been information campaigns about energy efficiency and alternative, lower carbon heating technologies such as heat pumps.

Swedish **building codes** have contributed to the increasing dominance of air-to-air heat pumps over GSHPs since 2005[19].

Applicability to the UK

Sweden has high levels of district heating deployment, but much of this took place before energy market liberalisation so the policies involved may be less transferable to the UK. Heat networks were initially managed by municipalities, and then transferred into municipal ownership. Sweden was able to reduce the risk of demand uncertainty through heat planning, including granting monopoly powers to district heating companies, leading to the ability to access capital at very low rates. Municipalities' responsibilities and powers regarding heat planning have decreased following energy market liberalisation, and heat planning has become less widely used.

District heating and heat pumps were deployed in the absence of extensive natural gas heating and the abundance of a relatively cheap supply of low carbon electricity supply from hydro-electricity and nuclear power, as well as the lack of domestic gas reserves. The availability of clean electricity in Sweden has allowed heat pumps to be viewed favourably by policy makers.

In the UK, heat supply from natural gas is relatively cheap and convenient. Nevertheless, the experience of Sweden demonstrates that it is possible to replace incumbent forms of heating, in this case oil and electric heating over a period of several decades, even though consumers may prefer established heating technology in general. This transition has been enabled by the high carbon tax in Sweden and investment subsidies for the replacement of oil and electric heating. Investment subsidies for biomass CHP, tradable renewable energy certificates and bans on landfill waste have also supported a decarbonisation and diversification of energy sources for district heating systems since the 1970s, when oil was the main fuel used for district heating supply.

The drivers for the development of district heating in pre-liberalisation Sweden were not related to decarbonisation specifically: the transition to district heating was driven by objectives to increase energy efficiency, improve air quality and subsequently as a response to the 1970s oil crises. An additional feature which has facilitated the deployment of district heating and heat pumps in Sweden is public acceptance of high energy taxes.

[19] (Zimny, Michalak, and Szczotka 2015)

5.3 Japan

Introduction

Japan is classified as a low endowment archetype in Section 3 of this report and utilises a mix of fuels for heating. Japan's energy policy, including for heating and cooling, is characterised by an emphasis on energy security, economic efficiency and environment plus safety (3E+S). Following the 2011 Great Earthquake turned nuclear disaster, each of these tenants has been pursued with increased resolve specifically in regards to safety. Japan oversees the basic direction of its national energy generation and consumption via a Strategic Energy Plan overseen by the Ministry of Economy, Trade and Industry (METI). The 4th Strategic Energy Plan, which began in 2014, is currently underway. Unlike the UK, Japanese energy demand peaks in the summer months from intensive air conditioner usage as a result of Japan's warmer climate.

Trends over the last 10-15 years

The 2011 Great Earthquake turned nuclear disaster serves as the inflection point of the last 10-15 years of Japanese energy generation. The Great Earthquake prompted a complete rethinking of Japanese energy policy and resulted in a shift from nuclear power toward increased reliance on fossil fuels such as coal, oil and natural gas.

Japan is the world's largest liquefied natural gas (LNG) importer, of which LNG imports are used for power generation and space heating. Japan has an extensive natural gas grid with 28 million commercial and residential gas users. 54% of dwellings are connected to the gas grid. The city gas market consumed 37bcm of natural gas from April 2014 to March 2015.[20]

To mitigate the high energy costs resulting from the idling of Japan's nuclear reactors, Japan has taken steps to liberalise its electricity and natural gas markets. The disaggregation of distribution, generation and retail has increased public awareness of energy consumption and energy prices. However, Japan's electricity and gas market liberalisations remain incomplete due to grid interconnectivity issues - a legacy of entrenched government erected monopolies in these markets prior to liberalisation. Despite these reforms, Japanese electricity and gas prices remain above average OECD levels. These high prices act as market based financial incentives for electricity and heat conservation.

Advancements in fuel cell technologies have allowed Japan to lead the way in fuel cell commercialisation. Starting in 2009, 200,000 micro-CHP fuel cells have been sold under the ENE-FARM brand by a syndicate of firms. The ENE-FARMs are capable of providing Japanese households with hot-water, electricity and sometimes space heating and consume approximately 37% less primary energy while emitting approximately 49% less CO_2 than conventional thermal power from electricity and hot water from

[20] (International Energy Agency 2016)

city gas generation.[21] The ENE-FARM can be easily attached to the city gas grid and converts the gas to hydrogen before use. As long as the stream of city gas is not interrupted, ENE-FARMs are resilient to national electricity grid failures. Japan owns 60% of hydrogen fuel cell patents worldwide.

Japan also has a comparatively large number of district heating systems (DHC) as a result of DHC's suitability for Japan's densely populated cities. 77 Japanese companies operate 139 DCH systems throughout Japan. As of 2014, Japan had 10,046MW of mostly gas cogeneration capacity, of which 2,073 was for residential and commercial use.[22]

Policy drivers

Japan's leadership in energy efficiency is the result of the interaction between policy makers and market forces since 1979. Japan's approach to reducing energy usage and cutting carbon intensity has primarily been through promoting efficiency programs. These energy efficiency programs are then supported by deep government subsidies, loans, tax incentives and research development and demonstration (RD&D) finance support.

The 1979 Act on the Rational Use of Energy is the cornerstone of Japanese energy efficiency policy. 'The Act' is the legislative vehicle by which energy efficiency standards, energy efficiency reporting and energy efficiency programmes are introduced. The Act has been amended multiple times and was most recently amended in 2016 so as to count wasted heat when measuring energy efficiency for business operators.

The Top Runner Programme, a component of the Act on the Rational Use of Energy, covers energy efficiency standards for heating and cooling appliances. The programme covers air conditioners, space heaters, gas water heaters, oil water heaters and electric water heaters. Since the programme's inception, air conditioner energy consumption has been reduced by 33%.

Subsidies, loans and tax incentives have been extended to local governments, households and the private sector to help meet renewable heat objectives. SMEs are eligible for JPY 720 million [approximately £5million] in renewable heating loan schemes, while tax incentives of 10% of renovation costs (up to JPY 2.5 million [approximately £17,250]) are available for homeowners.[23] Since 2011, policy initiatives have sought to increase the number of building energy management systems (BEMSs) and home energy management systems (HEMS) to further conserve electricity and gas. BEMSs are eligible for either a

[21] (Interview evidence), (Tokyo Gas Co. Ltd. and Panasonic Corporation 2013). It has been estimated that a comparable micro-CHP fuel cell system with an output of 1kW in the UK would result in a daily savings of 4.5 kg of CO_2 in the winter and 3 kg of CO_2 in the summer per household (Ellamla et al. 2015).

[22] (International Energy Agency 2016)

[23] If also installing solar panels during the renovation, the tax incentive maximum is raised to JPY 3.5 million [approximately £24,000] (International Energy Agency 2016).

tax exemption equal to 7% of the equipment cost or a depreciation of 30% of the acquisition cost. Subsidy support is also available.[24]

Part of the 4th Strategic Energy Plan includes the creation of a road map to Japan's envisioned 'Hydrogen Society'. The Hydrogen Society initiative involves 3 phases of development on the path to the eventual achievement of renewable hydrogen production. The first phase (2014-2025), currently underway, encompasses the planned dramatic expansion of hydrogen including the introduction of stationary (ENE-Farm) and vehicle fuel cells into society.[25] This initiative has benefited from public R&D finance and close collaboration with large commercial firms. METI, assisted by Japan's New Energy and Industrial Technology Development Organization (NEDO), has played a critical role in devising the road map and facilitating the successful collaboration between key market participants, R&D institutes and policy makers. Japan's technological prowess has proven advantageous in attempting to realise the ambitious hydrogen society initiative.

Applicability to the UK

Japan's quest to increase energy efficiency while reducing carbon intensity and energy dependence offers multiple lessons for the decarbonisation of heat systems in the UK:

- **Developing a network of capable partners** including policy makers, technological leaders and commercial firms able to plan and implement decarbonised heating is crucial for policy initiatives to succeed. This network can be enhanced by including international partners.
- **Adopting technologies that can readily plug into existing grid infrastructure**, such as the ENE-FARM, can increase the rate of decarbonisation while requiring relatively less public and private resources.
- **Appropriate institutional arrangements are key for success.** METI's ability to rapidly reshape the energy system in Japan and plan and execute projects decades in advance demonstrates the potency of a policy making body with near complete control over national energy systems and regulation.
- **Increasing energy efficiency requirements**, although unable to completely decarbonise a heating system, can make a significant difference in the intensity of carbon leakage in the national heating system
- **Consumer perceptions of energy efficient products matter**. Reducing initially high prices with subsidies while promoting diffuse product characteristics is important for achieving the widespread adoption of decarbonised heating products in homes and businesses. A focus on the resilient characteristics of decarbonised heating systems can lead to increased adoption by heat consumers.

However, the hydrogen and CHP technologies being developed in the residential sector are much smaller than would typically be required of a UK household. Also, the micro CHP technologies are primarily being used with natural gas, implying that they still have substantial carbon emissions. Therefore, these technologies may not be directly applicable to the UK in the context of decarbonisation.

[24] (Okuya 2014)

[25] Details on phase 2 and 3 of Japan's hydrogen society initiative can be found in Annex section 3

5.4 The Netherlands

Introduction

The Netherlands is a single endowment country and reliant on gas with a liberalized heat market. It is the second largest exporter and producer of gas in Europe after Norway. Almost 95% of buildings are heated through gas and 94% are connected to the gas grid. Only 5.5% of heat demand was met by renewables in 2015.[26] Evidently the heat transition policies have had limited impact in shifting households away from gas heating so far. The Netherlands, like the UK, has one of the lowest shares of renewable heating in the EU. The Netherlands has significantly fewer dwellings than the UK, with approximately 7 million in 2015. It has a temperature climate similar to the UKs with a winter peak in heating and cooling demand. Gas has been so important to heating that previously output from the Groningen gas fields were fluctuated to peak in winter and match heating demand.[27]

Decarbonisation trends and roadmap

The Netherlands is phasing out gas, with an aim to reduce emissions from low temperature heat processes by 80-95% in 2050.[28] This target was articulated under the Energy Agenda. To meet these ambitions 6-7 million houses need to become gas free in 2030-2050.

District heating plays a small, but growing role, in heat in the Netherlands. District heating currently only meets approximately 4.4% of heat demand, covering 363,000 houses in 2030.[29] This is set to grow significantly in the future, particularly using waste heat from power plants. By 2030 the number of houses serviced by a heat network will likely increase to 549,000.

Energy efficiency has been a key pillar in efforts to decarbonize heat so far. Energy demand dropped by 10% in the seven years between 2008 and 2015 largely due to subdued economic growth and decreasing heat demand. Falling heat demand has been driven by progressively stronger energy efficiency standards. Between 2000 and 2012 the energy savings rate was a significant 2.5%. Energy efficiency standards are continuing to become increasingly stringent and will drive energy savings though to 2020.[30]

Reducing emissions from heat will likely require a mix of different technologies, including green gas, geothermal, district heating and electrification. District heating and electric solutions are common across

[26] CE Delft, "Towards a Climate-Neutral Built Environment in 2050" (Delft, the Netherlands, 2016).

[27] Anouk Honoré, "The Dutch Gas Market: Trials, Tribulations and Trends," 2017, https://www.oxfordenergy.org/publications/dutch-gas-market-trials-tribulations-trends/.

[28] ECN, "Discussion Piece: The Transition Path for Low Temperature Heat" (Petten, the Netherlands, 2017).

[29] Netherlands Oil and Gas Portal, "Oil and Gas," 2016, http://www.nlog.nl/en/oilGas/oilGas.html.

[30] ECN, "National Energy Outlook 2016" (Petten, the Netherlands, 2016).

different modelling exercises, but the balance between the two varies. Gasunie estimated that the split in 2050 would be 50% district heating, 25% electric heat pumps and 25% hybrid heat pumps supplied with green gas. CE Delft put forward several 2050 scenarios, including one in which all the heat supply in the Netherlands was provided through electrification and green gas heat pumps. Another more balanced scenario roughly converged with the Gasunie estimate and saw green gas meeting 17% of heating demands, electricity 31% and district heating 52%.

The recent Dutch Coalition Accord[31] suggests that the transition will prioritise electrification and district heating. The Accord outlines a number of measures on heating including energy efficiency, insulation, heat pumps and district heating, and neither green gas nor geothermal are mentioned.[32] Overall, there are no precise plans indicating how the long-term heating system will look, but initial signals from the new government suggest that electrification will be central.

Policy and drivers

The move away from natural gas has been driven by climate policy, gas depletion and the loss of the gas industries social licence. The 2016 Energy Agenda created a target to reduce emissions by 80-95% by 2050.[33] More recently the Dutch coalition accord agreed to reduce emissions by 49% by and phase-out all coal-fired power by 2030.[34] Low temperature heat constitutes 53% of final energy demand and will need to be addressed to fulfil these goals.[35] In 2012 tremors in Groningen, caused partly by gas extraction, triggered both a social and political response.[36] Public support for the gas industry waned and the government limited production. Maximum extraction was capped at 24 billion cubic meters annually (bcma) in 2016, 30bcma less than 2013.

Numerous local level programs and plans would suggest that there is public support for the heat transition. The Hague and Delft have both pledged to create a carbon neutral heat supply by 2050, while Rotterdam is significantly advanced in the use of district heating. The “Green Deal Natural Gas Free Districts” initiative has brought together over 30 municipalities looking to shift away from gas heating. However, there is little evidence on the state of public perception for individual policies or the transition as a whole.

[31] In the 2017 election a broad coalition of the Liberals, the Christian Democrats, the D66 and the Christian Union was needed to form government. This broad coalition put forward a pact known as the ‘Dutch Coalition Accord’ which outlined common, agreed policy positions.

[32] Karel Beckman, “Dutch Coalition Accord: The Netherlands Goes for Climate Leadership in Europe,” *Energy Post*, October 2017, http://energypost.eu/dutch-coalition-accord-the-netherlands-goes-for-climate-leadership-in-europe/.

[33] Ministry of Economic Affairs, “Energy Agenda” (The Hague, the Netherlands, 2016).

[34] Karel Beckman, “Dutch Coalition Accord: The Netherlands Goes for Climate Leadership in Europe,” *Energy Post*, October 2017, http://energypost.eu/dutch-coalition-accord-the-netherlands-goes-for-climate-leadership-in-europe/.

[35] Lex Bosselaar, “Netherlands Heating Policy” (The Hague, the Netherlands, 2017).

[36] Anouk Honore, “The Dutch Gas Market: Trials, Tribulations, and Trends” (Oxford, UK., 2017).

The most successful and central policy to date has been the Stimulation of Sustainable Energy Production Scheme (SDE+). It is an operating grant that provides financial compensation for renewable electricity, renewable gas and renewable heat (or a combination of renewable heat and electricity).[37] In 2016 the overall budget was almost €12 billion, with €3.4 billion going towards renewable heat and biogas projects.

The SDE+ has been complemented by a package of policies which aim to incentive renewable heating, and decarbonise new building stock:

- **The ISDE+** is a fund which subsidises renewable heating installations in private homes and businesses. The fund is currently €90 million and covers a range of different renewable heating technologies including heat pumps and solar thermal. The subsidy for a heat pump boiler is €500 (regardless of capacity), while a hybrid heat pump is €1,000 for thermal power up to 5kW, plus €100 for every kW over this level up to €1,500;
- **The Geothermal Guarantee Fund** offsets the risks investors would normally carry in financing geothermal exploration and drilling activities;
- **Heat tariffs** are established on the basis that district heating must be supplied at a rate lower than that of an individual gas boiler;
- **The 'Green Funds Scheme'** is a scheme whereby renewable heat projects with capital gains taxes (normally 1.3%) are exempt for the first €50,000 of returns, and receive a 1.2% discount on their income tax. The Green Funds Schemes has been widely used and successful. Since 2008 approximately €7 billion has been invested by almost a quarter of a million investors;
- **Energy standards** for new constructions have been continuously strengthened culminating in new dwellings being close to carbon neutral by 2020, and government buildings by 2018;
- A **national rollout of smart gas and electricity meters** resulting in 15 million installations by 2020. The initial roll-out of smart meters led to effected households reducing their gas use by 0.9% and electricity use by 0.6%;[38]
- There are plans to **transplant part of the current tax on electricity onto gas**.

The Dutch heat transition will require innovation, and the government is focusing on research and development into hydrogen technology. Hybrid heat pumps combined with green gas and smart power control systems are being developed by state-owned energy company Gasunie. The multi-billion Euro 'Top consortia for Knowledge and Innovation' (TKI) fund spent €28 million on heat projects in 2013, with a strong focus on hydrogen.[39] This includes projects on hydrogen storage (HyStoRe), converting renewable energy into hydrogen (Power2Gas), and the extraction of hydrogen from gaseous streams (PurifHy). This research is accompanied by two world-first demonstration projects: A 1MW gas-to-power plant in

[37] Netherlands Enterprise Agency, "Stimulation of Sustainable Energy Production (SDE+)," 2017, https://english.rvo.nl/subsidies-programmes/sde.

[38] Henk Van Elburg, "Dutch Energy Savings Monitor for the Smart Meter" (Amsterdam, the Netherlands, 2014).

[39] Ministry of Infrastructure and the Environment, "Information on Fuel Cells and Hydrogen Developments in the Netherlands" (Amsterdam, the Netherlands, 2016).

Groningen and a 440MW gas-to-power hydrogen and carbon capture and storage plant in Eemshaven.[40] Both have the involvement of Gasunie and the latter has received support of by €200 million annually from the SDE+ scheme.

Despite numerous successes, efforts to reduce emissions from heat face challenges in implementation. Implementation requires further funding and policies, as the Netherlands is currently not on-track to meet either the 2020 renewable energy or energy savings targets.[41]

Applicability to the UK

Lessons from the Netherlands are potentially applicable to the UK due to several similarities. Both are single endowment countries reliant on gas with low usage of district heating.

One lesson is the significance of both district heating, and a broader technology mix, in undertaking the heat transition. The UK and the Netherlands face similar challenges in phasing-out gas and drastically increasing the uptake of district heating. The projected mix of district heating, green gas and heat pumps tailored to different areas and densities will likely be a suitable approach for the UK.

Another lesson is the importance of addressing both the energy efficiency and heating sources of new stock. The Netherlands has seen significant energy efficiency improvements and the 2020 standard for nearly zero energy buildings will make transitioning the new stock significantly easier. While the UK has previously announced a zero carbon homes plan, this never came to fruition and energy efficiency levels remain below the EU average. Quickly tightening energy efficiency building regulations towards a zero energy levels could be a useful policy measure that would complement existing policies such as the minimum energy efficiency standards.

The success of the SDE+ scheme could inform any future revisions to the Domestic Renewable Heat Incentive (RHI) program in the UK. First, the SDE+ has limited the compensation given to biomass co-gasification and cogeneration to 25 PJ annually and required rigorous third-party verification. The RHI has struggled with public criticism over payments for biomass generations, which a cap and verification approach could help address. Second, expanding the scope of the RHI to cover hybrid heat pumps and wind (as the SDE+ does) may be beneficial, although it would entail increased funding.

Some instruments, while useful, may not be relevant for the UK. Price regulations which place district heating below the market price of gas are a key Dutch policy to encourage the adoption of district heating, but will likely be inapplicable to the UK. The UK free market conditions and consumer protection regulations would be incompatible with such a pricing policy.

[40] Gerard Reijn, "The First Climate-Neutral Power Plant in the World Is Located in Eemshaven," *De Volkskrant*, July 2017, https://www.volkskrant.nl/binnenland/eerste-klimaatneutrale-energiecentrale-ter-wereld-komt-in-eemshaven~a4505018/; Gasunie, "Gasunie Converts Sustainable Energy into Hydrogen with First 1 MW Power-to-Gas Installation in the Netherlands," *Gasunie*, June 2017, https://www.gasunie.nl/en/news/gasunie-zet-duurzame-energie-om-in-waterstof-met-eerste-1-mw-powe.

[41] ECN, "National Energy Outlook 2016."

5.5 France

Introduction

Although a large majority of France's electricity comes from nuclear generation, it has a more mixed use of energy for heat. For commercial and residential buildings, approximately 15% of heat is derived from electricity, with approximately 40% from gas. Within the residential sector, 30% of households use direct electric heating, 40% gas boilers, 18% oil and coal and the reminder a mix of biomass (4%), district heating (4%), and heat pumps (3%). France has approximately 29.1 million households in France, very close to the UK's number of households. The country also has a similar temperate climate to the UK, though with warmer temperatures in the south east. France has historically needed to increase energy imports in winter to meet demand peaks.

Decarbonisation trends and roadmap

France has plans to transition away from direct electric and high-carbon fossil fuels in heating towards renewable alternatives. France aims to double the share of renewables in heat to 38% by 2030, and to increase the share of renewables and waste energy supplying district heating five-fold by 2030[42]. At the same time, France aims to reduce its share of electricity generated from nuclear power to 50% by 2025 and to increase the share of renewables in energy consumption to 32% in 2030, equivalent to a 70% increase in production from 2016[43].

France imports and uses significant volumes of fossil fuels, primarily for use in transportation but also for heating. Consumption of energy from thermal renewables and waste doubled between 1973 and 2015, though natural gas consumption tripled and electricity consumption increased 15-fold over the same time period.

France has nearly eliminated the use of coal for heating buildings, and oil consumption is falling[44]. Over a longer period from 1973 to 2015, the share of oil and coal in primary energy consumption have been falling, down by almost half (from 69% to 35%)[45].

However, the demand for heat has increased overall, and natural gas demand and heat pump installations have increased. Sales of heat pumps have increased significantly over the past decade: between the mid-1980s and the mid-2000s, heat pump sales were below 20,000 units per annum, but have increased significantly since 2005 to nearly 160,000 units per annum by 2015 (with an earlier similar peak, then crash, in 2008)[46]. France is now one of the largest markets for heat pumps in the EU.

[42] (Assemblé Nationale 2015)
[43] (Assemblé Nationale 2015)
[44] (Service de l'observation et des statistiques 2017a)
[45] (Service de l'observation et des statistiques 2017a)
[46] (Delta Energy & Environment 2017), (Collier, 2018)

France is lagging in the deployment of district heating. District heating current supplies only around 6% of households, less than half the EU average of 13%[47]. Currently, fossil fuels supply half of district heating, but with sizeable shares of heat from waste (around 30%) and biomass (15%). Geothermal sources currently only supply around 4% of district heating.

Policy and drivers

France is undertaking a heating transition based on a combination of targets, regulations and fiscal policies. Its targets for a doubling of renewable heat by 2030 are ambitious compared with other countries, and it has also set interim targets for 2018 and 2023[48]. However, it has already had to revise its interim targets set in 2012 downwards, reflecting challenges in deploying renewables at scale. France's recent Grand Investment Plan 2018-2022 includes plans to invest €4.9 billion in renewable energy development, including increasing production capacity of renewable heat networks by more than 50% by 2023[49].

Regulatory and fiscal incentives have driven the shift from direct electric heating to heat pumps and biomass in both residential and commercial sectors. These policies have aimed to limit the installation of direct electric heating in new builds, while simultaneously subsidising the replacement and retrofitting of direct electric heating with renewable alternatives. France also encourages the shift toward renewable heating through its carbon tax, which may be especially helpful in maintaining renewables' competitiveness during periods of low gas prices.

Key elements of France's policy package are:

— The **Crédit d'Impôt pour la Transition Énergétique** (CITE, Tax Credit for Energy Transition), which supports residential purchases of energy efficient and renewable energy equipment through a tax credit of up to 30% of capital costs, with a limit of €8,000/€16,000 for an individual/a couple, with an additional €400 per household dependent. Additionally, renovation projects that are eligible for the CITE credit can also benefit from a reduced Value Added Tax (VAT) rate of 5.5%, compared to the standard rate of 10% for residential renovation projects[50].

— The 0% interest **Eco-loan** up to €30,000 for energy-efficient residential renovations, including the installation, regulation or replacement of heating or hot water systems, including those using renewable energy.

— The commercial sector-focused **Fonds Chaleur** (Heat Fund), which supports the deployment of renewable heat and district heating, through subsidies for both project development (40%-80% of costs) and project implementation (25%-80% of costs), with an annual budget of €220 million and aims to support the production of 5.5 Mtoe of renewable heat by 2020.

— Preferential-rate loans for domestic energy saving projects through the **Livret de développement durable et solidaire** (LDDS), is a fixed-rate savings account established, with banks required to allocate a share of the funds raised through these accounts to finance energy-saving projects in older buildings.

[47] (Collier, 2018)
[48] (La ministre de l'environnement 2016)
[49] (Pisani Ferry 2017)
[50] (International Energy Agency 2016b)

- The **2012 Régulation thermique,** requires all new buildings (constructed after 1 January 2013) to achieve primary energy consumption below 50 kW/m^2 per year, de facto eliminating the possibility of direct electric heating in new buildings.
- A **carbon tax** (taxe intérieure de consommation sur les produits énergétiques) which applies to CO_2 emissions from the industry, buildings and transport sectors (with exemptions for operators covered by the EU emissions trading system), due to increase from €31/tCO_2e at present to €100/tCO_2e by 2030. The carbon tax may play an important role in maintaining the relative competitiveness of renewables compared to gas options for new builds and retrofits.

The combination of regulations and fiscal support (both subsidised capital costs and subsidised loans) has contributed to a substantial increase in heat pump installations in new builds. The policy mix also suggests an innovative approach to managing the risks of households switching to natural gas when moving away from direct electric heating, coal or oil, by combining incentives to move away from less efficient electric and fossil fuels systems with an additional cost barrier to switching to natural gas.

Despite some successes, at historic rates of expansion it would miss all 2023 targets except for heat pumps. The data on new build installations suggests that this approach has had mixed success so far, and there has also been a significant decline in the price of fossil fuels since the incentives programme for renewable heat (including the CITE, Eco-loan and Fonds Chaleur) was devised, increasing the competitiveness challenge for renewable heat options[51]. However the anticipated increase in the carbon price between now and 2030 should strengthen the consumer incentive to adopt renewable heat technologies.

Applicability to the UK

Experience from France's heat transition could be transferable to the UK. France's experience shows clear potential to increase the share of heat pumps in new builds, through a combination of building regulations and fiscal incentives through the CITE and the Eco-loan programme, where the lump-sum subsidy payment after a set time period (until the next tax payments are processed) provides certainty about how and when subsidy benefits will be realised. Additionally, in September 2017 the government announced that CITE credit would be replaced by a post-completion 'premium' for renewable heat installations from 2019, which should decrease the gap between upfront investment and subsidy payment, potentially decreasing capital constraints that reduce investment incentives. France's carbon tax also shows clear potential as a mechanism for incentivising switching of existing gas users and to moderate installation of gas in new builds, with future price increases (up to three times the current price by 2030) likely to provide a stronger incentive to households.

[51] (Chabrillat 2017)

6 Conclusions

BEIS commissioned Vivid Economics to summarise the evidence base on how other countries provide heating and cooling and what the UK can learn from them. The focus of this report is heating and cooling in buildings, viewed broadly across residential and non-residential sectors with an emphasis on OECD countries. Within this context, two specific research questions are posed:

— What **challenges** are shared by the UK and with other countries in the area of heat decarbonisation and where is there less commonality?
— What **learning and innovation** opportunities exist outside of the UK, both in countries where there are clear points of comparisons as well as contrasts?

Decarbonisation challenges

A key challenge of decarbonisation is moving away from relatively low cost sources of energy that form the natural endowment of a nation. The archetype analysis in this work suggests that there is a strong relationship between endowment and fuel mix used for heating.

— **Single endowment countries have historically tended to use their endowment as the dominant heating source.** Countries with large amounts of hydro have a lot of electric heating. For example, in both Norway and New Zealand, over 70% of heating is supplied by electricity. Countries with large gas reserves have extensive gas grids and use gas as the key source for heating. Examples are the UK and the Netherlands where over 80% of heating is delivered from gas. High biomass countries like Sweden, use biomass in district heating, although district heating in these countries was initially developed to use fossil fuels.
— **Both mixed endowment countries and no endowment countries end up with a diverse heating fuel mix**. The US and Canada use a mix of gas and electricity for heating. Germany and Japan largely import oil and gas for heating.

Moving away from the natural endowment, which is uncommon across the countries investigated (although this has happened to some degree in Germany and Sweden), may entail increasing cost, or developing new infrastructure. There may also be substantial lock-in costs associated with existing infrastructure, such as the costs of decommissioning the gas grid, that are challenging to overcome

Progress in moving away from gas heating delivered via a gas network has not been achieved to a large degree despite substantial efforts – suggesting this is a particularly challenging aspect of heat decarbonisation. This is important for the UK, which has the highest penetration of on-gas-grid heating in the OECD. An important example is Germany, where despite over a decade of policy effort, almost all new heating purchases for existing buildings remain fossil fuel. Possible reasons for the lack of progress regarding gas grid transitions include the low cost of gas fuel and boilers, the high level of service provided by gas boilers, the disruption associated with retrofits and the lock-in costs associated with existing infrastructure.

Transitions have been however more successful in new builds and off-grid buildings. In new builds, substantial transitions are underway in multiple countries with regards to new build supported by regulations. In Germany, the majority of heat pumps have been installed in new builds. In Sweden, the share of oil fired boilers has fallen significantly in off-grid homes as they have moved towards biofuel based alternatives and heat pumps and have heavily taxed heating oil. In off gas grid areas, district heating, biomass and heat pumps are used to provide heating and material transitions are taking place. In Sweden, the share of oil fired boilers has fallen significantly in off-grid homes as they have moved towards biofuel based alternatives and heat pumps.

Heating transitions, policy and learnings

Focusing on the period since 1970, heating transitions have been triggered by a range of factors, including security of supply concerns, changes in resource endowments, market forces and natural disasters. In some countries policy served to assist in the development of indigenous resources, for example in facilitation of the town gas and then natural gas networks in the UK. In others, policy needed to shift as resource endowment changed, for example, Norway promoted diversification away from resistive heating towards heat pumps and district heating as its hydro resources became stretched. In Germany, policy has been shaped by a relative absence of indigenous resource, by developing a mixed profile of heating fuels and technologies.

Focusing on the period since 2000, a shift towards low carbon fuels and technologies has begun to gain traction in some jurisdictions due to climate policy. More recently, countries have embarked on a transition towards low carbon heating due to climate change targets such as a transition towards heat pumps in Germany and towards heat pumps and biomass powered district heating in Sweden. The Renewable Energy Directive has been an important driver for EU countries in general.

Policy has been a key driver in transitions – achieving material changes in the composition of heating and cooling technologies and fuels has occurred over a multi-decadal timeframe with sustained policy support. Long term and consistent policies that combined planning, regulation, standards, information and finance have been pivotal for successful heat transitions. For example, Germany's transition off the gas grid (in new builds) and away from oil has been due to a combination of targets, subsidies and complementary policies that have been in place since early 2000s. Sweden's transition from oil and electric heating towards heat pumps and district heating has been successful due to a mix of policies since the 1970s that have included subsidies, tax incentives, standards, planning rules and energy taxes.

Policy has targeted various market failures and barriers in the heat sector, for example:

- **natural monopoly**: the development of district heating has typically required centralised planning and the capacity to collaborate between energy utilities, localities and states. District heating in Sweden, for example, developed prior to liberalisation and was planned and organised by local governments.
- **information provision**: technical and informational barriers regarding new low carbon technologies have been addressed through information provision and awareness raising campaigns. In Germany, establishment of the German heat pump association (IWP), the publication of technical manuals and guidance and the information campaigns by the IWP played a role in steady growth of heat pump sales in

the 1990s. The heat pump market in Sweden has also been supported through technical standards and information campaigns.

— **innovation**: governments have supported R&D in technologies and provided support for innovative renewable technologies. German's Market Incentive Programme for renewable heat provides bonus supports for innovative renewable heating technologies or combination of different technologies. Japan's hydrogen society initiative has invested significantly in fuel cell research to improve its energy efficiency and bring down the price.
— **long-term (un)certainty:** countries with a successful transition have a credible long-term commitment to decarbonise. Sweden has an ambition to phase out fossil fuels by 2020, and is well on the way to achieve this. Germany's energy transition has stringent targets for the buildings sector.
— **building codes/standards:** building codes that require a certain percentage of heat to be supplied from renewables have encouraged the take up of low carbon technologies. Building codes have also set progressively more stringent energy efficiency standards, for example for new builds in Germany.
— **financial barriers**: technology uptake has been encouraged by financial support in the form of subsidies and grants. Grants/subsidies have been provided for individual technologies as well as district heating investments. However, where policies have been credible and coherent, such as Sweden and Norway, grants/subsidies have been phased out as the technologies became competitive. Energy or carbon taxes have been quite successful in some countries such as Sweden in a switch away from oil and gas towards use of renewable technologies.

Packages of policies have been more successful than single policies as there are synergies between policy goals. For example strong building codes or support for district heating are in part a response to cold climate, seeking to ensure that citizens have acceptable levels of comfort at affordable prices. Additionally, they have also made decarbonisation easier to achieve over time. While district heating permits the fuel source for heat to be decarbonized, such as transition from fossil fuel to biomass in Sweden, efficient building stock makes heat pumps feasible.

Supporting evidence for the benefits of a co-ordinated policy package is found in the detailed case studies:
— **Germany's heating transition is based on a combination of targets, subsidies and building codes**. These are beginning to have an effect in the new build sector, where heat pumps are installed in almost a quarter of households. Germany has been successful in transitioning away from oil, towards heat pumps, particularly in new builds, and district heating. However there has been little movement away from established natural gas heating in many existing buildings. Energy efficiency policies are also important. Heat consumption in residential buildings decreased by 20% from 2000 to 2012.
— **Sweden has also used a mix of policies to drive a transition from electric resistive and oil fired heating towards heat pumps and district heating.** Historically, this included a range of subsidies and tax incentives, which were gradually phased out. Quality standards helped to ensure that heat pump systems achieve high levels of performance and building codes have contributed to the increasing dominance of air-to-air heat pumps over GSHPs since 2005. District heating was also encouraged by strong planning rules and investment subsidies. Sweden also has the highest carbon tax in Europe, which was introduced in 1991 and has more than tripled since then. In addition to the carbon tax, there is an energy tax on natural gas for heating and tax on heating oil. Taxes on oil combined with the promotion of biomass have led to oil boilers being substituted by wood fuel alternatives or heat pumps.

— **Japan is promoting hydrogen through subsidies, tax incentives and R&D finance support as well as energy efficiency policies to meet its renewable heat objectives.** The Top Runner Programme covers energy efficiency standards for heating and cooling appliances. The hydrogen society initiative is being supported by public and private R&D finance, in close collaboration with large commercial firms. The Ministry of Economy, Trade and Industry (METI), assisted by Japan's New Energy and Industrial Technology Development Organization (NEDO), has played a critical role in devising the road map and facilitating the successful collaboration between key market participants, R&D institutes and policy makers.

— **The Netherlands is using a package of different policies centred around subsidy programs and increasingly stringent energy efficiency standards.** Progressively stronger efficiency standards for new-build housing has led to improving energy savings in the past decade. The SDE+ and ISDE subsidy programs, coupled with a number of other more targeted policies, are helping to drive a shift towards district heating, electric solutions and green gas. Hydrogen may play a role in the longer-term. The exact mix in the heating supply is currently unclear, but the most recent Dutch government appears to favour a largely electrified heating system.

— **France is pursuing its ambition to double the share of renewables in heating to 38% by 2030 through subsidies for commercial and residential heat, alongside a number of other policy instruments.** The CITE tax credit and the zero percent Eco-loan programme support residential renovations and installations, while the Fonds Chaleur supports commercial installations. The 2012 Regulation Thermique also helps limit continued deployment of direct electric heating in new builds, while a carbon tax may help limit switching from direct electric to natural gas.

In comparing the design of different subsidy schemes, the UK's RHI was the only identified tariff scheme for small scale installations. Renewable heat subsidy schemes divide broadly into those that provide subsidy close to the point of purchase and those that provide subsidy over the life of the asset (via tariff mechanism). Upfront subsidy mechanisms (such as tax offsets in France and grants in Germany) are the more frequent mode of subsidy provision. There is evidence of cost barriers for renewable heat, and as a result, upfront schemes may be preferred because they more directly address cost barriers[52]. More research is required on the relative cost effectiveness of subsidy schemes with different designs.

Market forces have also been a driver in some of these transitions, but have worked in combination with policy. Early deployment of heat pumps and heat networks in leading countries took place as a response to the oil crises in the 1970s, partly as prices rose but also as a result of policies. However, in the decades that followed, a combination of planning, regulation, taxation and incentives brought around a transformation of heat provision. In Norway, rising electricity prices in the late 1990s encouraged a move towards heat pumps and district heating, but it was supported by policies to facilitate take up.

<u>Areas for further analysis</u>

This study has been intended primarily as a summary of evidence, rather than the creation of new evidence, or a deep dive into the details of policy design and implementation. In order to better understand the

[52] (CCC 2016)

effectiveness of different policies and approaches in different contexts, further evaluation is required of the most relevant case studies. Key areas for further research could include:

- The differing cost-effectiveness of international subsidy programmes (e.g. Germany, France, Netherlands and Sweden);
- The role of supporting policies (technical standards, information and R&D) in building trust in heat pumps and district heating in Germany and Sweden;
- The role that consumer perceptions and engagement have had in shaping energy transitions and policy implementation (and the policies that were introduced to facilitate this);
- Technical details and standards of heating technologies being deployed internationally to help ensure consistency in the UK;
- The impact of low carbon homes legislation and how energy efficiency policy and low carbon heating provision have interacted.

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Company Profile

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