Annex: International Comparisons of Heating, Cooling and Heat Decarbonisation Policies

Report prepared for The Department for Business, Energy and Industrial Strategy (BEIS)

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Contents

Annex 1: Methodology

This section discusses the overall project approach, methodology used to compile the database on heating and cooling policy case studies, key results of the evidence review and selection of priority case studies. The study focuses on eight countries – Canada, Germany, Japan, the Netherlands, New Zealand, Norway, Sweden and the US. This streamlining was due to two reasons:

- an initial scan of the evidence found there to be reliable and relevant evidence for these countries; and
- the countries have a range of characteristics enabling similarities and differences in their heating and cooling practices to be explored.

Section 1 presents the overall project approach, section 2 describes the methodology for evidence screening, section 3 presents results of evidence screening, and section 4 discusses the section criteria for case studies.

1 Project approach

The project is structured in to three phases. Figure 1 presents a broad outline of the approach.

— **Phase 1** involves a broad review of evidence. An assessment of the reliability and relevance of this evidence was used to establish countries for further study and identify evidence gaps.

— **Phase 2** comprises research on eight OECD countries, and detailed case studies on three countries

— **Phase 3** involves drafting the report and iteration with the client.

Figure 1. **Overall methodology**

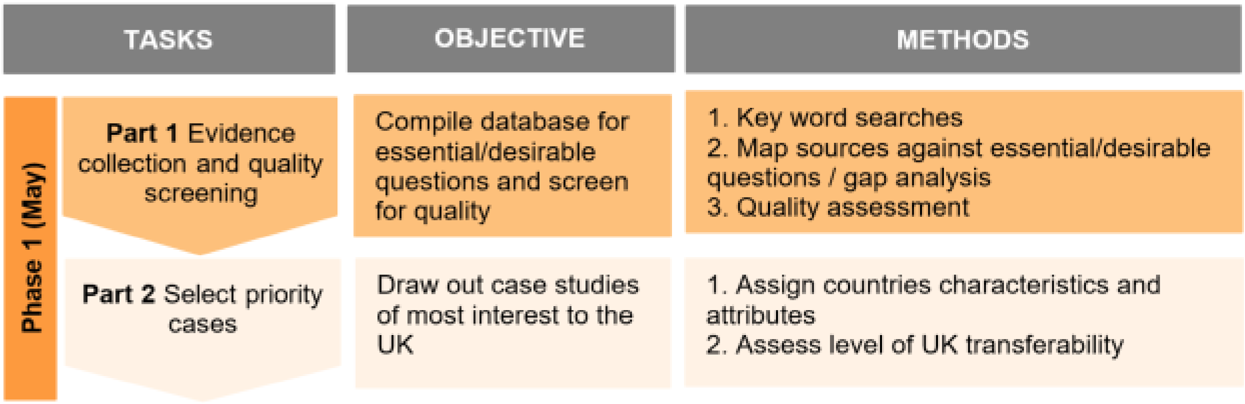
	TASKS	OBJECTIVE	METHODS
Phase 1 (May)	**Part 1** Evidence collection and quality screening	Compile database for essential/desirable questions and screen for quality	1. Key word searches 2. Map sources against essential/desirable questions / gap analysis 3. Quality assessment
	Part 2 Select priority cases	Draw out case studies of most interest to the UK	1. Assign countries characteristics and attributes 2. Assess level of UK transferability
Phase 2 (Jun)	**Part 1**: Detailed review of screened evidence sources	Use screened evidence sources to answer key research questions	1. Review of heating/cooling in OECD countries 2. Archetypes and barriers assessment 3. Review of technology transitions
	Part 2: Evaluation of priority cases	Deeper dive policy evaluation for a subset of priority cases	1. Evaluation of strategy and policy efficiency, effectiveness and feasibility 2. Key stakeholder interviews 3. Policy evaluation in UK context
Phase 3 (Jul-Aug)	**Part 1**: Draft and final report	Synthesise work into clear final report and spreadsheet	1. Drafting and iteration with client of draft report and excel workbook of evidence
	Part 2: Draft and final report	Synthesise work into clear final report	1. Drafting and iteration with client of draft report

Source: *Vivid Economics*

2 Phase 1 Methodology

The objective of phase 1 was to compile a database with evidence on case studies that would answer the essential and desirable questions, to identify gaps in the database and to screen the data sources for quality. The data screening process is summarised in Figure 2. To begin with this was done by conducting a rapid search of key databases[1], and using a literature review search tool (Publish or Perish). Figure 3 shows the list of keywords that were used for the search.

Figure 2. **Phase 1, part 1 of the work focuses on evidence collection and quality screening**



Source: *Vivid Economics*

Figure 3. **Search terms**

Technology	Policy	Policy evaluation
• Evaporative coolers	• Tax	• Evaluation
• Heat pumps	• Standards	• Assessment
• Biomass	• Regulation	• Effectiveness
• District heating	• Subsidy	• Impact assessment
• Heat Networks	• Grant	
• CCHP	• Marketing	
• Tri-generation	• R&D	
• Micro CHP		
• Hybrid and gas absorption		
• Hydrogen		

Source: *Vivid Economics*

[1] (Google, Microsoft Academy, UKERC database and Science Direct)

The rapid evidence review was conducted across four categories: demand, supply, technology and policy. To streamline the study, it was agreed with BEIS to predominantly focus on eight countries that were found to have a good amount of robust and reliable evidence: Canada, Germany, Japan, the Netherlands, New Zealand, Norway, Sweden and the US.

The steps to assemble the database included:

- **broad systematic search of academic literature**: the first ten sources under each search term from key databases were recorded;
- **targeted search based on research questions provided by BEIS**: a detailed mapping of the sources to the research questions to identify where the evidence is particularly strong and where there are gaps;
- **quantitative data search:** building on the database that supported the recent UKERC (2016) on *Best Practice in Heat Decarbonisation Policy*, and adding several new elements with a focus on data in the last decade.

The next step was to assess the evidence for its quality, for which there are two dimensions, reliability and relevance. Based on these, the evidence sources were allocated one of the nine quality codes as shown in the data assessment matrix in Table 1.

The quality metric can either be reliable, indicative or unreliable:

- **reliable**: includes national accounts, international organisations and peer-reviewed academic papers; evidence may be produced on a regular periodic basis; evidence is judged to be relatively free from institutional bias;
- **indicative**: evidence could include surveys and publications from non-governmental institutions; there may be presence of some bias in conclusions;
- **unreliable**: literature which has had single occurrence rather than as part of a programme of published work (for example, news articles); evidence where there is a clear logic for bias (for example, public relations material).

The relevance metric can be assessed based on the following guidelines:

- **relevant**: provides quantitative data that directly answers essential and desirable questions and/or provides analysis that draws out the lessons learned from national case studies of heating/cooling policy interventions;
- **supporting evidence:** provides analysis of heating and cooling strategy or policy options in particular OECD countries but does not draw out clear lessons learned;
- **irrelevant:** sources do not provide information that is useful towards answering the essential and desirable questions.

Table 1. **Evidence assessment matrix with assessment codes**

	Relevant	Supporting evidence	Irrelevant
Reliable	RR	RS	RI
Indicative	IR	IS	II
Unreliable	UR	US	UI

Source: Vivid Economics

The quality assessment filters out unreliable and irrelevant sources, as well as highlighting the most relevant evaluations of heating transitions.

The output of this task is a workbook of case studies, mapped to the essential and desirable questions and with the quality ratings attached.

3 Outcomes of Phase 1 – evidence assessment

The results from phase 1 provided the basis for a discussion with BEIS regarding the priority areas as well as the key countries to be included. The output consists of the results of broad and targeted searches, combined with expert input, and is provided in two supplementary spreadsheets:
- one containing around 250 academic sources; and
- a targeted spreadsheet containing the top 50 sources.

There is also a description of the top 50 sources and their potential usage.

The key conclusions from these 50 sources are:
- **demand**: strongest evidence is present in Europe, the US (heating only) , Canada 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;
- **technologies**: 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.

The paragraphs below discuss the content and quality of the evidence relating to the research questions under each theme (see Table 3). Answers to desirable questions are presented in Table 2

<u>Demand</u>

1. *what proportion of energy demand and CO_2 emissions in each country is driven by heating and cooling (that is, how much of a priority is energy demand from heat and cooling in terms of energy bills and carbon targets)?*

Europe, New Zealand, the US (heating only) and Canada have detailed heating and cooling share of energy demand. There are data gaps on heating and cooling demand for Japan. For emissions, the International Energy Agency (IEA) and Electronic Data Gathering Analysis and Retrieval System (EDGAR) databases have data on CO_2 emissions from electricity and heat consumption in the buildings sector (residential and commercial buildings).

2. *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?*

Sector split provided is for residential energy consumption for all countries in IEA data, from this heating/cooling can be estimated given shares of heating/cooling consumption in residential energy consumption. Urban/rural population split is provided by World Bank indicators but comprehensive information of urban/rural heating/cooling demand split is not available. Gas grid access has been assembled for key EU countries in the UKERC database by looking at number of natural gas customers from Eurogas. BP statistical review provides fuel reserves by countries over time.

Supply

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

There is good evidence for all countries assessed on energy sources used in residential energy consumption from the IEA. Lack of data on split of fuel sources between residential and commercial buildings. Data on heating demand fuel shares available for all countries except Japan.

Detailed breakdowns of district heating sources are available for the Nordic region.

4. *how is energy distributed at a national and local level (segmentation as above)?*

There is poor data availability on spatial information on how heating demands are met outside Europe. Residential surveys only go to a country level (in case of Europe) or regional level (in case of the US).

5. *how are energy system challenges driven by daily and seasonal heat demand peaks mitigated?*

Data on monthly (but not daily) demand for Europe and seasonal data for different regions in the US is available. However, there is no systematic evaluation of how seasonality is addressed internationally. Data on inter-seasonal gas storage was not available.

Technology

6. *what technologies are used to provide heating and cooling (segmented as above)?*

The IEA *Tracking progress* report provides heat by technology and country, IEA global database provides fossil based residential demand data. Sales data for heat pumps is available for Europe and New Zealand. Poor data on technology mix in Norway and Japan.

7. *what factors have driven this technology mix?*

Factors are well documented for European countries, little information is available for other countries.

Policy

8. *what low carbon heating and cooling policies and strategies have been deployed or proposed?*

Detailed country level database of heating and cooling policies is available for Europe and the Nordic region (from report on Nordic heating and cooling[2]). IEA global database provides heating and cooling policies for all countries.

9. *what major innovation strategies are in place, or are currently being developed, which are relevant to decarbonising heating and cooling?*

The recent IEA workshop details the future plans of Sweden, Denmark, the Netherlands and France. Heat roadmaps are available for countries in Europe. The Nordic region heating strategy has information for Sweden, Denmark and Norway. The US Mid Century strategy, the Japan hydrogen society and NZ heat pump rollout are all good sources.

Table 2. **Desirable questions**

Question	Answer
What demand smoothing technologies or measures are used and what drives this?	There is poor evidence of demand smoothing technologies, beyond gas storage quantities in EU
How is low carbon heating delivered (segmented as above) where there is limited or no gas grid? What examples are there of gas grid decommissioning or decarbonisation?	Data for Europe on off gas-grid heating, but not segmented and no reported examples of large scale gas grid decommissioning
Are there examples of using single technology for both heat and cooling and what conditions support/enable that?	Examples and analysis of absorption coolers in district heating / cooling in Nordic region examples of reversible heat pumps in southern Europe
What decarbonisation targets have been proposed, and what legal status do they have?	Decarbonisation targets and their legal status are available from the IEA policies and measures database
Which incumbent regulatory regimes have proven supportive or challenging for heat decarbonisation? Where they exist, how have transitions been initiated and delivered (i.e., market led vs government intervention, regional vs national deployment)?	There is poor evidence linking regulatory regimes and decarbonisation, although Vivid Economics has conducted a number of projects looking at this for private clients

Source: Vivid Economics

[2] (Nordic Council of Ministers 2017)

Table 3. **Overall results of quality assessment for the top 50 sources**

Question	Relevant and reliable sources (% of total)	Supplementary sources
Demand	**15 (35%)**	**18 (34%)**
1)	9 (21%)	9 (17%)
2)	6 (14%)	9 (17%)
Supply	**7 (16%)**	**9 (17%)**
3)	6 (14%)	5 (9%)
4)	1 (2%)	2 (4%)
5)	0 (0%)	2 (4%)
Technology	**6 (14%)**	**18 (34%)**
6 i)	5 (12%)	10 (19%)
6 ii)	1 (2%)	8 (15%)
Policy	**15 (35%)**	**8 (15%)**
7)	10 (23%)	4 (8%)
8)	5 (12%)	4 (8%)

Source: *Vivid Economics*

4. Selecting priority cases

There are four criteria used to select priority cases 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 similar to the UK or in contrast to the UK.

The results of this assessment for the eight countries are summarised in Table 4.

Based on these factors, five case studies were chosen and these are undertaken in Annex 3.

- **Germany**: Germany has begun to make a heating transition away from oil and gas, mainly towards heat pumps based on a combination of targets, subsidies and complementary policies. There is strong data and evidence available for Germany and although the country's heating sector is well studied, not many studies have analysed it in the context of its decarbonisation policy. Germany is similar to the UK as it has a moderate penetration of gas connection, liberalised markets and similar climate.
- **Sweden**: Sweden has had a duel transition – towards heat pumps as well as an increase in the share of renewable energy for district heating. Similar to Germany, Sweden has good data availability and has been studied before but not in the context of a decarbonisation policy. Sweden is similar to the UK in that it also has a single large endowment (of biomass), but is in contrast to the UK as it has a small gas infrastructure and [not fully liberalised markets].
- **Japan**: Japan is interesting for further study as it is one of the few countries that is making efforts to commercialise hydrogen fuel cells on a large scale in the heating sector. Moderate amount of information is available for Japan mainly from the IEA and the Japanese Ministry of Economy, Trade and Industry. Few studies have looked at this recent transition in the Japanese heating sector. Japan is in contrast to the UK in terms of resource endowments, markets and climatic zones, although it has a moderately large gas infrastructure similar to the UK.
- **The Netherlands**: The Netherlands has an ambitious plan to reduce emissions from low-temperature heating by 80-95 % by 2050. A mix of policies is currently being used, with a focus on renewable heating subsidy programs. The long-term future of the heat system is unclear, but it appears that the government will transition towards electrification (including hybrid-heat pumps) and district heating. The Netherlands is similar to the UK in both heating profile (single endowment of gas, limited district heating) and climate, making policy lessons particularly applicable.
- **France**: France has ambitious plans to double the share of renewables in heating to 38% by 2030. France's primary policy instruments to drive this transition are subsidies for residential and commercial renewable heat, alongside regulations to limit continued deployment of direct electric heating. France (and northern France in particular) has a broadly similar heating profile to the UK, but has no natural endowments, but uses large shares of electricity and gas for heating, and so can provide interesting lessons around promoting renewables over natural gas as households switch away from direct electric heating.

Table 4. **Priority case assessment**

Potential Case Study	What could be explored?	Types of evidence that will be used?	Done Before?	Applicability/Relevance to UK	Other Comments
Germany	The characteristics and drivers of the German transition from gas, oil and electric heating to district heating and heat pumps (including the role and impact of decarbonisation policy on this transition) can be explored. In this sense, Germany is a potentially useful case study because Germany has achieved a high level of decarbonisation as a result of 10% of heating now sourced from DH, 30% of new buildings including heat pumps, and the replacement of some gas grids.	The IEA, Eurostat, UKERC, heat pump market data, the euro heat and power district heating database, BSRIA, and Eurogas statistical reports provide data on the heating and cooling sector in Germany. Additional quality reports from Stratego and the joint research centre in addition to National statistics, from the Das Statistik Portal may contain other useful data.	Germany is well studied, however, Germany is not well studied in the context of heat generation decarbonisation policy.	Germany's heating situation is applicable to UK. It has a moderate penetration of gas connections, liberalised markets, and a similar climate, mix of gas heating, heat pumps and heat networks.	Feasible
New Zealand	The characteristics and drivers of New Zealand's rapid increase in air source heat pump installations (including the role and impact of New Zealand's radical decarbonisation policy) are of interest. Particularly relevant to the UK is New Zealand's use of heat pumps for heating and cooling in poorly insulated homes.	The IEA policy database and the EECA heat database for technologies provide data on the heating and cooling sector in New Zealand. Evaluations of the 'Warm Up New Zealand' programme may also contain other useful data.	Vivid Economics has already completed work examining energy use and decarbonisation in New Zealand-	New Zealand's heat generation contrasts sharply with the UK. New Zealand has very small oil and gas reserves and a very low penetration of gas connections.	Feasible
Sweden	In Sweden, the characteristics and impact of a policy-driven heat pump transition and market development (50% of homes now have a heat pump) can be explored. Also of interest are the characteristics and drivers of an uptake in district heating and fuel switching from oil towards biomass and oil.	The IEA, Eurostat, UKERC, heat pump market data, the euro heat and power district heating database; BSRIA, and Eurogas statistical reports provide data on the heating and cooling sector in Sweden. The 'Nordic heating and cooling' documents and Swedish energy agency documents may also contain other useful data.	Sweden is well studied, but not in the context of decarbonisation policy. Sweden's transition to renewable heat is studied in detail in IEA reports.	Sweden contrasts with UK in regard to its low quantity of oil reserves and gas connections.	Sweden is of particular interest because of its dual transition to HP and DH Feasible

Norway	Norway offers a look at the characteristics and drivers of its transition from electric heating (sourced from hydropower) to district heating.	The IEA, Eurostat, UKERC, heat pump market data, the euro heat and power district heating database, BSRIA, and eurogas statistical reports provide data on the heating and cooling sector in Norway.The 'Nordic heating and cooling' document may also contain useful data.	Norway is well studied, but not in the context of decarbonisation policy.	In contrast to UK, Norway has a very low penetration of gas connections, despite its very large gas reserves	Feasible
Netherlands and Canada	For the Netherlands and Canada there is minimal evidence of a significant transition to low carbon heat generation technologies. An exploration of the policies in place, the challenges remaining and any discernable shift in attitudes towards gas usage could be of value. Exploring the state of policy development and innovations currently taking place in these countries may be of interest as well.	The IEA, Eurostat, UKERC, heat pump market data, the euro heat and power district heating database; BSRIA, and eurogas statistical reports provide data on the heating and cooling sectors in Netherlands and Canada. Provincial reports in Canada may also contain useful information on policy initiatives.	These countries are well studied, but not well studied in the context of decarbonisation policy.	Both countries are similar to the UK, although Canada's colder temperature extremes and greater land mass differ from the UK.	There is limited learning potential because a major decarbonisation transition has not occurred in these heating markets Less feasible
France/Germany/ Netherlands/Italy/ Other EU country where heat pumps use is increasing	It may be beneficial to understand what is driving the increase in heat pumps (including information about how the technology was introduced, received and/or its impact on electricity and gas networks) in these countries	The IEA, Eurostat, UKERC, heat pump market data, the euro heat and power district heating database, BSRIA, and eurogas statistical reports provide data on the heating and cooling sector in these selected countries.	A considerable amount of research has been done on the drivers of heat pump uptake in these countries.	These countries are generally similar to the UK.	Feasible
Japan	An exploration of Japan's continuing development and initial commercialisation of hydrogen fuel cells (ENE-FARM micro-CHP for homes) could shed light on the applicability and feasibility of hydrogen heating in the UK. Japan's longstanding and highly effective energy efficiency policies monitored, promoted and implemented by the MET Imay also be of interest.	METI and IEA have data on the heating and cooling sector in Japan.	Japan's hydrogen society initiative is relatively understudied and Japan's renewable heat policy has not been studied in the context of decarbonisation	In contrast to the UK, a lower percentage of Japanese households use natural gas. Japan also ranks as one of the most resource dependent countries in the world and sees peak energy demand during summer months due to the intensification of AC usage.	Less feasible

Spain	Of interest is the implementation and impact of the introduction of smart tariffs to address the challenge of peak load from air conditioning. These smart tariffs could potentially offer some lessons and insights for electrification and managing of peak load resulting from increased heat pump adoption in the UK and elsewhere.	The IEA, Eurostat, UKERC, heat pump market data, the euro heat and power district heating database, BSRIA, and eurogas statistical reports provide data on the heating and cooling sector in Spain. Vivid Economics would need to find additional information evaluating Spanish renewable heating and cooling policies.	..	Spain sees a higher percentage of energy demand from space cooling than the UK.	Level of feasibility is unclear. Vivid Economics has not assessed for this study specifically
Ireland	The implementation and impact of the introduction of smart tariffs in response to wind-dominated generation in conjunction with Ireland's high penetration of electric heating could be explored.	The IEA, Eurostat, UKERC, heat pump market data, the euro heat and power district heating database; BSRIA, and eurogas statistical reports provide data on the heating and cooling sector in Ireland. Vivid Economics would need to find additional information evaluating Irish renewable heating and cooling policies.	..	Ireland's climate is very similar to the UK and entails similar heating demands.	Level of feasibility is unclear. Vivid Economics has not assessed for this study specifically

Source: Vivid Economics

Annex 2: Country-level summaries

This section provides detailed summaries by countries that cover the research questions.

1 Germany

About half of the total final energy consumption in Germany is comprised of heating and cooling demand. Heating accounts for 34% of total final energy consumption while demand for cooling is relatively small, accounting for only 1% of total final energy consumption.[3] The residential sector has the largest consumption of heat at 460 TWh, 42% of total heat demand in 2013[4].

Germany has a mixed portfolio of heating technologies – gas and oil based heating, heat pumps as well as district heating. Although the majority of heating systems in Germany use natural gas and oil, there has been a shift towards heat pumps and district heating, particularly in new builds. This is discussed in detail in Annex 3, section 1. Currently, 50% of residential buildings use gas for heating, 30% use oil, 12% use district heating and 5% use electricity.[5] Germany has very little domestic oil and natural gas production and relies heavily on imports.[6]

Germany is the leading European heat pump market with about 500,000 heat pumps being installed in residential buildings in 2012[7]. In new builds, heat pumps are the second most popular heat source after gas. In 2016, 13% of heat consumption came from renewables, a significant increase from only 4% in 2000[8]. Currently, 87% of renewable heat is supplied from biomass.

Germany has a market based approach to deployment of energy technologies. As a result, beyond the gas and electricity grids, there is not a widespread use of centralised infrastructure for heat as there is in Nordic countries, although district heating infrastructure is growing.

Germany's recent transition towards low carbon technologies has been driven by policies promoting renewable heat, as well as energy efficiency. Heat pump uptake in Germany increased due to a combination of regulations governing building energy efficiency, the Market Incentive Programme which provides financial support to buildings for energy efficiency; and an increase in standard VAT rate from 16% to 19%. Germany also used soft instruments including information provision and awareness raising campaigns, in particular as a response to technical problems and lack of installation experience with heat pumps in the 1980s. More recently in Germany, utilities and energy agencies have led information campaigns to raise consumer awareness about heat pumps. See Annex 3, section 1 for further discussion on these policies.

[3] (Kalz 2016)

[4] *(Euroheat 2015)*

[5] (Christoph Scabell, Laura Echternacht, Hans Reckhaus, Navina Manirjo 2015)

[6] (IEA 2012)

[7] (European Commission 2016)

[8] (Collier, 2018)

2 Japan

In Japan, heating and cooling, derived primarily from electric and gas generation, was 54% of residential energy use in 2014. In contrast to the UK, Japan has a high building demolition rate and a relatively new building stock with 75% of Japan's buildings built after 1980. Japan is the world's largest LNG importer and Japan's city gas market alone consumed 37.1 bcm of natural gas in FY2014.[9]

Gas and oil are the main space heating energy sources in Japan, although, district heating and cooling and more recently micro-CHP hydrogen fuel cells are gaining market share. Japan's large and densely populated urban centres make Japan an attractive market for DHC. 77 companies operate 139 DHC systems in Japan. Starting in 2009, a consortium of Japanese firms began to offer a micro-CHP hydrogen fuel cell system known as the ENE-FARM. As of July 2017, 200,000 units have been installed with government plans to install 5.3 million (one in ten dwellings) by 2030.[10] These units convert city gas into hydrogen and cleanly burn to produce electricity and hot water. The increasingly widespread adoption of the ENE-FARM is viewed as one of the first programmes from Japan's 'hydrogen society' initiative to come to fruition. For example, it is estimated that residential fuel cells would reduce carbon emissions by 1-2 tCO_2 each year for the average home in the UK.[11]

Japan has one of the least favourable resource endowments of any country and frequent natural disasters. As a result of this, the Japanese government and the Ministry of Economy, Trade and Industry (METI), which is tasked with monitoring and implementing energy policy, add special consideration to technologies that increase Japanese energy security and increase energy system resilience. Hydrogen fuel cells are viewed as one of the technologies capable of meeting both of these objectives. Fuel cells can provide decentralised electricity during disasters improving system resilience in addition to smoothing energy demand peaks by producing during peak times. They can also achieve total energy efficiency rates of 95% reducing demand for energy from abroad.

Unlike the UK, seasonal demand in Japan peaks during July and August when air conditioning use intensifies to combat warm sub-tropical temperatures. The northern island of Hokkaido is the most likely location for demand peaks during the winter months in order to meet space heating needs.[12]

Japan liberalised the electricity market in 2016 and the gas market in 2017 to increase competition, service variety and decrease electricity prices, which are among some of the highest in the world. By 2020 Japan also intends to unbundle power distribution from generation and retail. Japan's market

[9] (International Energy Agency 2016a)

[10] Interview evidence

[11] (Dodds et al. 2014)

[12] (International Energy Agency 2016a)

liberalisation has been met with grid interconnectivity issues and the entrenched practices of decades old regional power monopolies. The electricity wholesale market remains particularly illiquid.

Japan takes a holistic energy efficiency approach where energy security, economic efficiency and environment plus safety (3E+S) are emphasised. The METI is tasked with preparing strategic energy plans and turning energy policy into practice. For example, Japan's Top Runner Programme energy efficiency standards have cut air conditioner energy use by 33% and a hydrogen road map with three phases (2015-2040) has been created to achieve Japan's stated goal of a becoming a hydrogen reliant society. [13]

[13] (International Energy Agency 2016a)

3 Sweden

Total energy demand for building heating and cooling in residential and commercial sectors in 2015 was around 76 TWh, 21% of total energy demand. Non-residential buildings accounted for 27% of the demand. Sweden has the largest share of renewable heat production in the EU with 69% of heat demand met by renewables in 2015[14].

District heating is the main source of energy for heating and hot water in residential and commercial buildings, supplying 60% of demand. Around 80% of the total 55 TWh of district heat consumed in Sweden was used in buildings in 2014. Biofuels account for major share, around 62%, of total energy input in district heating. The role of district heating is especially prevalent in multi-family and non-residential buildings, while biofuels and electricity are dominant sources in single-family houses. District cooling market has also grown in Sweden, despite the cold climate. Sweden is the leading country in the EU for district cooling, the cooling delivered reached 1 TWh in 2015.

Over a million heat pumps are installed currently in Sweden, mainly in single family houses. Heat pumps have replaced direct electric heating, electric boilers and oil boilers, to some extent wood and pellets, and to very limited extent also district heating. Growth in heat pumps has been rapid between 2009 and 2014; the amount of heat pumps installed grew by approximately 6% per annum in residential buildings and 2% per annum in non-residential buildings.

Energy taxes have been the main driver of Sweden's transformation towards renewables in heating. Natural gas used in heating has been taxed since 1985 and carbon tax on fuels was introduced in 1991. Additionally, tax on heating oil has been in place since the 1950s. These taxes have risen substantially over time. This taxation has resulted in a switch away from individual fossil fuel heating towards district heating and heat pumps. In district heating, high taxes have led to transition away from heating oil to biomass. Heat pumps were initially supported by subsidies but are now cost-competitive and receive no financial support.

In addition to taxes, tightening Swedish building codes over time have resulted in Sweden having the most efficient building stock in the EU. Building codes also encourage use of renewable heat.

[14] *(Collier, 2018)*

4 Netherlands

I**n the Netherlands, buildings heat is 23% of final energy consumption**. Total buildings heat demand was 150 TWh in 2014 . Buildings use 46% of total heat, followed by industry at 42%, and agriculture at 10%. Cooling demand is relatively small.

Similar to the UK, the Netherlands has an extensive gas network and very little district heating. Natural gas accounts for 78% of heat supplied and became dominant as a result of large indigenous reserves. However, indigenous reserves have reduced significantly in recent years, raising concerns about energy security[15]. Approximately 94% of households are connected to the gas grid whereas only 4% of households are served by district heating[16]. Netherlands along with the UK has the lowest share of renewable heat in the EU, with only 5.5% of heat demand met by renewables in 2015[17]. There were 180,000 heat pumps installed in residential buildings in 2012, supplying only 2% of the residential heat demand.[18]

Netherland's future policy focuses on moving towards renewable heat sources. The Minister of Economic Affairs published a heat vision in April 2015 suggesting a twin strategy of reducing heat demand through energy strategy and switching to renewable heat sources. It identified potential for the use of heat pumps in less densely populated areas and district heating in areas with dense heat demand. Currently, the main instrument for renewable heat is the Stimulation of Sustainable Energy Production Scheme, a combined support for renewable electricity, biogas and renewable heating technologies. It is one of the largest support programmes available for renewable heat globally – a total of €3.4 billion was available for renewable heat technologies and biogas in 2016. Renewable heat projects are however very competitive with renewable electricity under this scheme as it supports the cheapest options first, and moves to more expensive ones until the budget is exhausted[19].

The government has emphasised the need for significant innovation to make further progress in heating and cooling. This could include the use of aquifers for heat storage, hybrid heat pumps and a better alignment between energy efficiency, residual heat and renewables[20].

[15] *(Collier, 2018)*

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

[17] (Eurostat, 2017)

[18] (Kleefkens 2015)

[19] *(Collier, 2018)*

[20] (De Vries, 2017)

5 France

In France, heat accounts for 47% of final energy consumption, which was 70.6 Mtoe (821 TWh) in 2013. Residential consumption accounts for over half (56%) of total heat consumption, with industry (25%) and commercial use (18%) accounting for the majority of the remaining consumption.

France has no substantial natural endowments, but uses a mix of fuels in heating. France's buildings are heated by a mix of fuels, consisting of gas (42%), oil (21%), electricity (primarily direct electric, 15%), biofuels and waste (12%) and district heating and other sources (10%). However, 30% of households in France rely on electric heating, linked to the legacy of cheap electric power available due to large investments in nuclear power over the second half of the twentieth century. France relies on imports of energy or inputs rather than natural endowments to meet its fossil fuel heating needs – it imports all or almost all (99%-100%) of its natural gas (primarily from Norway and Russia), its oil (primarily from Saudi Arabia and Kazakhstan), and its coal (primarily from Australia and Russia)

France is one of the leading heat pump markets in Europe. Installation of heat pumps has increased significantly over the past decade. Sales neared 160,000 units per annum in 2008, though this halved to just over 80,000 units per annum in 2010. However, sales have increased in the period since, nearing 190,000 units per annum again by 2015, and France is now one of the largest markets for heat pumps in the EU[21]. However, France is lagging in the deployment of district heating, despite studies indicating that there is significant potential for district heating and that costs would be competitive with electric heating and heat pumps in France[22].

France has set out an innovative policy package consisting of fiscal incentives, loans, targets and a carbon tax to meet its ambitious heat energy transition targets. France is undertaking a heating transition based on a combination of targets, regulations and fiscal policies. The country has set ambitious overall targets for a doubling of renewable heat by 2030, as well as ambitious interim targets for 2018 and 2023. The approach is beginning to have an effect in the new build sector – France has become a key growth market for heat pumps within Europe, and heat pumps have been installed in almost 40% of new builds. Fiscal incentives support the replacement of systems in existing buildings with renewable heating ones. However, these incentives appear to have been less effective in driving uptake of renewable heat in retrofits to existing dwellings. Additionally, new dwellings are also turning to gas heating alongside heat pumps (c. 55% of properties). France's current strategy and policies may not be sufficient to meet its ambitious goals – it has already had to revise its interim targets for individual renewable heat incentives downwards as it recognised it was unlikely to meet them, and faces challenges in deploying renewable technologies at sufficient scale to meet these revised targets.

[21](Nille 2015) (Collier, 2018)

[22] (Collier, 2018)

6 Canada

Heating and cooling from buildings account for 24% of the final energy consumption and 18% of total GHG emissions in Canada.[23] Total heating and cooling demands in buildings were approximately 535 TWh and 21 TWh respectively in 2014 . Residential buildings' share around two-thirds in the total heating and cooling demand and the rest accrues to the commercial sector. Energy intensity of residential space heating declined by approximately 40% between 1990 and 2013, while energy use stayed the same as the number of houses have increased. Energy efficiency gains were achieved largely by replacement of less efficient systems with regulated medium to high efficiency systems.[24]

Gas and electricity are the main sources of space heating in both residential and commercial buildings. In residential buildings, gas provides heat to 50% of the households, followed by electricity providing 37%. For space cooling however, electricity is the main source [stats]. In 2014, about 5% of the households, 0.7 million, are fitted with a heat pump, a rise from 2% in 1990.

Canada has abundant and cheap supplies of fossil fuels and low electricity prices. It has large reserves of natural gas and oil. It produces hydroelectricity due to its abundant water resources, and nuclear power using uranium, which also available domestically.

Canada lacks a unified policy for promotion of renewable heating and cooling applications. Biomass and solar thermal represent the greatest potential resources for renewable energy for heating. The main mechanism that Canada uses is financial incentives for energy efficiency.[25] Renewable energy programmes also provide subsidies at federal and provincial levels.

[23] (Natural Resources Canada 2017)

[24] (Office of Energy Efficiency Natural Resources Canada 2016)

[25] (IEA-RETD 2011)

7 New Zealand

Building space heating and cooling demand was 14% of total final energy demand in 2015. Heating demand in buildings was 20 TWh, while space cooling demand was small, approximately 3 TWh . Emissions from space heating and cooling were 6% of total GHG emissions.

Electricity is the main fuel for space heating and cooling in buildings. Electricity supplies two-thirds of the heating and cooling demand. This is followed by natural gas, which provides 20% of the demand. Around 40% of heat is delivered via heat pump, 20% through gas boilers, 20% from resistive heating and the remaining 20% via burners providing direct heat. For cooling, heat pumps are the only technology used. Growth in heat pumps in residential buildings has accelerated in the last ten years and heat pumps have mainly displaced non-electric heating.[26] In 2004, only 4% of households had heat pumps, today heat pumps are very popular with over half of new households having at least one.

Rapid uptake of heat pumps is leading to new energy and peak power demand on the electricity supply system. Although heat pumps are promoted for winter heating, over 60% of houses use them for cooling as well, leading to a rise in demand on summer electric load. Heating schedules are longer in houses fitted with heat pumps. Heat pump thermostats are also being set to higher temperatures than previously found in New Zealand homes.

Heat pump uptake has been mainly driven by clean heating programmes that encourage take up through subsidies. 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.

[26] (Energy Efficiency and Conservation Authority 2014)

8 Norway

There is no data available in Norway showing total actual energy usage for heating in the residential and service sectors. Self-reported data from ENOVA based on a sample of 3,415 buildings in 2015 represents 8.4 TWh of energy usage in space heating. The European Commission estimated energy consumption by residential space heating in 2012 at 25 TWh.[27] Total residential and service sector energy consumption, not limited to heating and hot water, is around 90 TWh in 2015[28].

Electricity is the main source of heating and hot water in the residential and commercial sectors. ENOVA estimated that 85% of space heating used electricity in 2015. About 11% of heat is delivered from district heating.

The heat pump market has seen a strong growth in the last 10 years. There were about 750,000 installed heat pumps (a third of total households), corresponding to 15 TWh of heat delivery in 2015. Historically, installation and sale of heat pumps correlates with cold winters and high electricity costs for end-users.

District heating is small relative to other Nordic countries; it supplies 5 TWh of heat to end users. Access to relatively cheap electricity and alternative sources of heating had led to limited size of this market. However, due to increasing electricity prices in the late 1990s, district heating investment subsidies were introduced to promote the build-up of district heating. Subsequently, investments and capacity of infrastructure have grown significantly. In 2015, 82% of the total district heat delivered to end users was consumed by the residential and service sectors.

The development of district heating and heat pump market in Norway is a result of both market forces and policy. Increasing electricity prices initially encouraged take up of heat pumps and investment in district heating. Air source heat pumps were subsidised in 2003, which helped stimulate growth in market but investment support has now been removed. End user investments for air-to-water and liquid-to-water heat pumps are still subsidised. The current energy labelling programme also promotes the use of heat pumps in buildings. For district heating, as discussed above, infrastructure investments were also subsidised in the early 2000s, due to increase in electricity prices.

[27] (European Commission 2016)

[28] (SSB, 2015)

9 US

Total residential and commercial heating demand accounted for 15% of final energy demand in 2015. Residential heating and hot water demand was 75% of total heating demand at 1,800 TWh, and commercial heating and hot water demand was 25% at 840 TWh[29]. Data on cooling demand was not available.

Natural gas and electricity are the main space heating fuels in households. Natural gas is the main space heating fuel in almost half of the households. Electricity supplies space heating in 36% of households as well as water heating in 45% of households. Around 10% of households or 12 million, use heat pumps. Most of these are in humid regions of the US which have mild winters and are mainly used for air conditioning in summers. Renewable heat remains underdeveloped and there is less comprehensive data on deployment[30]. District heating plays a small role in the US and is primarily supplied by gas.

The US does not have specific targets for renewable heat or a clear policy on heat at the federal level. Tax credits have been available at the federal level for various renewable heat technologies, most of which expired at the end of 2016. Tax incentives are available for wood stoves and biomass boilers in eleven states. However, evaluating the success of federal and state-level policies is difficult as very little deployment data linked to specific policies is published.

[29] (RECS, 2015)

[30] *(Collier, 2018)*

Annex 3: Detailed case studies

This section provides detailed case studies for Germany, Sweden, Japan, the Netherlands and France. While section 5 in the main report shows summaries of these case studies, this annex presents details on implications of archetypes, decarbonisation trends in the last 10-15 years, the policies and drivers facilitating transition, innovative aspects of transition, outstanding challenges, and applicability to the UK.

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 and 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:

- **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.

1 Germany

In section 3 of the main report, Germany is identified as having a low resource endowment, and has a heterogeneous use of fuels for heating. This means that Germany is likely to contain case studies that are relevant to the UK, for example, transitioning off the gas grid, and transitioning away from oil. Germany also has interesting developments in the new build housing stock. In summary:

- 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 also been successful in transitioning away from oil, mainly towards heat pumps and district heating.
- Energy efficiency regulations have addressed landlord-tenant issues and are planned to continue to ratchet up.
- However, most replacement heating systems in existing buildings remain fossil fuelled, and new policies are required to address this.

1.1 Implications of archetypes for the heating and cooling transition

In order to understand the heating transition in Germany it is important to consider the following:

Endowment and infrastructure

Germany has a relatively high proportion (54%) of households connected to the gas grid, around the median of European countries, but lower than the UK (83%). This suggests that there is a relatively high level of lock in to gas, given that the proportion of existing buildings using natural gas for heating has increased significantly in the last 20 years (see Figure 5. However, although Germany has the 4th highest indigenous production of natural gas in the EU (98 TWh gross calorific value in 2014), its gas production is still significantly below that of the UK (425.5 TWh in 2014)). Germany also imports most of its gas supplies from Russia (403 TWh) and Norway and other countries (329.5 TWh). Germany does not have a large natural endowment in hydro, and has not traditionally relied on electric heating to a large degree. Moreover, Germany has committed to the complete phase-out of nuclear power by 2022 (in response to the Fukushima disaster in 2011).

44% of total final energy consumption in Germany is from heat. In 2016, 13% of heat consumption was sourced from renewables, compared to 4% in 2000. Biomass supplies 87% of renewable heat, with just 6% supplied through district heating. Germany has a higher share of renewable heat than in the UK, where only 5.5% of heat consumption was met by renewables in 2015, and the majority of heat in buildings is supplied by gas (75%) or oil (8%) boilers[31].

In 2015 there were approximately 40.5 million dwellings in Germany (a higher number than in the UK), of which the majority (54%) were multi-family dwellings, 30% single-family households, and 16% two-family

[31] (CCC, 2015; IEA Insights, 2017)

dwellings[32]. Almost 50% of the housing stock is privately-rented, with approximately 40% being owner-occupied.

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 built in 1918 to 53 kWh/m^2/year for single family homes built in 2010. In the UK, a mid-terrace house built before 1920 has an average heating consumption of 305 kWh/m^2/year, compared to 268 kWh/m^2/year for a 1980's detached house and 103 kWh/m^2/year for a mid-terrace house built after 2002[33]. The UK housing stock is also older than in Germany. Approximately 21% of the UK's housing stock was built before 1919, and 38% before 1946. 24% of Germany's housing stock was built before 1946, while 40% was constructed before 1961. Heat consumption in Germany's residential buildings decreased by 20% from 2000 to 2012, a trend which has been linked to building energy efficiency improvements, despite increased living space per person and higher living standards.[34]

Market liberalisation

There is a market based approach to the deployment of energy technologies. As a result, beyond the gas and electricity grids, there is not as widespread use of centralised infrastructure for heat as there is in Nordic countries. Nevertheless, Germany has the potential for a very strong planning framework, particularly post-liberalisation. District heating stands at around 14% of primary heating energy in the existing housing stock and is growing, albeit slowly overall (see Figure 5). In comparison, district heating networks in the UK supply only about 2% of total heat demand, mainly from gas boilers and small co-generation plants[35].

Heating profile

Germany is in a temperate region similar to the UK, and therefore has a seasonal peak for energy for heating and cooling in winter.

1.2 Decarbonisation trends in the last 10-15 years

Although the majority of new heating systems in Germany use natural gas, there has been a significant shift in the **last fifteen years**. In 2005, the share of **oil heating** installed in new homes was 14%, but this has declined to negligible levels now. In 2016, solid biomass at 114.5 TWh had the largest share of renewable heat consumption for all sectors in Germany (residential, commercial and industrial) followed by biogas at 17.4 TWh and biogenic waste at 11.8 TWh[36].

[32] 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)

[33] (Buildings Performance Institute Europe 2011)

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

[35] (IEA Insights, 2017)

[36] (Bundesamt für Umwelt 2017)

In the existing housing stock, there has been a shift from oil to natural gas heating, while the proportion of existing homes supplied by district heating and heat pumps has increased only marginally in the last ten to twenty years. In 1995, natural gas supplied 37% of existing homes, compared to 49% in 2015; the share of oil heating in retrofits decreased from 34% in 1995 to 27% in 2015 (see Figure 5). The share of district heating in existing properties increased only slightly from 1995 (12%) to 2015 (14%). 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** has grown from 7 to 22% of new homes between 2000 and 2016 (see Figure 4). In 2002, over half of the energy used by CHP for district heating was sourced from coal and approximately 35% from natural gas. In 2015, CHP plants supplied 83% of district heating, but 42% of this was still from coal and only 12% from renewable heat.

In 2000 the share of **heat pumps** was less than 1% of **new homes**, compared to 23% of new homes in 2016 (see Figure 4). Particularly rapid growth in the share of heat pumps in new homes took place between 2005 (5.4%) and 2009 (24%), after which time this share has actually levelled off or declined marginally. The following section discusses some policy drivers which may have influenced this growth, which include the Energy Efficiency Ordinance (EnEv) and Market Incentive Programme.

Air-to-water heat pumps accounted for 57% of the total of 69,700 heat pump sales in Germany in 2015, with most of the remaining sales split evenly between sanitary hot water heat pumps and brine-water heat pumps. Air-to-water heat pumps are most popular in new build single or two-family houses, while air-to-air heat pumps are used commonly in hotels or energy efficient stores. Ground source heat pumps are typically used in large buildings which also have cooling requirements.

1.3 Policy and drivers

The rapid increase in annual heat pump installations observed in 2006 can be linked to the EnEV regulations governing building energy efficiency and an increase in the standard VAT rate from 16% to 19% in 2007. Meanwhile, a similarly sharp growth in heat pump sales in 2008 can be attributed to a peak in fossil fuel prices and the introduction of the Market Incentive Programme in 2008, which provides investment subsidies or low interest loans for heat pumps and district heating. The financial crisis and falling oil and gas prices contributed to a slowdown in annual heat pump sales in 2009 and 2010, with the German government implementing budget cuts in 2010, which included a 3-month suspension of the Market Incentive Programme. 57,000 heat pumps for space heating were sold in Germany in 2015, with increased funding from the Market Incentive Programme leading to a tripling of applications to the scheme.

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 for renewable heat** (2008-2017 (ongoing)) 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). Investment grants are available for air to water heat pumps with a minimum SPF of 3.5, ground source heat pumps with an SPF of at least 3.8 and small solar thermal installations (up to 40 m^2) usually appropriate for single family houses. The MAP provides a core subsidy and various additional subsidies, according to the type of heat pump and the project. For retrofit installations, the value of support ranges from a minimum of €1,950 euros for air-to-water heat pumps to a maximum of €15,000 euros for GSHPs. In new builds the level of support is lower, ranging from €1,300 for air-to-water heat pumps to €10,000 for GSHPs. In 2016, a bonus was introduced at 20% of the core rate for retrofit, with an additional bonus of €600 available for installations which replace a non-condensing gas or oil boiler. Despite higher support for retrofit installations, sales have been shifting towards new build installations more recently. From 2005 to 2009, at least 60% of heat pump sales in Germany were for retrofits to existing buildings, but since 2011, the majority of heat pump sales (around 60% from 2013-2016) have been in new builds.

Since 2012, 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 (bonus) 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 German government-owned KfW development bank provides soft loans for larger scale systems, for example subsidies for large solar collectors and for heat pumps of 100 kW and larger. 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 sets out requirements for at least 50% of heat demand in new buildings to be supplied by renewable energy, with the percentage varying by technology. The EEWArmeGaims 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 subject to the following conditions: a substantial share of heat comes from renewable sources; or at least 50% of heat is sourced from CHP, waste heat, or a combination of CHP, waste heat and/or renewable heat. The EEWarmeG requires heat pumps to have a minimum seasonal performance factor (SPF) of between 3.3 and 4 (varying by heat source and depending on whether domestic water heating is included). In addition to national regulations, Baden-Württemberg has a regional law which requires renewable heat to be installed in buildings when heating systems are replaced.

Further to the above policies, 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. The majority of public subsidies in the Energiewende have been directed towards the electricity sector. Nevertheless, the Energiewende developed a modernisation programme for buildings which comprised a number of different elements: minimum standards for energy performance in new and existing buildings; an obligation for new buildings to use renewable heat; and, in 2012, changes to the tenancy law to tackle the split incentives barrier to refurbishment by dividing advantages and costs between landlords and tenants. With respect to the latter, landlords are permitted to increase rents by up to 11% per year to cover the cost of energy refurbishment[37].

In Germany, 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. In 2013, single payments totalling €110 million were distributed under the German CHP Act to fund 1,017 district heating systems with a total length of 423 km[38].

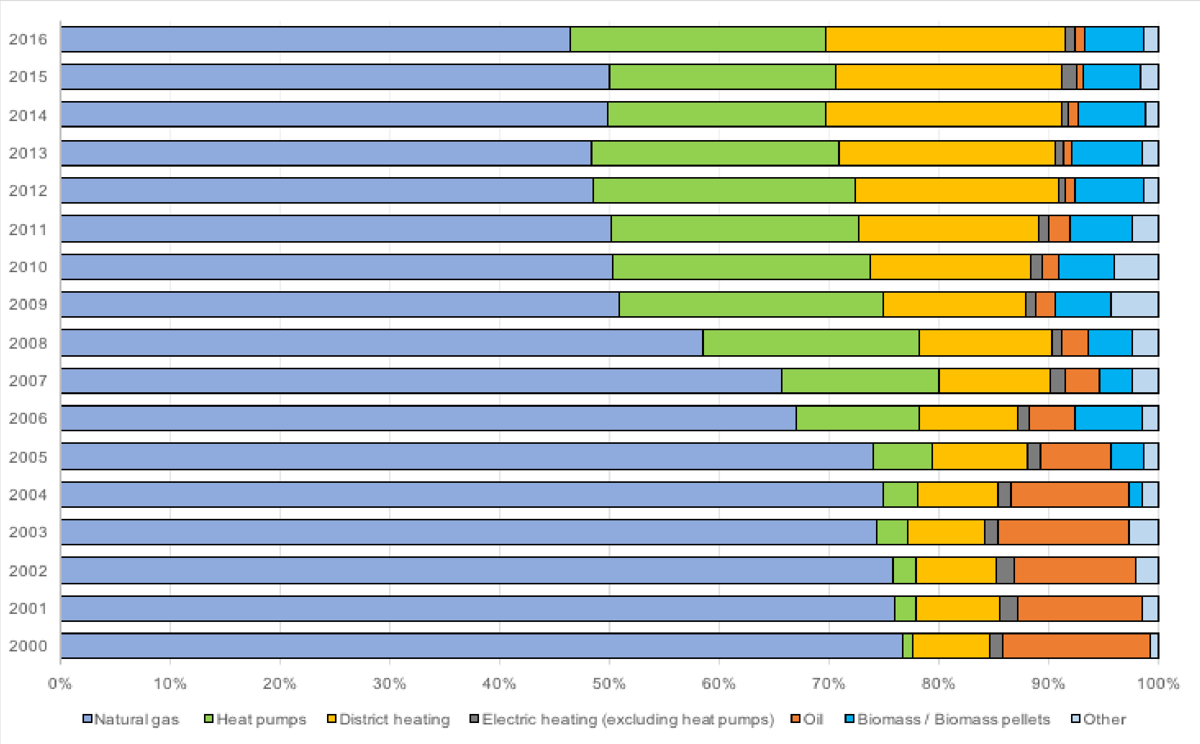
German municipal codes enable municipalities to enforce mandatory heat planning in certain areas if they choose to, as long as the municipality fulfils certain criteria and has sufficient control over the local district heating utility. This can include obliging all building owners to connect to and use district heating as their sole heating technology. The stability provided could help municipalities to plan heat sources and networks more efficiently and secure investment, particularly in areas without any nearby heat networks which would require completely new investment in district heating infrastructure. Some municipalities have used mandatory heat planning, but it can be unpopular and this may account for it being relatively little used; increasing public involvement in the process could help to promote acceptance.

Soft instruments include information provision and awareness raising campaigns which have been implemented as a response to technical problems and lack of installation experience with heat pumps in the 1980s. More recently in Germany, 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. The NRW Energy Agency has produced radio adverts and engaged with communities by attending local trade fairs and setting up information dissemination events in town halls. RWE’s information campaign from 2005 to 2010 was motivated by their objective to encourage customers to switch from gas or oil to electricity. RWE set up an online heat pump forum for consumers to access information about heat pumps, installers and products. Consumers can search a database of installers by postcode, on which installers can advertise at low cost, while manufacturers also pay to advertise their products on the website. The RWE database may also raise consumer confidence in heat pump products and installers through being associated with RWE as a trusted brand.

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

[38] (Galifuss 2016)

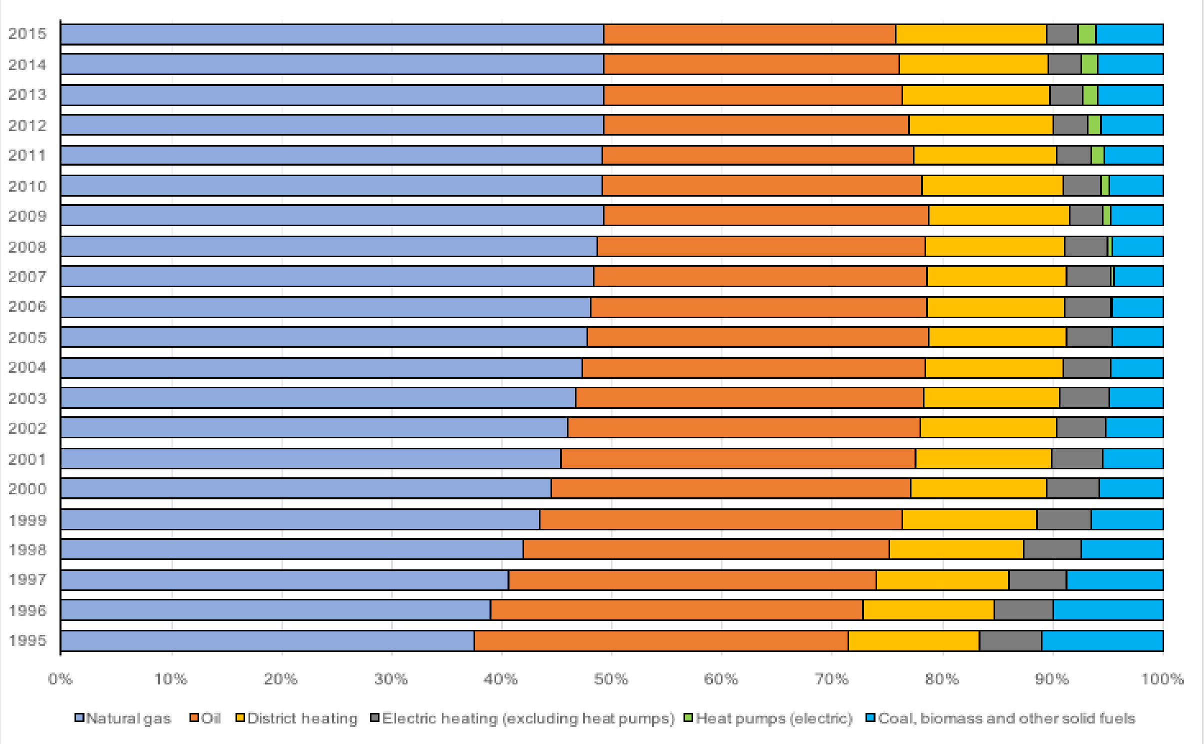
Figure 4. **Heating systems in new homes approved for construction, 2000 to 2016 (% of primary heating energy), Germany**



Note: *In Figure 4, the data for 2016 applies to January to September only.*

Source: *AG Energiebilanzen e.V. (2016) Energieverbrauch in Deutschland: daten für das 1.-4. Quartal 2016. http://www.ag-energiebilanzen.de/20-0-Berichte.html*

Figure 5. **Heating structure of the existing housing stock (% of primary heating energy), Germany**



Source: *AG Energiebilanzen e.V. (2016) Energieverbrauch in Deutschland: daten für das 1.-4. Quartal 2016. http://www.ag-energiebilanzen.de/20-0-Berichte.html*

Table 5. **Analysis of key policies - Germany**

Variable	Incidence	Modality	Duration	Complementary measures
German Energy Saving Ordinance (EnEv)	New and existing buildings	Energy performance requirements	2001-2017 (ongoing)	EEWarmeG; Energiewende; Market Incentive Programme
Federal Renewable Energies Heat Law (EEWarmeG)	Applies to new build properties and also to renovation of public buildings	Requirements for specific percentage of heat demand to be supplied by renewable energy	2009-2020	EnEv; Market Incentive Programme
Market Incentive Programme (Marktanreizprogramm)	Residential, commercial industry and energy sectors	Grants for small-scale renewable heat systems; low-interest loans; low-interest loans for industry and district heating	2008-2017 (ongoing) (Currently €300 million per year available in grants or low-interest loans)	EnEv
Energiewende	All economic sectors, buildings, industry, transport and energy sector	Sets out targets to reduce greenhouse gas emissions by 2020 and a pathway for decarbonisation through to 2050; includes energy efficiency and decarbonisation programme for buildings.	2010-2050	Market Incentive Programme; EEWarmeG

Source: *Vivid Economics*

Box 1. **Interview evidence – Coordinator Heat Pumps, Fraunhofer-Institut für Solare Energiesysteme ISE**

Germany has not yet successfully transitioned away from oil based heating. The transition, which started 10 years ago, remains modest. However, the transition from oil burners to gas boilers has been successful. The number of oil boilers in new buildings is very small (<5%), while the share of heat pumps is growing: 34% of new buildings last year were equipped with a heat pump. Despite this, no dramatic movement from gas and oil technologies has taken place overall. The majority of all heat pumps in 2016 were installed in new buildings, but not in large absolute numbers (overall heat pump market encompasses approximately 60.000 units). Historically, there has been a high share of oil boilers. As a result of this large previously installed amount, the total number continues to grow slightly.

There has been no consistent movement towards heat pumps -yearly data depicts spikes and troughs in adoption numbers from year to year. This is partially a result of continually changing subsidies and the volatility of energy prices. When the price of electricity is high, while gas and oil are cheap, running costs are quite expensive for heat pump end users. There are also still subsidies for installing new gas boilers that distort the market away from increased heat pump adoption.

Heat pumps growing pains have been minimal- technical issues with heat pumps in existing homes may still come up, however, they have been successfully solved in majority of cases. Monitoring projects in existing buildings for heat pumps have found that the efficiency of heat pumps in these homes (at different levels of retrofit) can be quite high. Some efficiency levels approach the levels achieved in new buildings.

Additional measures are required to increase heating pump installations in existing buildings. Supporting programmes that incentivise building owners to adopt heat pumps will have to be combined with continued heat pump innovation. Easier installation technology and techniques will help facilitate this transition while research into utilising more accessible heat sources, such as using the ground or the geothermal insulating properties of the earth, are required.

1.4 Innovative aspects and solutions

During the early stages of growth in the heat pump market, difficulties were experienced with the quality of products and their installation. The German Ministry of Research and Technology initiated heat pump R&D in 1974. A tax-credit scheme was introduced in 1979 which supported building energy saving measures, including heat pumps, and in 1983 this tax credit was extended for a further four years. Despite this, in the mid-1980s the heat pump market collapsed and declined from a peak of over 2,500 sales in 1980 to approximately 500 sales per year in the mid-to-late 1980s. This has been explained by the adverse impact on the reputation of heat pumps caused by poor product standards, a lack of maintenance and experience of installers, as well as falling oil and natural gas prices. The steady growth in heat pump sales in Germany during the 1990s can be attributed to a number of different policies, which include the establishment of the German heat pump association (IWP) in 1993, the publication of technical manuals and guidance, federal subsidies for

GSHPs and related promotion activities, and the information campaign led by the IWP several years subsequently.

Co-operation between different delivery agents in the heat pump industry has been important, particularly the pivotal role played by the formation of heat pump associations and their subsequent activities. In 1993, the German heat pump association (IWP Heat Pump Action Group) was created, with a first task of improving component quality and installation practices. The IWP was formed from a partnership between large utilities and heat pump manufacturers, who were aiming to revive the heat pump market in the early 1990s. The IWP commenced a wide information campaign in 1997, in partnership with the German Electricity Association, to stimulate sales of heat pumps, which was also supported through the introduction of federal subsidies. As a result, heat pump sales in Germany increased from 500 per year in 1990 to 5,000 per year in 1998.

Revenue support for CHP also plays a strong role in recent district heating deployment in Germany. The German Combined Heat and Power Act (KWKModG) includes bonus payments for electricity from CHP for a set time period to offset the higher investment costs of CHP compared to conventional power plants. The KWKModG also mandates the grid connection of CHP and gives equal priority to the purchase of electricity from cogeneration and renewables over electricity from conventional sources (Ecoheat4EU, 2011a). This move towards integrating CHP generation with renewables seems likely to give CHP a less active and effective role balancing electricity systems than in Denmark, where CHP plants trade on the spot market, but it also seems reasonable that the administrative burden on CHP operators will be lower[39].

1.5 Outstanding challenges

The German *Energiewende* (energy transition) includes a target for the buildings sector to be close to carbon neutral by 2050, as outlined above. There are additional sub-targets for 2020 on the pathway to 2050 which include energy savings, renewable energy development and GHG emissions reductions. These targets will require energy efficiency and renewable heat to be scaled up significantly. In 2015, the federal government published a strategy for the building sector which presents a ‘business as usual’ scenario and finds that the 2050 target cannot be achieved with the current mix of policies such as the market incentive programme and building regulations.

Meeting longer-term CO_2 reduction targets will necessitate a major transition away from fossil fuels for heating. District heating supply is mainly from fossil fuels and will need to be decarbonised, while heat networks will require extending in some areas. There are continuing difficulties in addressing energy efficiency and encouraging uptake of renewables heat. The Energiewiende has not really penetrated the existing building stock. Around 90% of annual refurbishments are still fossil fuel.

Reducing heat consumption in buildings continues to be a challenge with respect to Germany’s target to achieve 14% renewable heat in overall heat consumption in 2020. It has been estimated that renewable heat

[39] (Toke & Fragaki, 2008)

supply would need to increase by up to 190 TWh to meet this target[40]. Heat consumption in residential buildings fell by 20% from 2000 to 2012, while temperature-adjusted specific heat demand per m² fell by 11% from 2008 to 2013. Assuming that this trend continues, the refurbishment rate of buildings will still need to increase by 2% per annum in order to achieve the 2020 Energiewende targets for residential heat consumption. Sub-targets for the refurbishment rate and projected heat demand reduction in existing buildings conflict in terms of their relationship with the overall national GHG emission reduction target. A particular problem is the way in which heat demand is defined, since it does not distinguish between renewable and fossil heat. Therefore, heat demand met wholly through renewable energy should satisfy national targets for GHG emission reductions. One solution could be to introduce the concept of 'net heat demand', whereby renewable heat is considered both as having zero emissions and as a reduction of total heat demand[41].

Improved regulation under the Energiewende in 2012 set out to address the problem of split incentives between landlords and tenants, in which landlords have a low incentive to purchase low carbon or energy efficient technologies for their properties since they are not responsible for paying the energy bills, as their tenants are. However the split incentives issue has not been resolved sufficiently, particularly given that approximately half of flats in Germany are not owner-occupied. One proposed solution is to adjust the rent index used to determine new rental agreements so that it accounts for the energy efficiency standards of each given flat. Flats with higher energy efficiency standards would have higher rents, but tenants would save costs on their energy bills, and vice versa. However, this proposal has adverse implications in that it would lower the affordability of energy efficient homes to low-income households.

1.6 Applicability to the UK

There are several lessons for the UK from Germany's heat transition, and some policies and strategies used by Germany are quite relevant to the UK. An important challenge for achieving a sustainable heat pump market in the UK is 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. Separate studies have demonstrated that the performance of heat pumps installed in households may be compromised by poor installation standards[42]. 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 up front 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

[40] (Kemfert et al., 2015)

[41] (Kemfert et al., 2015)

[42] (Miara et al. 2011; Energy Saving Trust 2010)

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.

In the UK, ongoing financial incentives such as the RHI could require continuity of policy support over a longer time period in order to maximise their effectiveness. A lack of policy stability could adversely affect industry confidence. For example, on the one hand, the majority of Microgeneration Certification Scheme installers surveyed by DECC (2016)[43] reported that the RHI had led to increased enquiries and sales for renewable heat systems. Conversely, almost a quarter of Microgeneration Certification Scheme installers considered that the uncertainty of the RHI's digression mechanism had impacted negatively on the renewable heat market[44].

In terms of lessons for transitioning off a gas grid, there may be some partial transferability to the UK since 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.

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, promotes regular exchange between local utilities and other key stakeholders, and develops case studies on alternatives forms of energy supply in new urban development schemes. This initiative has frequently led to the construction of new CHP plants or connections to existing district heating networks[45].

In the UK, changed district heating policy may have created uncertainty and perceived risks for local government and the commercial sector[46]. UK grant programmes have triggered some development activity, but low industry confidence in future support schemes meant investment in skills or supply chains was not triggered – instead, prices and lead times for specialist consultancy services were temporarily driven up[47]. As

[43] (Department for Energy & Climate Change 2016)

[44] (Department for Energy & Climate Change 2016)

[45] (UNEP 2015)

[46] (Webb et al., 2014)

[47] (Hawkey, 2012)

with investment subsidies, the way ongoing financial support is administered can impact on its effectiveness. In Germany, a recent review of the bonus payments for electricity from CHP included the amount and duration of payments being decided in advance of construction for projects over 10MWe. Previously, projects had to be completed before payments began and uncertainty over whether payment levels would change before project completion reduced willingness to invest[48].

[48] (Gailfuss, 2016)

Table 6. **Policy applicability - Germany**

Policy	Effectiveness	Efficiency	Feasibility
German Energy Saving Ordinance (EnEv)	These building regulations have the advantage that they consider primary rather than end use energy, so they account for the efficiency benefits of DH from CHP or renewables.	The ENEv has led to a decrease in heat demand over time, while the level of heat demand has become less certain due to regular changes in the legislation.	Heat consumption in residential buildings fell by 20% from 2000 to 2012 but, assuming that this trend continues, the refurbishment rate of buildings will need to increase by 2% per annum in order to achieve the 2020 Energiewende targets for residential heat consumption.
Market Incentive Programme (Marktanreizprogramm)	In 2016, €190 million of grants from the Ministry for Economy and Export Control (BAFA) supported the deployment of 28,000 solar thermal systems, 28,300 biomass boilers and 11,300 heat pumps.	500,000 to 600,000 heating systems are refurbished each year, but 90% of the refurbished systems are fossil fired systems. This may lead to a lock-in effect until at least 2030.	Support for renewable heat increased from 2015. Offers €300 million per year as grants or low interest loans, but this represents a fraction of the €25.4 billion of support for renewable electricity under the German Feed-In Tariff.
Federal Renewable Energies Heat Law (EEWarmeG)	In 2011, 60% of new heat pump installations and 66% of new biomass central heating systems were in new buildings. Nevertheless, the renewable heat and energy efficiency laws could benefit from more integration, and Federal policy aims to harmonise them.	The EEWarmeG requires heat pumps to have a minimum seasonal performance factor (SPF) of between 3.3 and 4 (varying by heat source and depending on whether domestic water heating is included).	The EEWarmeG has increased connections to district heating, which were in decline before. However, the market growth of renewable heat has been constrained by slow rates of construction of new buildings.
Energiewende	The Energiewiende has not really penetrated the existing building stock. Around 90% of annual refurbishments are still fossil fuel.	2050 target cannot be achieved with the current mix of policies such as the market incentive programme and building regulations.	Improved regulation under the Energiewende in 2012 set out to address the problem of split incentives between landlords and tenants. However the split incentives issue has not been resolved sufficiently, particularly given that approximately half of flats in Germany are not owner-occupied.

Source: Vivid Economics

2 Sweden

Sweden has a significant endowment of biomass resources, and biomass is a dominant source for heating, while Sweden's abundant hydro resources have historically been used for electric heating. Key technologies for supplying heating in buildings currently include district heating and heat pumps. There are lessons to learn for the UK from Sweden's dual transition – from oil and electric heating towards heat pumps, and from the use of fossil fuels in district heating towards the use of biomass and waste.

In summary:

- The limited access to gas means that heating and cooling options for Sweden use electricity, renewables and oil.
- It is on track to phase out fossil fuels in heating by 2020.
- Almost one in three households in Sweden have a heat pump, which works well in the cool climate due to highly efficient building stock.
- The heat pump market initially struggled due to technical issues. In recent years, uptake of heat pumps is a result of the carbon tax, subsidies, product standards and quality assurance measures. Heat pumps have also fallen in cost, are now cost effective and receive no direct support.
- Challenges have included poor heat pump performance (overcome by new quality controls), inefficiency of heat pump subsidies and the impact of heat pumps on peak electricity demand.
- Most of the district heating infrastructure was built in the 1970s, prior to liberalisation, but was predominantly supplied by fossil fuels. Sweden has experienced significant diversification and decarbonisation of fuels sources in the last 25 years, and now mainly uses biomass and waste incineration.

2.1 Implications of archetypes for the heating and cooling transition

In order to understand the heating transition in Sweden it is important to consider the following:

<u>Endowment and infrastructure</u>

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. In single family houses in 2015, biomass and electricity (including heat pumps) accounted for approximately three quarters of heating and hot water consumption. In multi-family houses and non-residential premises, district heating is by far the dominant source of heating and hot water.

Sweden produces no natural gas and has a negligible number of households connected to gas. In 2014, Sweden imported just 9.7 TWh of natural gas[49]. Prior to the shift to district heating, biomass and heat pumps, Sweden relied on oil and direct electric heating to a large degree. The first Swedish district heating development was in operation in 1948, but more rapid development of district heating began in the 1960s. At this time the main motivation for development was efficient electricity production from CHP, and an additional motivation was to improve air quality (by controlling emissions at a few points rather than at individual boilers, and using taller chimneys). High taxes on oil were introduced following the 1970s oil crises, and contributed to a major shift from oil CHP to alternative heat sources including coal, municipal solid waste incineration, heat pumps, and industrial waste heat. 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. Much of this inefficient form of heating has now been replaced by heat pumps and district heating.

There were approximately 4.8 million dwellings in Sweden in 2015 (a much lower number than in the UK), of which 51% were single-family dwellings and 47% multi-family dwellings. In comparison to other European countries, Sweden has a particularly large proportion of its housing stock in the socially-rented sector (approximately 40%) with an additional 46% being owner-occupied homes. 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. In the UK, a mid-terrace house built before 1920 has an average heating consumption of 305 kWh/m^2/year, compared to 268 kWh kWh/m^2/year for a 1980's detached house and 103 kWh/m^2/year for a mid-terrace house built after 2002.[50] The UK housing stock is also older than in Sweden. Approximately 21% of the UK's housing stock was built before 1919, and 38% before 1946. In Sweden, around a quarter of the housing stock was built before 1946, while 40% was constructed before 1961.

Market liberalisation

There is a market based approach to electricity (since electricity market liberalisation in 1996) but there is still a widespread use of centralised infrastructure for heat. Most of Sweden's district heating networks were developed under municipal ownership from the 1950s to the mid-1990s. In 2015, most of Sweden's 170 district heating companies were still municipally-owned. District heating is considered to be a natural monopoly and the market is regulated by the District Heating Act. De-regulation of prices following energy market liberalisation led to protests from consumers who argued that district heating operators were then in a position to take advantage of operating as a natural monopoly; this has triggered two government investigations[51]. In 2005, Reko quality certification was introduced, followed by the District Heating in 2008 in order to increase consumer confidence and raise pricing transparency. The Swedish District Heating Association (SDHA) was established in 1949 and has an important role in setting technical standards for performance (e.g. of pipes) and

[49] (Eurogas, 2015)

[50] (Buildings Performance Institute Europe 2011)

[51] (Onate, Kessels, and Six 2014)

interoperability between different components in district heating systems[52]. The SDHA acted independently until 2016, when it became 'Swedenergy' following a merger with the national electricity supply and distribution association[53].

Heating profile

Sweden is temperate in the south and subarctic in the north, and therefore differs in part from the UK which is in a temperate region. Recent building regulations in Sweden set out restrictions on air/water heat pumps, which may only be installed in new buildings in the southern part of the country as a result of their impact on peak electricity demand. There are no such restrictions on air/water heat pumps being installed throughout the country in retrofit buildings.

2.2 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 once 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 (Figure 6). In single family homes, oil heating declined from around 9 TWh of total energy consumed in this household type in 2002 to 1 TWh 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.

Almost one in three households in Sweden have a heat pump: the total stock of heat pumps was 1.5 million in 2015 compared to a total of 4.8 households[54]. The share of **heat pumps** supplying one or two family dwellings is 52% - equivalent to 1 million heat pumps. Air to air heat pumps with a heating function accounted for 53% of the total of 103,000 heat pump sales in residential and non-residential buildings in Sweden in 2015, with most of the remaining sales accounted for by brine-water heat pumps (26%) and exhaust air heat pumps (13%). Heat pumps have mainly replaced oil boilers, direct electric heating and electric boilers.

Sweden is a leading European market in the deployment of heat pumps. Air-to-air heat pumps are the most cost-effective option for replacing direct electric heating in existing dwellings. Air-to-air heat pumps are also used in small shops, offices and restaurants, while there has also been a recent trend towards their installation in holiday homes. Air/water heat pumps typically replace boilers and are more commonly installed in the south of Sweden where the climate is more temperate. Ground source heat pumps are mainly comprised of vertical systems, with horizontal systems constrained due to their substantial space requirements[55].

[52] (Ericsson 2009)

[53] (Werner 2017)

[54] (EHPA, 2016)

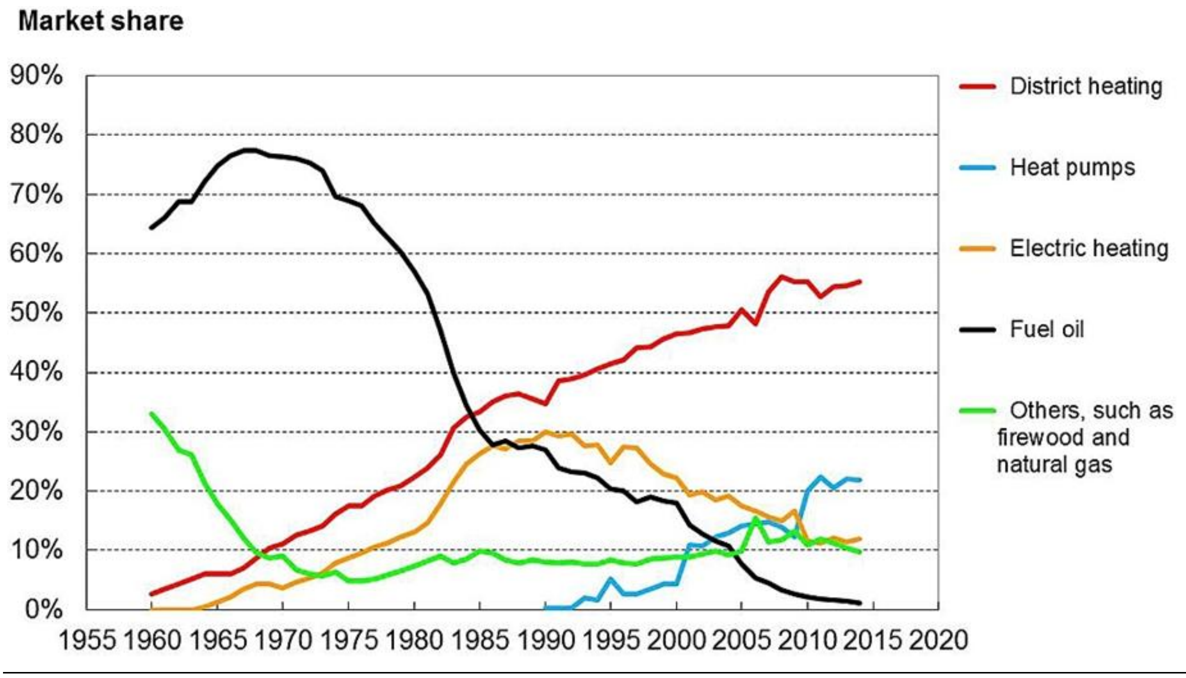
[55] (EHPA 2014)

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.

Despite its relatively cold climate, Sweden is the leading supplier of **district cooling** in the EU, delivering 1TWh of cooling in 2015. One factor that has driven demand for cooling has been a growth in the construction of new buildings in dense urban areas well suited to district cooling networks. The length of the district cooling network in Sweden has increased from around 400km in 2006 to 500km in 2013.

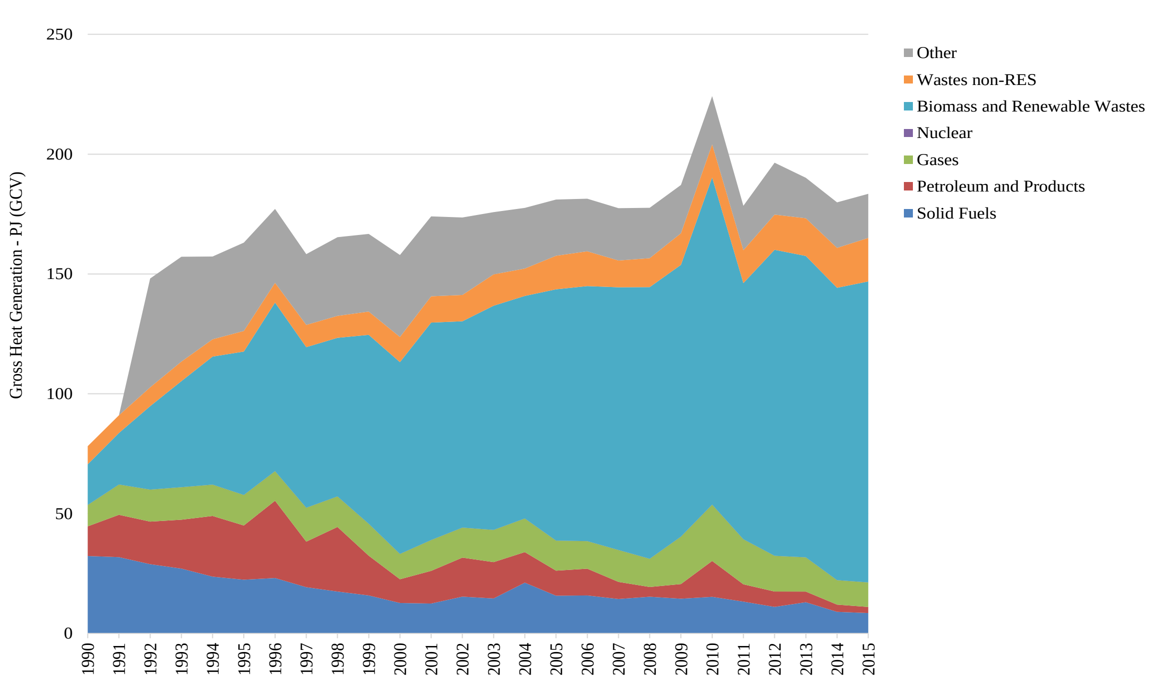
High end-use energy prices in the 2000s, principally due to the rising level of carbon tax, led to many households making energy efficiency improvements such as more effective insulation or energy efficient windows. Between 2002 and 2015, total energy consumption of heating and hot water in the residential and service sectors decreased by an average of 1% per year.

Figure 6. **Market shares for heat supply to residential and service sector buildings in Sweden**



Source: Werner (2017) District heating and cooling in Sweden. Energy, 126, p.419-429

Figure 7. **Fuel mix: heat production (heat sold), 1990 to 2015, Sweden**



Source *EU Commission 2017: Energy datasheets*

2.3 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. However, Sweden now provides no specific financial support for renewable heating in buildings – relying instead on carbon and energy taxes.

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 was available at a higher rate (with a higher upper grant limit) than the oil heating replacement subsidy, due to the additional costs of installing central heating. 80% of the subsidies awarded for electric heating replacement in any residential building were for a shift 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 subsidy for replacement of oil boilers had high and rapid uptake, so that by March 2007 all of the 450 million SEK that had been allocated to this subsidy for the period 2006-2010 had been used up. This subsidy has also been criticised for poor cost-effectiveness, due to high administrative costs and because replacing oil heating was profitable even without the subsidy due to ageing oil boilers, high oil prices, energy and carbon taxes[56].

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.

More recently Swedish building codes 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[57].

[56] (Ericsson, 2009)

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

Table 7. **Analysis of key policies - Sweden**

Variable	Incidence	Modality	Duration	Complementary measures
Carbon tax	Payable on each kg of CO_2, except for biomass and peat (with reductions on district heating plants under the EU ETS). Different rates of CO_2 tax for residential sector and industry	Taxation on fossil fuels; exemption on renewable electricity and CHP plants which are part of EU ETS	1991 – 2017 (ongoing)	Energy taxes; investment subsidies for biomass CHP; tradable electricity certificates for biomass CHP
Consumer subsidies to replace oil and direct electric heating	Residential properties	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	2006-2010	Carbon tax / energy taxes
Investment subsidies for biomass CHP	Biomass CHP plants	Investment subsidies for retrofitting of fossil-fired CHP plants and district heating plants (into CHP).	1991-1996; 1997-2002	Tradable electricity certificates for biomass CHP; carbon tax / energy taxes
Tradable electricity certificates (TRECs) for biomass CHP	Biomass CHP plants	Market-based certificates for renewable electricity generated from biomass CHP	2003 – 2013 (certificates time limited for some plants after 2013)	Investment subsidies for biomass CHP; carbon tax / energy taxes

Source: *Vivid Economics*

2.4 Innovative aspects and solutions

The heat pump market collapsed in the mid-1980s in part due to declining oil prices, but also due to the ending of government subsidies for residential heat pumps, the compromised reputation of heat pumps due to poor technical standards, and a slowdown in the construction of new homes. New policy instruments were implemented in Sweden in the late 1980s / early 1990s which focused on technical improvements and increasing quality assurance.

As one of a number of mechanisms to improve quality assurance, in 1989 Sweden set up the VPN - an independent complaints board or 'Heat Pump Court' to address litigation cases relating to the false claims of installers about heat pump performance. The VPN is run by the Swedish Heat Pump Association and allows customers to bring a claim directly against installation companies if heat pumps are perceived to underperform relative to expectations. Installers found to be 'guilty' are required to resolve the problem and a small court fee paid by the customer. More than 500 complaints have been dealt with through the VPN, which in recent years handles around 40 cases per year. It has been estimated that customers win around 60% of cases, with 90% of these being the result of problems with installations rather than products. Court decisions on cases are made public so that companies linked to substandard installations are effectively 'named and shamed'. In addition to helping to raise consumer confidence, the heat pump court has incentivised manufacturers to monitor the standards of installers who fit their products, while also encouraging installers to improve the quality of their installations to meet consumer expectations.

A procurement programme was launched in Sweden by NUTEK (Swedish Agency for Economic and Regional Growth) in 1993 to develop and commercialise innovative ground source heat pumps. In cooperation with a group of purchasers and specialists, NUTEK developed the requirements for a competition to procure technically advanced heat pumps which were 30% cheaper and 30% more efficient than existing heat pumps on the market. NUTEK invited manufacturers to enter prototype heat pumps into the competition which met these requirements, with the buyer's group agreeing to purchase at least 2,000 units of the winning model. Prototypes and whole heating systems were also independently tested by third-parties to ensure the competition was transparent; a quarter of the budget of the procurement programme was dedicated to free tests of prototypes for competitors and product certification. Additionally, half of the budget of the NUTEK programme was assigned to information dissemination activities, while the programme was also linked to investment subsidies for heat pumps. The effectiveness of this procurement competition can be expressed through the doubling of Swedish heat pump sales from 1995 to 1996.

2.5 Outstanding challenges

Sweden has ambitious climate targets relative to other EU countries, with the Swedish Climate Roadmap 2050 setting out targets, scenarios and policy proposals to reach zero net greenhouse gas emissions by 2050. In 2016, the main political parties reached an Energy Framework Agreement on Sweden's long-term energy policy goals and measures. This agreement emphasises the need for a cost-effective district heating sector and lower electricity consumption for the renewable supply of heat, in particular during cold winter days. The heat market is saturated due to high standards of energy efficiency and decreasing energy demand. The business case for some district heating systems is weakened by low heat demand.

Cost-based pricing for district heating was mandated up until energy market liberalisation in 1996. Supply from different district heating systems could be priced differently based on technical factors affecting cost, but district heating companies were prohibited from making a profit. Following energy market liberalisation, price was no longer regulated and municipal or private companies have sought different levels of annual return, which can explain some of the significant variation in tariffs between different systems. For example, in the early 2000's, some utilities supplying district heating (Fortum in Stockholm and Vattenfall in Uppsala) increased prices by 13% - 17% in particular years, while other district heat suppliers did not increase their prices during these years. This has caused some controversy since district heating represents a natural monopoly, and although customers are free to switch to alternative heat technologies some argue that the presence of the existing network creates a lock-in effect that effectively prevents them from doing so.

In 2005, the ‘Reko’ district heating quality certification aimed to increase consumer confidence in district heating following liberalisation, and included pricing transparency. In addition, a new District Heating Act came into force in 2008, mandating transparent pricing, setting out contract conditions, and introducing an independent District Heating Board to mediate disputes between customers and suppliers[58].

The Swedish heat pump market is now considered to be mature, with at least one in two homes in Sweden fitted with a heat pump. Heat pump technology has received recognition and acceptance by the general public over many years. The market is now aiming at sales to ‘late majority’ consumers: sales to single-family dwellings are levelling off, but there is an increasing interest in selling heat pumps for installation in multi-family homes and commercial buildings.

2.6 Applicability to the UK

Sweden has achieved 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, and willingness to invest for relatively low rates of return. In the majority of cases, investment subsidies were not involved in the extensive development of district heating seen in Sweden. Municipalities’ responsibilities and powers regarding heat planning have decreased following energy market liberalisation, and heat planning has become less widely used.

In Sweden, the uptake of heat pumps has been facilitated by the abundant, 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, notwithstanding the impact of the increased deployment of heat pumps on peak electricity demand.

District heating and heat pumps were deployed in the absence of extensive natural gas heating, whereas 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. However, the drivers for the development of district heating in pre-liberalisation Sweden were not related to decarbonisation

[58] (Ericson, 2009; Werner, 2017)

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 prices/taxes – which the UK public might not be willing to accept – and it is also important to consider the impact on vulnerable consumers.

Table 8. **Policy applicability - Sweden**

Policy	Effectiveness	Efficiency	Feasibility
Carbon tax	Supported a shift away from fossil fuel heating for individual homes to district heating and heat pumps. High taxes have resulted in a transition from heating oil to biomass as a fuel for district heating.	The carbon tax has more than tripled from a standard rate of $44 per metric ton of CO_2 in 1991, to $168/t$CO_2$ in 2014. Sweden has had the highest average annual natural gas price for any country in the EU over the last decade.	Facilitated by public acceptance of high energy prices/taxes – which the UK public might not be willing to accept – while a carbon tax could also have adverse impacts on vulnerable consumers.
Consumer subsidies to replace oil and direct electric heating	Heat pumps were the most popular replacement and connection to district heating accounted for around 20% of the subsidy. A subsidy to replace direct electric heating in any type of home was available at a higher rate, due to the additional costs of installing central heating, and lead to approx. 80% shift to district heating, although with significant variation between regions depending on local feasibility.	A subsidy for replacement of oil boilers in one or two family homes had high uptake and resulted in more rapid replacement, but has been criticised for poor cost-effectiveness.	Many biomass pellet burners installed through this subsidy scheme failed to meet customer expectations, largely due to malfunctions or poor performance. More recently, an increasing number of these pellet systems have been replaced by heat pumps.
Investment subsidies for biomass CHP	Aimed to increase biomass CHP generation and driven by planned closure of nuclear generators. Relatively small direct impact on national electricity generation, but may have helped to raise the profile of CHP.	The investment subsidies were a response to the energy taxation system which favoured biomass use in heat production over that in electricity production.	Biomass-based electricity production was not economically competitive during the period of the subsidy due to low electricity prices. Several new biomass-fired CHP plants were built, but the subsidy made only a small contribution to Swedish electricity production of approximately 0.8 TWh/year.
Tradable electricity certificates (TRECs) for biomass CHP	A survey of the energy companies and forest industries indicated that TRECs were often most important factor in decisions to invest in CHP. TRECS resulted in an increase in CHP for DH, which previously decreased after the development of nuclear generation.	For some plants there was a time limit for obtaining certificates in 2013, resulting in a subsequent increase in CHP from plants which do not receive certificates.	The scheme has been linked to a significant increase in biomass-based electricity production. Between 2002 and 2007 total annual biomass electricity production increased from 4.3 to 9 TWh/year.

Source: Vivid Economics

Box 2. **Interview evidence – Senior Advisor Energy and Circular Economy, Division Built Environment, Research Institutes of Sweden (RISE)**

Sweden's heat pump transition was supported by technical standards, research and development support, information provision and a stable policy environment. The first wave of heat pumps happened in 1980s when the technique was still non-mature and people had low confidence, and the second wave in the 1990s which was more successful in uptake. Stable policy environment was the most important factor for this success. Along with this, technical standards for heat pumps, quality schemes, good information to consumers and research and development also supported the heat pump uptake. For example, the Swedish Energy Agency wanted to bring research institutes, universities and industry together to provide research and development support. There has been several R&D Programmes under the umbrella of the Swedish Energy Agency in the field of heat pumping technologies since 1995. The Programme involves RDD&D and the aim has been to bring the different actors together. The programme has contributed to innovation and improved collaboration. The collaboration between the Swedish heat pump association and the actors in the innovation chain has also been important. The Swedish Energy Agency has regularly initiated tests of technologies and posted results on its website to give consumers independent and reliable information about energy savings from heat pumps, as well as the noise and other important aspects to make it easy for the consumers to select a product.

Taxes for fossil fuels have also been an important factor in heating transition.
The price for electricity in comparison to oil has had large influence on the market uptake of heat pumps on the market.

After R&D, heat pumps now work well in cold climates. Development of technological components, systems and control of the heat pumps have improved efficiency. This was helped by the procurement competition and the SEA programme. Both air source and ground source heat pumps now cover the coldest days in Sweden. The continuation of the RDD&D Programme has been important with an aim to bring researchers and industry together and other actors in the value chain.

The loan programme around 1990, combining heat pump loans with energy efficiency, was less important. In order to get a loan, consumers needed to prove that their homes had a certain level of efficiency. The support level was quite low for this programme. Later there has been some subsidiary and tax reduction programs connected to the investment and installation of heat pumps. To some extent they have stimulated the market over time, but they have not been crucial. The stable support for the industry and the technology have been more important and has resulted in the development of heat pump market. This include RDD&D programmes, regular testing and publishing of data a dialogue between policy makers and industry in connection to the introduction of new directives and regulation on both national and European level. Heat pumps are now competitive, and have been so for a long time. Consumers could increase their mortgage to take out a targeted loan for a heat pump investment, this increases the value of the property as they don't have to pay the carbon tax and reduces the heating cost for the building. Ground source heat pump installations now cost around 120,000 SEK (11k GBP), air source heat pumps around 100,000 SEK (9k GBP) and air to air around 20,000 to 30,000 SEK (2-3k GBP).

What about the impact on the grid?

Heat pump deployment has increased, but not the overall electricity consumption as Sweden has rolled out other efficiency measures same time and this has offset the increase. Efficient lighting is one part of the explanation, but even more important is that the heating system in buildings with direct electricity heating have been replaced with heat pumps which has for each building contributed with energy savings of at least 50% for each building.

In addition more or less all buildings using oil is retrofitted, to a large extent with heat pumps, which has contributed to both decarbonisation and increased energy savings.

3 Japan

Japan is classified as a low endowment archetype and has a mix of fuels used in heating. Japan's ambitious efforts to commercialise hydrogen fuel cells on a large scale in the heating and cooling sector map provide lessons for the UK. Energy security, economic efficiency and environment plus safety (3E+S) are emphasised as the three pillars of Japan's national energy policy by the Ministry of Economy, Trade and Industry (METI), which oversees energy generation in Japan. Japan has also experienced interesting developments in the new building of housing stock and energy efficiency codes with important implications for space heating and cooling.

In summary:

- Japan experienced a radical shift away from low carbon nuclear energy following the 2011 Great Earthquake and Fukushima Daiichi nuclear disaster resulting in a heavier reliance on fossil fuels than predicted in the 3rd strategic energy plan (2010).
- Japan's 4th strategic energy plan (2014), overseen by the METI sets forth a three-phase road map to realising a 'hydrogen society' while also increasing energy efficiency requirements.
- Japan has successfully developed a commercial hydrogen fuel cell (ENE-FARM) able to provide hot water, electricity and sometimes space heating to homes and businesses.
- Stringent energy efficiency regulations combined with government energy efficiency R&D finance dating back to the 1970s have contributed to Japan's leadership in energy efficiency.
- Japan has recently liberalised both its electricity and gas retail markets, although the result of liberalisation has been mixed due to regional grid interconnectivity issues.

Following the 2011 earthquake and nuclear accident, Japan has supplemented the decline in the national share of nuclear energy generation with natural gas and oil imports resulting in a larger national carbon footprint, increased energy dependency and a balance of trade deficit. New policies and technologies are being pioneered by Japan to address this development.

3.1 Implications of archetypes for the heating and cooling transition

Endowment

Japan has one of the least favourable energy endowments of any developed country. Partially as a result of this, Japan has become a leader in energy efficiency by improving the energy efficiency of its economy by 40% over the last 40 years. Japan's 2013 energy self-sufficiency rate (the ratio of energy sourced from domestic resources) was only 6%. In terms of renewables, Japan lacks a large natural endowment in hydro (1.7% of TPES), is striving to expand its nascent solar and wind generation (0.8% and 0.2% of TPES respectively) and is in the process of rethinking its nuclear energy generation (0.6% of TPES) following the 2011 Great Earthquake.[59] Due to this unfavourable endowment and the shift away from nuclear energy, the Japanese government places special emphasis on technologies that reduce dependence on foreign and specifically

[59] (International Energy Agency 2016a)

volatile Middle Eastern sources of energy. Also faced with recurring natural disasters, resilient technologies, such as hydrogen fuel cells and district heating and cooling that can function if severed from the electric grid, are particularly prized.[60]

Infrastructure

In contrast to the UK, Japan has a high demolition rate resulting in a relatively new building stock. Only one dwelling in four was built before 1980 and only 2% were built before 1950. Occupied dwellings in Japan increased by 11.4 million units to 52.2 million dwellings from 1993 to 2013 while total floor area increased by 4.9 billion m^2. Japan has a high rental rate of 62% entailing potential principal-agent challenges for energy efficiency investment.[61] In further contrast with the UK, Japanese homes also generally lack central heating.

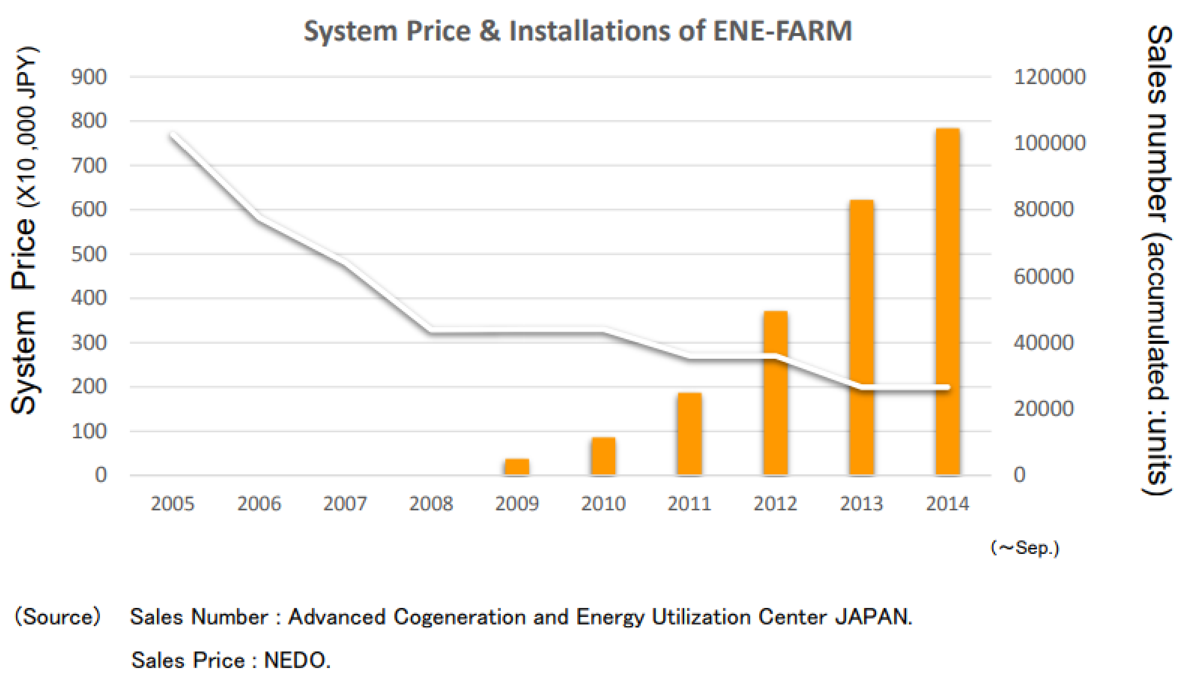
Japan's large and densely populated cities make Japan suitable for large scale district heating and cooling (DHC) development. There are currently 77 companies operating 139 DHC systems throughout Japan. DHC was first introduced in Osaka in 1970 and experienced a rise in popularity in the 1990s. As of March 2014, Japan had 10,046MW of mostly gas cogeneration capacity, of which 2,073MW was for residential and commercial use while the remainder was for industrial use.[62] The promotion of cogeneration has benefited from subsidies provided by the City Gas Promotion Centre and is specifically highlighted in the 4th strategic energy plan.[63]

Japan is the world's largest LNG importer and Japan's city gas market consumed 37bcm of natural gas at the end of fiscal year 2014 (April 2014 to March 2015). The household sector consumed 9.6 bcm (26%) while the commercial sector consumed 4.2 bcm (11.6%). Pipelines supply city gas to 30 million commercial and residential (28 million) users (54% of residential dwellings).[64]

Japan leads the world in fuel cell adoption and began commercial sales of the ENE-FARM brand micro-combined heat and power (CHP) hydrogen powered fuel cell in 2009. As of July 2017, 200,000 residential hydrogen fuel cells have been installed and the government is targeting fuel cells to be in 5.3 million dwellings (one in ten) by 2030[65] as part of the 'hydrogen society' initiative and 4th strategic energy plan.[66] Japan plans to showcase its hydrogen technology prowess during the 2020 Tokyo Olympic Games with a fleet of 100+ fuel cell buses. Prominent supporters of hydrogen include Japanese Prime Minister Abe who declared, 'Hydrogen energy is an ace in the hole for energy security and measures against global warming. Thanks to deregulation, a hydrogen society of the future is about to begin here in Japan.'

[60] (Okuya 2014)
[61] (International Energy Agency 2016a)
[62] (International Energy Agency 2016a)
[63] (Okuya 2014)
[64] (International Energy Agency 2016a)
[65] The Japan LP Gas Association cites a more conservative 2.5million dwellings estimate (Japan LP Gas Association 2017)
[66] (International Energy Agency 2016a) and interview evidence.

Figure 8. **Installations of ENE-FARM**



Source: (Hashimoto 2015)

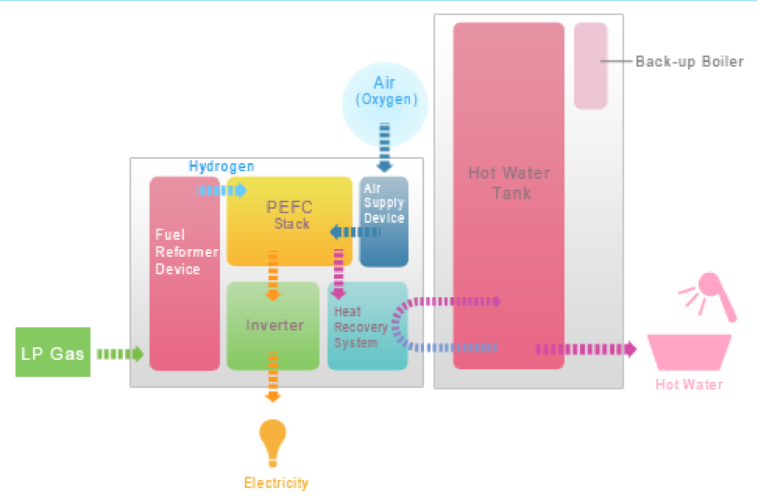
Despite being the most abundant substance in the universe, strictly speaking, hydrogen is only considered a renewable resource when produced from renewable power sources such as wind or solar. Japan plans to produce hydrogen from emission free sources by 2040.[67]

[67] (Watanabe 2017)

Box 3. **What is ENE-FARM?**

The ENE-FARM brand of Micro-CHP is a collaborative effort of Panasonic, Toshiba and Eneos (a joint venture between JX Nippon Oil & Sanyo).[68] ENE-FARM is a 700W cogeneration system for households that is attached to the gas grid and has dual fuel source adaptability (natural gas and LPG). The fuel is humidified and mixed with ambient oxygen to extract the hydrogen. ENE FARM can meet about 60% of typical household electricity demands and can be combined with solar to meet higher demand in a combination known as 'double generation' (Japan LP Gas Association 2017). The ENE-FARMs are 95% total energy efficiency and come with 10 year warranties to encourage adoption. They have no moving parts and do not use combustion to create energy. ENE-FARMS fuel cells are proton exchange membrane fuel cells (PEMFCs). PEMFCs are the same type of fuel cell as used in automobiles and are distinguished by their polymer electrolyte membrane often made of the precious metal platinum. They require high fuel purity in exchange for being able to operate at lower temperatures than solid oxide fuel cells (SOFCs). The high capital cost of the ENE-FARM system is offset by lower running costs than a comparable gas system. ENE-FARMs emit approximately 49% less CO_2 (not including embedded energy costs in the construction of the ENE-FARM or fuel delivery) than conventional thermal power from electricity and hot water from city gas generation.[69] ENE-FARMS also have countercyclical energy generating properties in relation to the electric grid as a result of their ability to smooth power demand by producing power during periods of peak consumption.[70]

Figure 9. **Operation of ENE-FARM -a residential micro-CHP fuel cell**



Source: *Japan LP Gas Association, 2017*

Market liberalisation

In response to the challenges of idling Japan's nuclear energy, high energy prices and to achieve the government's goals of increased energy market interconnectedness, efficiency and competition, liberalisation of the electricity retail market took effect in April 2016. As a result, 820,000 consumers decided to change their electricity supplier by the end of April.[71] Overseen by the Electricity and Gas Market Surveillance Commission (EGC), a sub-division of METI, 260 businesses entered the Japanese electricity market to offer new pricing schemes and services.[72]

In April 2020, the unbundling of the transmission and distribution components of electric power grid from the generation and retail segments is planned in order to further liberalise the market and to promote competition. The EGC is tasked with ensuring equal access to electricity network infrastructure before and after the unbundling takes place. Completing Japan's paradigm shift in the energy market, Japan's smart metering initiative is expected to be complete by 2024 to enable dynamic pricing.[73] Smart meters will encourage active consumer participation that is expected to further reduce energy usage in space heating and cooling.

Although these developments work to ensure the de jure liberalisation of the market, the de facto operation of Japan's electricity network is hampered by the lack of interconnectivity between Japan's 10 fragmented regional electricity markets. The IEA describes the situation as 'ten vertically integrated geographical monopolies'. This lack of network price integration and transmission interconnectivity hampers the utilisation of wind and solar renewables that could be more efficiently sourced for cooling needs. The Organisation for Cross-Border Coordination of Transmission Operators (OCCTO) was formed in 2015 in an effort to increase co-ordination between the 'ten geographical monopoly' service areas. As of 2016, the wholesale price of nine interconnected prize zones is available. Despite these efforts the electricity wholesale market still suffers from illiquidity.[74]

In April 2017, the retail gas market was also fully liberalised to increase competition and interconnectivity of Japan's gas grid. Improved third-party access to pipelines and LNG terminals is expected to follow. This is part of a broader Japanese strategy to develop a more flexible international LNG market complimented by the envisaged introduction of a major LNG trading hub in Japan. Results, implications and remaining challenges from this liberalisation are not yet clear. However, liberalisation combined with massive quantities of cheap natural gas on the global hydrocarbon market, partially as a result of the technological advances in natural gas extraction in the United States, offer the potential for Japanese consumers to see lower heating prices with lower carbon costs (at least compared to coal). However, the lack of a gas wholesale market still looms as an impediment to functionality and achieving a complete gas market liberalisation.[75]

[68] Toshiba withdrew from the ENE FARM market in June 2017. This was a result of its refocusing of resources following the heavy losses Toshiba incurred on behalf of its Westinghouse nuclear power subsidiary. Toshiba continues its pure hydrogen fuel cell systems business (Toshiba 2017), (Dodds et al. 2014).
[69] (Tokyo Gas Co. Ltd. and Panasonic Corporation 2013)
[70] (Dodds et al. 2014)
[71] (International Energy Agency 2016a)
[72] (Japan Electricity and Gas Market Surveillance Commission 2016)
[73] (International Energy Agency 2016a), (Kossoy et al. 2015)
[74] (International Energy Agency 2016a)
[75] (Tsukimori 2017)

Heating profile

Japan varies from a cool humid continental climate in the northern island of Hokkaido to a tropical climate in the south. 54% of Japan's residential energy use is for heating and cooling. Electricity demand peaks in July and August as a result of increased air conditioning. The exception is in Hokkaido when electricity demand peaks in winter from space heating. The government in collaboration with electricity companies has historically promoted electricity saving during peak seasons to smooth electricity consumption and reduce electricity grid strain. These efforts were redoubled after 2011 to avoid the possibility of blackouts as a result of the idling of nearly all Japanese nuclear energy plants.[76]

3.2 Decarbonisation trends in the last 10-15 years

As a result of the 2011 Great Earthquake and nuclear disaster, from 2010 to 2013 annual carbon dioxide emissions from power generation increased by one-fifth or more than 110 million tonnes (Mt). This occurred in conjunction with import dependence rising to 94% from 80% of TPES in 2010, which has provided additional impetus in Japan for finding domestic renewable sources of energy production.[77]

Japan met its 6% reduction in GHG emissions from 2008 to 2012 under the Kyoto Protocol and intends to reduce GHGs by 26% from FY2013-FY2030 as part of Japan's INDC to the Paris Climate Accord. Japan's 'Plan for Global Warming Countermeasures' increases carbon cutting measures across all sectors in order to meet the 2030 target. The plan also includes a gradually increasing the carbon tax from which proceeds will go to reducing CO_2 emissions.

Japan has taken an overall approach to reducing carbon emission by increasing energy efficiency. Japan's focus on reducing carbon emissions has been particularly effective in the transportation and building efficiency sectors. Nevertheless, initiatives are still in place to specifically target the space heating and cooling sectors with additional support outside of regulatory energy efficiency codes.[78]

3.3 Policy and drivers

The 1979 Act on The Rational Use of Energy, revised in May 2013, is the major legislation designed to implement energy efficient policies in Japan. Amongst other energy efficiency initiatives, it requires business operators to annually measure and report their energy consumption to the government. It also sets energy efficiency standards for residential and commercial buildings. In 2016, the Japanese government updated the act to include wasted heat as a measure of wasted energy under the energy efficiency guidelines. Japanese policy and industry efforts to exploit unused heat sources continue to evolve.

[76] (International Energy Agency 2016a)

[77] (International Energy Agency 2016a)

[78] (International Energy Agency 2016a)

The Top Runner Programme, introduced in 1998 and a subcomponent of Act on The Rational Use of Energy, covers energy efficiency standards for household appliances, equipment, vehicles and building materials (since 2013). The Top Runner Programme has resulted in the reduction of energy consumption of air conditioners by 33% and refrigerators by 43%. The programme covers 70% of household energy consumption including technologies directly related to space heating and cooling such as space heaters, gas water heaters, oil water heaters, electric water heaters, and multi-paned glazing.[79]

METI oversees electricity generation and energy efficiency, including heating and cooling efficiency, in Japan while also being tasked with formulating Japan's Strategic Energy Plans. For example, METI oversees the implementation of the 2015 Act for the Improvement of Energy Consumption Performance of Buildings, which introduced mandatory efficiency standards for large new buildings and new residential buildings (starting 2020). The policy provides financial incentives and performance labelling. METI discloses which businesses are performing 'well beyond the target' and subsector data to highlight best practice. Another outgrowth of the policy rethink following the 2011 Great Earthquake is the planned 'special stage' from 2018 to 2020 of the strategic energy plan that is designed as a reform period for a variety of energy systems, which will also be run by METI.[80]

Home energy management systems (HEMS) and building energy management systems (BEMS) have been promoted by the government since 2011 as a technology that offers real-time information on electricity and gas consumption and cost. BEMS benefit from either a tax exemption equal to 7% of the equipment cost for SMEs, a depreciation of 30% of the acquisition cost or subsidy support for SME energy efficiency and conservation equipment introduction.[81]

Subsidies and loans for renewable heat have been made available to local governments, households and the private sector as well. 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] (JPY 3.5 million [approximately £24,100] if installing solar panels) can be deducted from that year's income tax.[82]

The 4th strategic energy plan includes the adoption of a hydrogen and fuel cell road map:[83]

— *Phase 1 (2014-2025):* Dramatic expansion of hydrogen use with the fully-fledged introduction of stationary and vehicle fuel cells into society.

[79] (International Energy Agency 2016a)

[80] (Okuya 2014)

[81] (International Energy Agency 2016a)

[82] (International Energy Agency 2016a)

[83] (Japanese Agency for Natural Resources and Energy 2014)

- *Phase 2 (2025-2030):* Fully-fledged introduction of hydrogen power generation and establishment of a large-scale system for the supply of hydrogen. This will be accompanied by expanding demand for hydrogen by establishing a secondary energy structure where hydrogen will be added to electricity and heat (gas) existing energy resources.
- *Phase 3 (2040):* Establishment of a zero-carbon emission hydrogen supply system

The rationale for promoting Japan's hydrogen society is influenced by the following national energy priorities that hydrogen fuel cells are able to:

- Increase energy security as a result of various storage and transportation options. Energy derived from LNG is more favourably as a result of the location of LNG imports - only 34% (2012) of LNG imports are reliant on the volatile geostrategic shipping lanes such as the strait of Malacca whereas 83% (2012) of Japanese crude oil imports do (reliance on the strait of Hormuz is approximately the same).
- Lower environmental burden with increased energy efficiency and reduced greenhouse gas emissions
- Increase resilience from distributed energy sources and decentralised energy generation during times of emergency.
- Promote competitive industries and revitalise regional economies

Box 4. **Interview evidence – NEDO**

Japan's hydrogen society initiative is the result of the confluence of energy security concerns, technological prowess, and environmental consciousness in the aftermath of the 2011 Great Earthquake turned nuclear disaster. The hydrogen society is supported by long established institutional actors including METI and NEDO and is designed to reduce energy dependence, increase economic competitiveness and increase the resilience of the Japanese energy system. Hydrogen is used in Japan's secondary energy production along with electricity and heat. The hydrogen society initiative includes stationary fuel cell for industries, fuel cell vehicles and residential micro-CHP.

The commercialisation of ENE-FARMS was accomplished by providing subsidies and leveraging nationally interested parties. City gas providers were incentivised to participate as a result of profit potential and government subsidies while consumers were keen to purchase ENE-FARMS due to the ENE-FARM's energy efficiency, resilience and green attributes. As of July 2017, 220,000 units have been sold and prices have fallen to JPY 1.4 million (£9900) per ENE-FARM with a subsidy of JPY 160,000 (£1130). Prior RD&D financing by the Japanese government also helped facilitate the surmounting of key technological barriers.

Reducing the cost of ENE-FARMs for consumers was crucial for commercial success and resulted from a set of closely aligned policies. The Japanese government provided significant initial hydrogen R&D financing to organisations such as NEDO, while subsidies worked to increase the number of ENE-FARMs sold resulting in economy of scale effects, which further reduced prices.

Future hydrogen society plans remain ambitious. Japan is only in phase one and two of three in the hydrogen society road map. Producing renewable hydrogen via a steam methane reforming process is still in the demonstration stage. Hydrogen cannot yet be distributed through the Japanese gas system and large-scale fuel cell energy generation also remains in the demonstration stage. More RD&D into hydrogen is required, specifically for large scale hydrogen generators.

Establishing a safe, efficient and effective hydrogen delivery system will remain a major challenge for phase 2 of the hydrogen road map. Hydrogen differs chemically from natural gas. Hydrogen is better able to diffuse through existing iron and steel pipes (primarily at pipe joints) resulting in larger distribution losses while also requiring greater pipe pressurisation, which increases the probability of pipe failure.[84] Polyethylene pipes have proven more effective at transporting hydrogen.

Following the 2011 Great Earthquake, the *setsuden* movement, which translates to 'saving electricity', was a nationwide energy efficiency and conservation effort in response to Japan's national energy challenges. In addition to an environmental movement, setsuden arose in response to tight electricity supplies following the idling of nuclear power generation. Part of the rationale for the deployment of smart metering is for the

[84] For an overview of the challenges facing gas to hydrogen infrastructure conversion see: Dodds, P. E. (2013). Conversion of the UK gas system to transport hydrogen. *International Journal of Hydrogen Energy*, *38*(0). https://doi.org/10.1016/j.ijhydene.2013.03.070

government to capitalise on this trend of energy consumption behaviour modification to further conserve energy. Components of the setsuden movement even entailed a renewed interest in a government initiative called 'Super Cool Biz' (begun in 2005) that promotes the modification of clothing to more casual and comfortable styles in order to reduce air conditioning energy usage.[85] Setsuden helped reduce electricity usage by 22GW during the summer of 2011.[86]

Table 9. **Analysis of key policies - Japan**

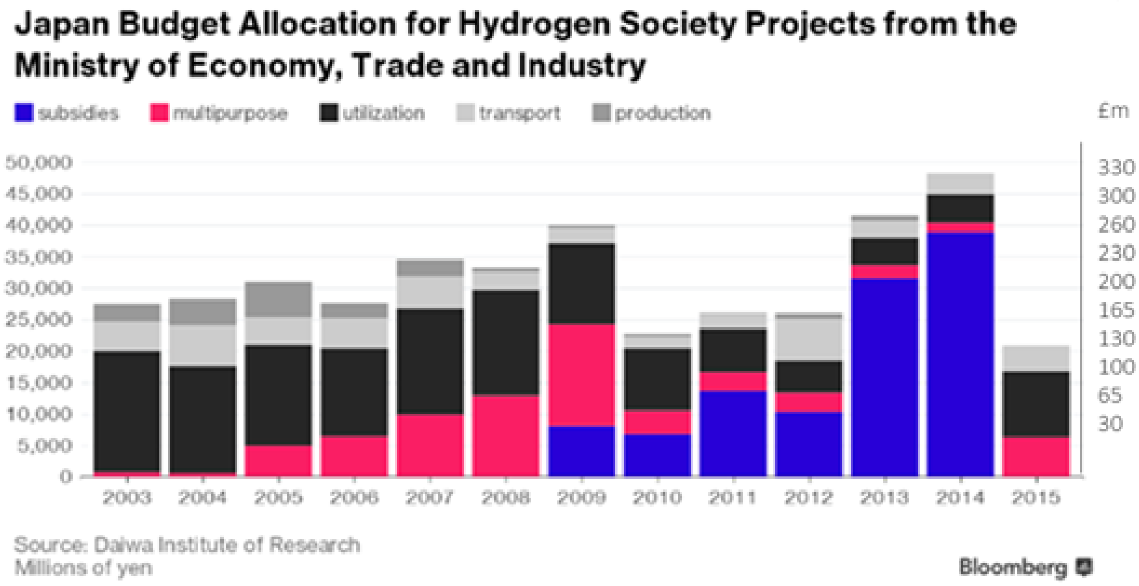
Variable	Incidence	Modality	Duration	Complementary measures
Act on the Rational Use of Energy	Japan-wide	Energy performance requirements	1979, modified 2013	Setsuden
Top Runner Programme	Appliances, equipment, vehicles and building materials	Energy efficiency requirements	Introduced 1998	Hydrogen society initiative
Subsidies & Tax Incentives	Residential, commercial industry and energy sectors, specific focus on SMEs	Grants for small-scale renewable heat systems; low-interest loans; low-interest loans for industry and district heating	2009	Extensive government R&D spending on energy efficiency, NEDO, initial subsidies for ENE-FARM
Hydrogen Society Initiative	Vehicles, power generation, hydrogen supply system, renewable hydrogen production	R&D, demonstration projects, subsidies, studies, promotion	2015-2040	4th Strategic Energy Plan

Source: Vivid Economics, based on secondary sources

[85] (BBC 2011)

[86] (International Energy Agency 2016a)

Figure 10. **Budget allocation for hydrogen society projects**



Note: *1GBP = 151.74 Japanese Yen*

Source: *Bloomberg*

3.4 Innovative aspects and solutions

Japan owns 60% of worldwide hydrogen fuel cell patents and continues to be a global leader in energy efficiency RD&D. This is a result of Japan's 30+ years of experience in hydrogen RD&D.[87] Japan's innovations into hydrogen fuel cell micro-CHP technology can be directly attributed to the EUR 200 million per year in government funding for R&D and demonstration projects during the last 10-15 years.[88]

Fuel cell technology R&D has the potential to provide positive spill over effects toward other energy policy initiatives and the economy as a whole. The proton exchange membrane fuel cells (PEMFCs) used in CHP are also used by automobiles and are scalable, which sets them up as a potential energy producing general purpose technology. PEMFCs require higher fuel purity than solid oxide fuel cells (SOFCs), although the higher purity and electrolyte membrane allows PEMFCs to operate at lower temperatures than SOFCS. The New Energy and Industrial Technology Development Organisation (NEDO) is working on a SOFC type fuel cell project designed for large scale commercial power production. NEDO is also involved with research looking into reducing fuel cell platinum use. Platinum production, particularly for PEMFCs, is highly energy intensive and a major bottleneck to further reducing fuel cell prices and embedded energy.[89]

[87] (Hashimoto 2015)

[88] (Dodds et al. 2014)

[89] (Hashimoto 2015)

To potentially supply Japan's envisaged hydrogen society, Japan has also begun conducting research into methane hydrate extraction. Methane hydrate, also known as fire ice, is found in crystal form where ice crystals trap natural methane gas inside. These crystals are the product of unique geological pressures and temperatures that are most often found on the edge of continental shelves. A cubic metre of methane hydrate, when exposed to sufficient heat, releases approximately 160 cubic metres of gas. Methane hydrate's abundance off the eastern coast of Japan in conjunction with its energy intensiveness makes it an attractive potential source to mitigate Japan's foreign energy dependency. The US, Canada, South Korea, India and China are also exploring this hard extract clean burning resource.[90]

3.5 Outstanding challenges

Fuel cells remain a new technology without a developed market and support network both in Japan and globally. Reducing platinum usage in fuel cells is key to reducing overall fuel cell embedded energy and fabrication costs. Increasing economies of scale, which Japan has already achieved with mild success, is important for further reducing costs and increasing product diffusion. Foreign sales offer an avenue for Japanese micro-CHP fuel cell producers to gain additional returns from large sunk RD&D costs. Creating an adequate hydrogen supply system also remains a major obstacle to mainstreaming renewable hydrogen micro-CHP adoption at the household and commercial level. Renewable hydrogen production in itself holds substantial promise, although it has not been proven on a large scale. Additional RD&D is required to realise hydrogen fuel cell potential. Global awareness of fuel cell technology's potential to increase energy system resilience and energy efficiency while reducing carbon emissions is also low.

Japan lacks the appropriate remuneration framework for DHC producers to sell excess electricity on the wholesale spot market.[91] This is likely to increase DHC project uncertainty and reduce investment.

The Japanese electrical grid is still divided between 50 Hz (eastern Japan) and 60 Hz (western Japan) zones. This remains an obstacle to closer electricity grid integration and interconnectivity which is working to hinder the development of a truly national electricity market; as of August 2014, to bridge the frequency difference, there are only three frequency converter facilities. The OCCTO plans to increase the capability of frequency conversion facilities by including one connecting the Tokyo Electric Power Company (TEPCO) and Chubu Electric Power.[92]

3.6 Applicability to the UK

Japan has achieved high levels of success with hydrogen fuel cell technology, however Japan's success is in relation to energy goals (3E+S) that differ from those of the UK. Japan's fairly recent market liberalisation, in contrast to other major developed economies, experienced interconnectivity and integration frictions less

[90] (Okuya 2014), (Anderson 2014)

[91] (International Energy Agency 2016a)

[92] (International Energy Agency 2016a)

relevant to the energy situation in the UK. However, Japan's focus on energy resilience, the promotion of new technologies, cultivation of networks capable of widespread fuel cell commercialisation and the utilisation of the powerful METI offer lessons about how energy policy could be constructed and implemented as a full package of policy actions. In this respect, METI's ability to rapidly reshape the energy system in Japan and plan and execute projects decades in advance demonstrate the importance of proper institutional arrangements.

Although the UK does not benefit from the same sense of national camaraderie following the resulting energy challenges arising from the Great 2011 Earthquake or from being as exposed to foreign suppliers fluctuations, the UK may wish to consider that resilient and diversified multilayer energy systems have additional benefits including smoothing demand peaks and increasing system robustness and energy efficiency. The ability to relatively easily store hydrogen allows the adoption of hydrogen systems where other renewables such as wind and solar have not yet matured. The RD&D and promotional partnerships fostered by METI may also prove advantageous to fostering competitive energy technologies in the UK.

Specifically, in terms of micro-CHP hydrogen fuel cell systems, Europe (including the UK) is expected to lag substantially behind Asia. Dodds forecasts Europe to only have 50,000 micro CHP systems installed by 2020.[93] There is a non-negligible environmental cost to passing up this technology. Residential fuel cells in the UK can reduce carbon emissions by 1-2 tCO_2 each year for the average home. This is in addition to other air pollutants such as carbon monoxide and particulates from gas burning. Hydrogen boilers are anticipated to be less expensive than heat pumps and other alternatives. The UK can also benefit from adopting technologies that can readily plug into existing grid infrastructure, such as micro-CHP systems. These systems can reduce the carbon intensity of the space heating system while requiring relatively less public and private resources than more ambitious projects.

UK fuel cells costs for consumers may be lower than Japan as a result of the UK's feed in tariff (FIT) of 13.23p for each kWh of electricity generated.[94] The FIT tariff for the period 1 July – 1 September 2017 is now 13.95p. FIT support for micro CHP is subject to limitations:

- Only up to 2kW in installed electrical capacity
- Six-monthly 5MW deployment caps
- Contingent tariff degression (reduction) if a cap is hit

Current funding arrangements for the FIT scheme end in March 2019.

Fuel cell technology for micro-CHP already exists at the commercial level in Japan. It may be worthwhile for the UK to explore partnerships with Japanese commercial and R&D firms to obtain access to fuel cell technology. Additional resource could also be deployed to further investigate the feasibility of hydrogen distribution systems and the possibility of the UK adopting its own hydrogen society initiative.

[93] (Dodds et al. 2014)

[94] (H2FC SUPERGEN 2014)

Table 10. **Policy applicability - Japan**

Policy	Effectiveness	Efficiency	Feasibility
Act on the Rational Use of Energy	Japan has reduced the carbon intensity of its economy by 40 percent in 40 years. METI's coordinating ability has helped facilitate policy objectives.	Serves as the umbrella policy to outline economy wide energy efficiency while METI coordinates and implements the policy. The holistic approach has led to fewer unintended consequences - aside from overreliance on nuclear energy	**???**
Top Runner Programme	Energy efficiency codes have been particularly effective at reducing the amount of energy used in space cooling	Promotes competition between businesses to achieve increased energy savings by highlighting best practices	Increasing energy efficiency requirements for water heating, space cooling and space heating is possible. However, this will fail to address energy loss resulting from the old poorly insulated UK building stock
Subsidies and tax incentives	Subsidies for micro-CHP helped achieve economies of scale leading to commercial viability.	Coordination by METI has provided various, yet coherent space heating and cooling incentives that can be tooled to commercial, SME and household needs	Feasible for the UK, although, budget stresses may make additional subsidies for renewables politically difficult
Hydrogen Society Initiative	Japan leads the world in hydrogen fuel cell technology and is the first country with a mass market commercially viable micro-CHP hydrogen fuel cell. This has come at the cost of EUR 200 million per year for the last 10-15 years.	The 95% total energy efficiency rate of the ENE-FARM and its lower price than an equivalent fuel pump makes it a viable technology to reduce space heating energy and carbon costs. It is too early to tell whether the resources poured into hydrogen fuel cell research could have been more effectively deployed elsewhere to achieve the same policy objectives.	The hydrogen society initiative does not yet seem financially sustainable and entails huge costs to tax payers for R&D and subsidy support. However, the UK can establish partnerships and readily import ENE-FARMS from Japan, which mitigates the massive required sunk costs to establish an equivalent hydrogen initiative. The UK's established gas grid makes this approach logistically feasible.

Source: *Vivid Economics, based on secondary sources*

4 The Netherlands

The Netherlands has begun transitioning away from natural gas towards a package of low emissions technologies. Similar to the UK, the Netherlands has significant natural gas reserves, leading to gas providing approximately 95% of heating needs and 94% of households being connected to the gas grid. The multi-faceted transition is driven by a range of instruments such as grants, subsidies and legislative change.

In summary:

- The heating transition in the Netherlands has been driven by climate policy, the depletion of the Groningen gas fields, and the loss of social licence for the natural gas industry;
- The Netherlands has established an ambitious plan under the 2017 Energy Agenda to reduce emissions from low temperature heat processes by 80-95% by 2050;
- The transition will likely rely on suite of technologies including district heating and geothermal, green gas, heat pumps and hybrid heat pumps;
- One study estimated that a zero carbon 2050 heating system would be compromised of 50% geothermal and district heating, 25% heat pumps, and 25% hybrid heat pumps with green gas. Another suggested a high electric scenario whereby the entire heating demand of the Netherlands is supplied through electric sources and green gas hybrid heat pumps;
- The exact mix of heating technologies in the long-term is unclear and there are not definitive government plans. Initial indications from the new Dutch government suggest that electrification will be prioritised.
- Significant achievements in energy efficiency have been made with the average energy efficiency rate of households improving by 2.5% per year between 2000 and 2012;
- Nearly Zero Energy Buildings is the standard for new buildings from 2020 onwards and in 2018 for governmental buildings;
- Hydrogen is a potential long-term solution, and the Netherlands has some of the most advanced demonstrations in the world;
- The Netherlands does not have a concrete implementation plan yet for this strategy;
- There has been little progress to date in moving away from the gas grid, which still dominates heating provision;
- The key policies driving the transition are: The Stimulation of Sustainable Energy Production (SDE+) operating grant, the Energy Performance Coefficient, the Sustainable Energy Investment Subsidy Scheme (ISDE) and grants for heat pumps.

4.1 Implications of archetypes for the heating and cooling transition

Endowment and infrastructure

The Netherlands is a single endowment country and reliant on gas. It is the second largest producer and exporter of gas in Europe after Norway. Natural gas became dominant after the discovery of large indigenous gas reserves in the Groningen Gas Field in 1959. Approximately 95% of buildings are heated through gas, a situation which can be seen as ‘approaching saturation’.[95] 94% of households are connected to the gas grid,

[95] (CE Delft 2016; ECN 2016)

and despite the efforts of the Dutch government, there has been limited progress to date in significantly shifting buildings away from gas heating.

The predominance of gas has pushed out contributions from renewable heating sources. The Netherlands, along with the UK, has the lowest share of renewable heat in the European Union. Only 5.5% of heat demand met by renewables in 2015.[96] Similar to the UK, the Netherlands has an extensive gas network and very little district heating. Around 4.4% of domestic dwellings are connected to district heating, which meets approximately 4% of overall heat demand.[97] This equated to 410,000 homes in 2015.

There were approximately 7 million dwellings in the Netherlands in 2015 (significantly lower than the UK). Of these, 80% were single-family dwellings and 20% multi-family dwellings. About 60% of homes are owner-occupied; social housing constitutes 30% of the housing stock and is fully owned by the private sector. The average heating consumption of the housing stock is approximately 93kWh/m^2, lower than in the UK (at 128kWh/m^2).[98] The UK housing stock is also slightly older than in the Netherlands. Approximately 55% of the UK's housing stock was built before 1960, and 30% between 1961 and 1990. In the Netherlands, around 35% of the housing stock was built before 1960, while 45% was constructed between 1961 and 1990.[99]

Market liberalisation

There is a market based approach to heating. Both the gas and electricity market are fully liberalised, but highly concentrated. There are 35 retailers in the electricity sector, yet just three companies encompass 83% of the retail market. Similarly, three companies cover 81% of the 32-company strong gas retail market. Beyond the gas and electricity grids, there is not as widespread use of centralised infrastructure for heat as there is in Nordic countries. District heating is largely co-owned and financed by municipalities, cooperatives and heat providers.

Heating profile

The Netherlands is in a temperate region like the UK, and therefore has a seasonal peak for heating and cooling demand in winter. Meeting the winter peak while phasing out gas poses a challenge. Previously production from the Groningen gas fields would increase during the winter months and fall in summer to follow seasonal variations of gas demand in the heating sector.[100]

4.2 Decarbonisation trends and roadmap

[96] (ECN 2015)

[97] (Netherlands Oil and Gas Portal 2016)

[98] (Collier, 2018)

[99] (Oxford ECI 1999)

[100] (Honoré 2017)

The Netherlands is planning for a phase-out of natural gas. The 2016 Energy Agenda established goals to reduce emissions from low temperature heat processes (below 100 Degrees) by 80-95% by 2050.[101] To do so, 6-7 million houses will need to be gas free in 2030-2050. The low carbon low heat transition is based around three key aspects: reducing heat demand, meeting future additional demand through low-carbon sources, and converting energy infrastructure from gas towards electricity and low emissions sources.

The current share of heat delivered by district heating in the Netherlands is small, however there are plans for expansion during the next decade. The main source for existing heat distribution networks is waste heat from power plants. This share is expected to decrease from 69% in 2013 to 44% in 2030. The role of waste incinerators in district heating is projected to grow significantly, reaching 30% in 2030.[102] As part of the energy transition, more buildings will be connected to heat distribution networks in the future. The number of dwellings connected to a heat distribution network is set to grow from 363,000 in 2013 to 549,000 in 2030. In total, 17% of all new dwellings in the Netherlands built between 2013 and 2030 will be connected to district heating.[103] The total heat supply to dwellings with district heating is projected to increase from 11.5 PJ in 2013 to 12.9 PJ in 2030. This will account for 17% of new dwellings over this period.[104] The largest shares of new dwellings are in dense cities such as Amsterdam and Rotterdam (see Figure 11). The heat supply to existing dwellings will decrease but will be countered by an additional heat demand for new dwellings adding 3.6 PJ in 2030 (see Figure 12). The number of existing dwellings connected to district heating may be significantly higher in 2030 if ambitions of municipalities are considered, however their plans are not yet sufficiently concrete. Although some municipalities such as Rotterdam, are already advanced in the implementation of district heating plans (see Box 5).

Box 5. **District heating in Rotterdam, Netherlands**

Some cities, such as Rotterdam, have taken the lead in development district heating. The district heating development in Rotterdam was supported by both municipal government and private financing. €150 million of loans were underwritten along with €38 million in municipal equity, and a €27 million grant for avoided CO^2 and NO^x emissions. The level of municipal support that was tripled after a local waste incinerator closure led to the need for increased capital investments for a more extensive heat network. Legislative change also aided the project. In 2007 the Rotterdam building code was amended to enshrine an obligation to connect new dwellings to the district heating network.[105]

[101] (ECN 2017)

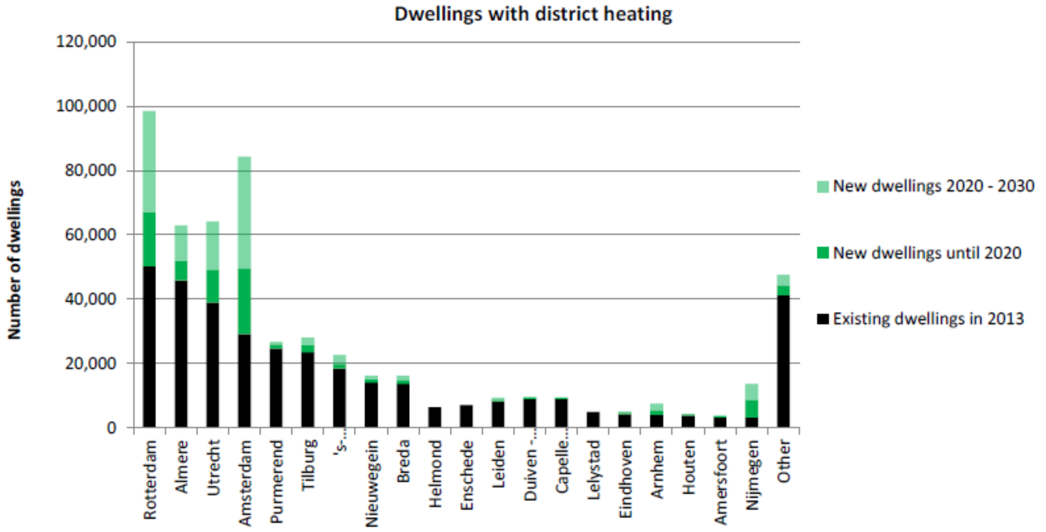
[102] (Lieshout and Scholten 2016)

[103] (Odyssee 2015)

[104] (Niessink and Rösler 2015)

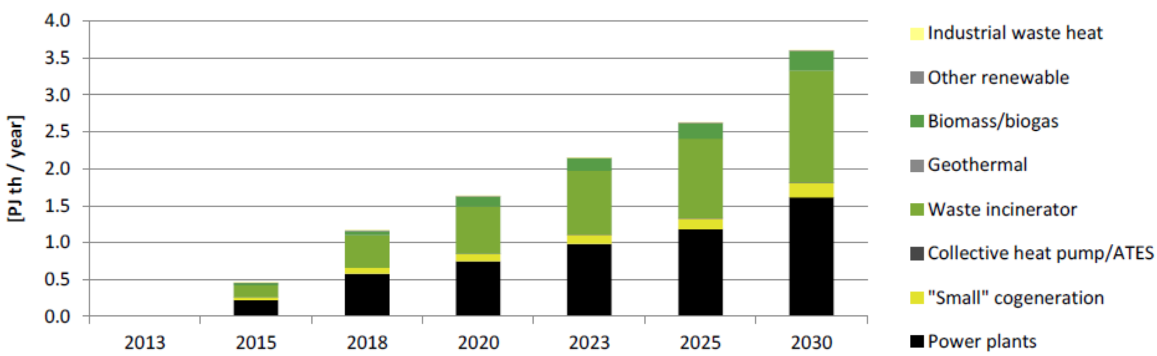
[105] (Hanna, Parrish, and Gross 2016)

Figure 11. **Projected number of dwellings with district heating**



Source: Buildings Performance Institute, 2011[106]

Figure 12. **Projected heat supply for new dwellings with district heating per source**



Source: Honore, 2017[107]

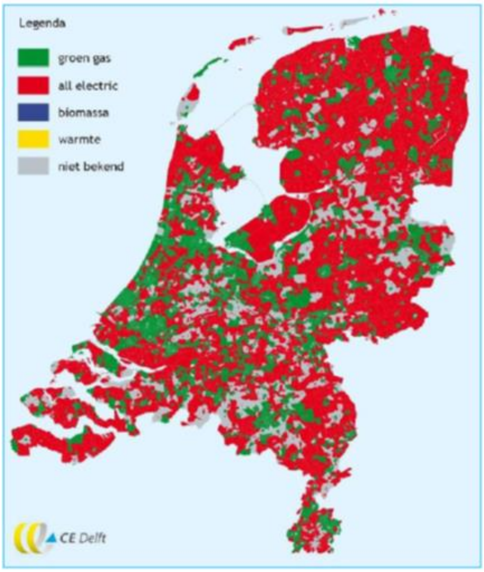
The decarbonisation of heat in the Netherlands will require a movement towards district heating, geothermal, green gas, and electrification. District heating and electric solutions are common across different modelling

[106] (Buildings Performance Institute Europe 2011)

[107] (Honoré 2017)

exercises, but the balance between the two varies. Gasunie puts forward one estimation that a 2050 carbon neutral heating system could be composed of a heat network of geothermal and district heating (50%), all electric heat supplies (25%) and hybrid heat pumps (25%).[108] This would be accompanied by a 60% drop in heat demand relative to 2015. CE Delft has modelled a number of scenarios, including a high-electric one where all heat is either electrified or supplied by green gas hybrid heat pumps (see Figure 13). The more balanced scenario saw green gas providing 0.9 billion cubic meters^2 (bcm^2) (with 0.4bcm^2 for peak demand management), electricity 2.4 bcm^2 and district heating 4.0 bcm^2 to fulfill a total energy demand of 7.7 bcm^2 in 2050.[109] Thus, while electrification, green gas and district heating are set to underpin the future Dutch heat system, the precise mix of technologies is unclear.

Figure 13. **A heat map for the Netherlands under a high-electric scenario**



Source: CE Delft 2016[110]. Legend: green= green gas, red= all electric, blue= biomass, yellow= district heating, grey= unknown.

While the details differ, most sources agree that different technologies will be needed for different areas. Urbanized, dense areas will rely on geothermal and district heating, city centers will utilize green gas, and rural areas will use electrification. While green gas would be the cheapest low-carbon heating source, it is limited in supply.

108 (Gasunie 2016)

109 (Wielders and Scholten 2017)

110 (CE Delft 2016)

There are no detailed plans for the long-term heating system, but it appears that electrification will be central. Most recently the new Dutch government released the Dutch Coalition Accord[111] outlining the key pillars of reducing emissions in the built environment: energy efficiency measures, heats pumps and district heating. This suggests that green gas may play less of a role to the primary technologies of electrification and heat networks.[112] However, further details are needed before the long-term future of heating in the Netherlands can be discerned.

4.3 Policy and drivers

The phaseout of natural gas has been driven by three factors: climate policy, gas depletion and the loss of social licence. The 2050 Dutch Energy Agenda, published in 2016, established a long-term goal to reduce emissions by 80-95% by 2050.[113] Low and high temperature heat are two of the points of focus in the agenda. This is logical given that low temperature accounts for 53% of final energy use in the Netherlands.[114] While climate policy has become increasingly ambitious, the Groningen gas fields have been beset by a loss of public support and production. Government forecasts indicate that production from Groningen gas field as well as other small fields is expected to reduce by around 80 per cent compared to today (see Figure 14). Severe earth tremors in 2012 due to gas extraction led to a significant public backlash against domestic gas production.[115] In response, the government decided to curtail the field's production. The maximum extraction was set at 24 billion cubic meters annually (bcma) on a normal year (mild winter) in June 2016.[116] This is about 30bcma less than the volume produced in 2013. Extraction rates are expected to decrease further after 2025 due to depletion, with the Netherlands becoming a net gas importer between 2030 and 2035.[117] There is a fear that energy security will be lost by importing Russian gas. This underlines the need to transition towards renewable heat sources.

[111] 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.

[112] (Beckman 2017)

[113] (Ministry of Economic Affairs 2016)

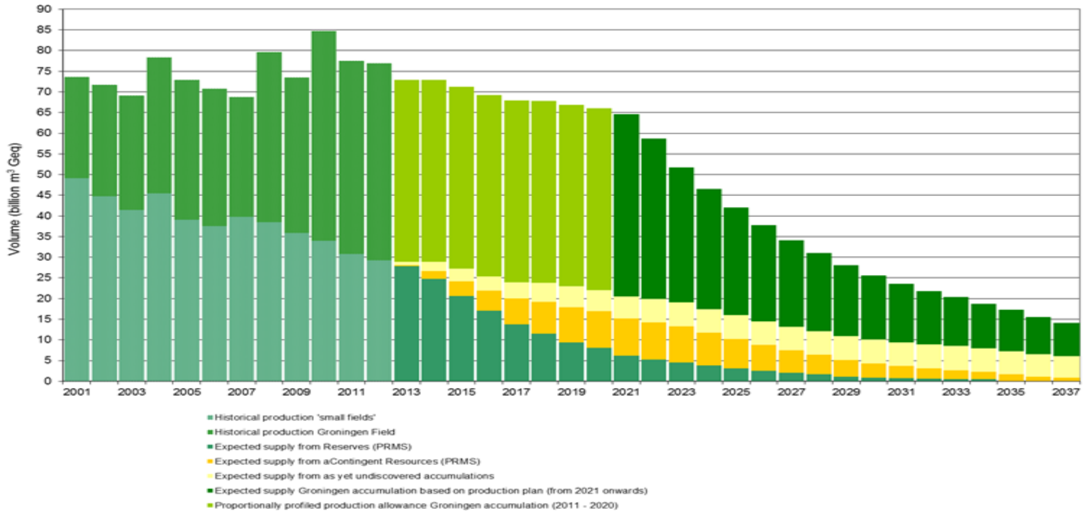
[114] (Bosselaar 2017)

[115] (Honore 2017)

[116] (Pardo et al. 2012)

[117] (ECN 2016)

Figure 14. **Historic and projected gas production in the Netherlands**



Source: Kleefkens, 2015[118]

The movement away from gas towards renewable heat is underpinned by several plans, most notably the Heat Vision. This vision was established in April of 2015 when the Dutch Ministry of Economic Affairs issued a letter to the Dutch parliament. This suggested a twin strategy of reducing heat demand through energy efficiency and switching to renewable heat sources. It identified potential for the use of thermal energy storage (TES), geothermal, solar thermal, biomass, heat pumps, as well as industrial waste heat. The Netherlands also has a renewable energy target of 14% by 2020 under the EU Renewable Energy Directive. This is similar to the UK's 15% target. The 2020 target is accompanied by a 2020 target of 5% energy savings annually (100pj by 2020), and a 16% renewable energy target in 2023.[119]

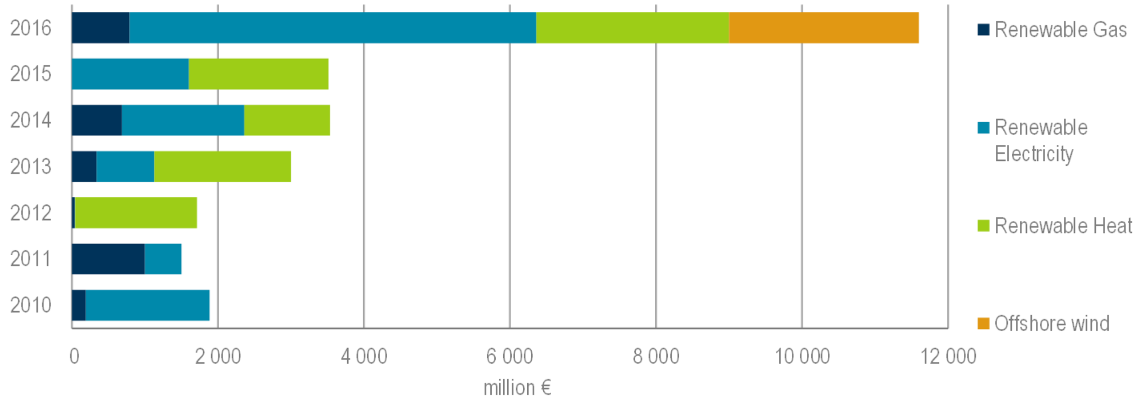
The key policy supporting the adoption of renewable heat is the Stimulation of Sustainable Energy Production Scheme (SDE+). It is an operating grant that provides financial compensation for renewable electricity, renewable gas and renewable heat (or a combination of renewable heat and electricity).[120] The fund pays for the 'unprofitable component' of renewable energy: the difference between the renewable energy price and regular market price. Renewable heat projects covered the majority of the SDE+ budget during 2012, 2013 and 2013. However, in 2016 the emphasis has shifted: renewable electricity is now the predominant receiver of funds (as depicted in Figure 15). The SDE+ is a tender process whereby the cheapest options are prioritised for funding. This generally leads to low-cost heat options such as renewable heat and biogas being preferred.

[118] (Kleefkens 2015)

[119] (Bosselaar 2017)

[120] (Netherlands Enterprise Agency 2017)

Figure 15. **SDE budget allocations by technology**



Source: RVO (2017)

The SDE+ is one of the largest fund programs available for renewable heat around the world. It is also one the fastest growing, as evident in Figure 15. In 2016 the overall budget was almost €12 billion, with €3.4 billion going towards renewable heat and biogas projects. In comparison, Germany's Marktanreizprogramm dedicates €300 million to such projects, and France's Fond Chaleurs €420 million. The growth of the SDE+ budget is indicative of its success thus far.

Complementing the SDE+ is the Sustainable Energy Investment Subsidy Scheme (ISDE). While the SDE+ is available only for companies, private groups and NGOs, the ISDE is targeted towards supporting smaller 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 a thermal power up to 5kW, plus €100 for every kW over this level up to €1,500

The government also provides tax incentives under the 'Green Funds Scheme'. This includes heat projects where capital gains taxes (normally 1.3%) are exempt for the first €50,000 of returns. They also get a 1.2% discount on their income tax. This gives a total of a 2.5% discount. 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.

These central schemes are supported by several instruments targeting specific technologies:

– **The Geothermal Guarantee Fund** offsets the risks investors would normally carry in financing geothermal exploration and drilling activities.
– **Heat tariffs** are used to encourage the use of district heating. The heat tariff is founded on the principle that district heating must be supplied at a rate lower than that of an individual gas boiler. For large consumers that heat price is often free. This principle provides the cornerstone for the 2014 Dutch 'Heat Act', which protects consumer with less than 100 kW heat capacity connections. An overview of the major heat instruments used in the Netherlands is provided in Table 12.

- **A national rollout of smart gas and electricity meters** resulting in 15 million installations by 2020.[121] The initial roll-out of smart meters led to effected households reducing their gas use by 0.9% and electricity use by 0.6%.

Both standards and legislative changes have helped to drive new buildings away from gas. Energy standards for new constructions have been progressively strengthened, as shown in Table 11. This resulted in a significant energy savings rate of 2.5% between 2000 and 2012.[122] Energy demand has fallen by 10% between 2008 and 2015, driven partly by falling energy demand for heating.[123] The standards are set to be further strengthened with new builds being nearly zero-energy by 2020, and government buildings by 2018.[124] Previously, new dwellings had a legal obligation to be connected to the gas network. This is being changed through legislation to an obligation to be connected to a heating network with sustainable technologies.[125] There is also discussion of moving part of the current electricity tax onto gas. This would deter gas usage and incentivize the uptake of electrical heating.

Local level action has been accelerated by existing national policies and incentives. The Hague and Delft both aim to create a carbon neutral heat supply by 2050.[126] These sub-national actions have been joined by networks such as the "Green Deal Natural Gas Free Districts" initiative. This is an agreement between 31 municipalities which aims to upscale and speed up the development of gas free communities through knowledge sharing, and the development of harmonised legislation, funding and regulations.[127] Together with the loss of public support for national gas production, this would appear to signal a shift in public sentiment in favour of the heat transition. However, there is little direct evidence on the level of public support for individual policies or the vision of the heat transition more broadly.

[121] (Metering and Smart Energy International 2014)

[122] (IEA 2013)

[123] (ECN 2016)

[124] (Kleefkens 2011)

[125] (ECN 2017)

[126] (Naber and Schepers 2017; Wielders and Scholten 2017)

[127] (Rijksdienst voor Ondernemend Nederland 2017)

Table 11. **Energy efficiency standards in the Netherlands (1995-2020)**

Year	Energy Performance Coefficient
1995	1.4
1998	1.2
2000	1
2006	0.8
2011	0.6
2015	0.4
2020	0

Source: Vivid Economics, using data from IEA, 2013[128]

Table 12. **An overview of low-emissions heating policies in the Netherlands**

Variable	Incidence	Modality	Duration	Complementary measures
Energy Performance Coefficient	New buildings	Energy performance requirements	1995-2017 (ongoing)	Smart meter rollout program.
Stimulering Duurzame Energie+ (SDE+)	Large companies, private groups and NGOs	Feed-in subsidy which covers the unprofitable component of renewable heat, renewable gas and renewable electricity projects	2011-2017 (ongoing)	ISDE; Green Funds Scheme.
Investeringssubidie Duurzame Energie (ISDE)	Renovation of households and small businesses	Subsidies to help cover the up-front costs of renewable heat technologies e.g. heat pumps, biomass boilers	2015-2020	SDE+; heat pump tariffs.
De Warmtewet (the Heat Act)	Households and buildings connected to district heating	Sets a heat tariff which provides a district heat price below that of an individual gas connection price	2014-2017 (ongoing)	Geothermal guarantee Fund; Green Funds Scheme.

Source: *Vivid Economics*

4.4 Innovative aspects and solutions

[128] (IEA 2013)

Significant innovation will be needed to deliver the ambitious Dutch heat transition. This could include the use of aquifers for heat storage, hybrid heat pumps and a better alignment between energy efficiency, residual heat and renewables.[129] Hybrid heat pumps could make an important contribution to the decarbonisation of heat by helping to manage peak demand. The government-owned energy company Gasunie has commissioned Berenschot, DNV GL and BDH to undertake research and development into hybrid heat pumps paired with green gas and smart power control systems.[130]

The Netherlands is exploring hydrogen as a long-term heating solution. The government has become a member of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE). While most of their hydrogen research is focused on transport, there are a number of initiatives on hydrogen for heating. The key research framework is the multi-billion Euro ‘Top consortia for Knowledge and Innovation’ (TKI) fund. The TKI includes a funding scheme focusing on moving from gas to hydrogen. The TKI spent €28 million on heat projects in 2013 alone.[131] It has funded several promising hydrogen pilot projects such as: PurifHy, a project which examines processes to extract hydrogen from gaseous streams, allowing for eventual feed-in to the current natural gas distribution network; Analysis P2G and Power2Gas, which are projects examining innovative methods to convert renewable electricity into hydrogen gas, and; HyStoRe, a research endeavour exploring hydrogen storage.[132] These are complemented by several hydrogen demonstration highlighted in Box 6.

[129] (Vries 2017)

[130] (Berenschot 2017)

[131] (Kleefkens 2011)

[132] (Ministry of Infrastructure and the Environment 2016)

Box 6. **Dutch Hydrogen Demonstration Projects**

The 'Hystock' pilot project is the first power-to-gas hydrogen plant in the Netherlands. The 1MW demonstration facility is run by the state-owned energy provider Gasunie. The plant uses an underground gas storage facility powered by 5,000 solar panels.[1] The provided solar energy is converted into hydrogen gas which can be stored in the facility. The project is in the gas-rich province of Groningen, and the hydrogen will be stored in depleted gas chambers. The sheer extent of emptied geological formations in the Groningen gas fields could allow for the site to undertake mass hydrogen gas storage in the future. A stated end-objective of the project is to kickstart a renewable powered hydrogen economy in the Netherlands which could export energy to neighbours such as Germany.

The Hystock project is accompanied by a 440MW gas-to-power hydrogen and CCS plant in Eemshaven. The plant is jointly owned and run by both Gasunie and the Norwegian owned company Statoil. It converts natural gas into hydrogen, with any resulting emissions captured and sequestered underground. It is the first and only CCS plant in the Netherlands. In addition to support from the government owned Gausunie, the plant has been subsidised by €200 million per year through the SDE+ financing scheme.[1] The plant has longer-term ambitions of sequestering carbon in deep-ocean sea beds off the Dutch coast and storing hydrogen in liquid form as an 'ammonia battery'.

Both innovative projects could have significant implications for the Dutch energy transition. Hydrogen with CCS, or powered by renewables, could make use of the existing gas pipeline networks, thus helping to avoid the costly early decommissioning of gas infrastructure. The development of hydrogen storage and batteries could become one way to overcome intermittency and allow for greater penetration of renewable energy into the both the Dutch electricity grid and heating system.

There are broader initiatives to induce innovation, but more is needed. This includes institutional innovations such as the Heating Expertise Centre. The centre provides tools such as guidelines for waste heat projects, factsheets, examples, heat maps and quicks scans of renewable heat for industry.[133] Such information could help to match specific heat technologies with different areas.

4.5 Outstanding challenges

Dutch heating and emissions targets are ambitious, but back-ended. The 2050 targets for emissions reductions and reductions in emissions from low-temperature heat are both 80-95%. These lofty goals are likely to be carried forward by the incoming coalition government. Interim targets are significantly less ambitious and the Netherlands is currently not on-track to meet either the 2020 renewable energy or energy savings targets.[134] There is agreement across existing studies that action cannot be delayed due to both the scale of changes required, and the long timescales involved with infrastructure change.[135] The Dutch

[133] (Bosselaar 2017)

[134] (ECN 2016)

[135] (ECN 2017)

government has announced several new ambitious interim targets including reducing emissions by 49% and the closure of all coal-fired power stations by 2030.[136]

The heating transition is already underway, but is surrounded by considerable uncertainty. While there are strong and continuous policies in place for new-build dwellings, the more difficult challenge is the retrofitting of existing buildings. To meet the 2050 targets 170,000 homes should be adjusted annually.[137] Moreover, the extensive gas delivery network will need to be either decommissioned and replaced, or used for alternatives that require further research, such as hydrogen and green gas. The Dutch Coalition Accord is expected to be further developed and result in new policies and measures.

4.6 Applicability to the UK

The Netherlands and the UK share several similarities in heating. Both are single endowment gas reliant countries with ambitious domestic 2050 emissions reductions targets. Both are among the lowest three countries in Europe for the number of residents connected to district heating. Both have liberalised market places. Accordingly, lessons from the Netherlands may be applicable to the UK.

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. Moreover, collaborating on research into technologies that can use existing gas infrastructure, such as hydrogen and green gas, would also be valuable to the UK and potentially help to avoid the costly premature decommissioning and replacement of gas infrastructure.

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. Gradually 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) programme in the UK. The two differ in terms of price and scope. The SDE+ is purely for companies and NGOs, while the RHI scheme has a tier to cover domestic projects. While the RHI is approximately £1.15 billion, the SDE+ is significantly larger at almost €12 billion in 2017. Payments for the RHI are set by a fixed rate tariff, while the SDE+ pays for the ‘unprofitable component’. Despite these differences there are some potential lessons. First, the SDE+ has limited the compensation given to biomass

[136] (Beckman 2017)

[137] (Ministry of Economic Affairs 2016)

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 (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. An overview of the suitability of sustainable heating policies from the Netherlands is summarised in Table 13.

Table 13. **Applying Dutch heat instruments to the UK**

Policy	Effectiveness	Efficiency	Feasibility
Building standards	Significant energy savings to date. The nearly zero standards are yet to be enforced.	High compliance and few unintended consequences.	Institutionally feasible, but may face political economy challenges.
SDE+	Appears to have been successful in both incentivising renewable energy investments and has received steady increases to grant funding.	Few issues with verification and strict regulations on the use of biomass.	Elements such as biomass regulations could be introduced into the non-domestic RHI. This would depend on the availability of funds.
Heat Price Regulations	There has been increased uptake, but it is difficult to attribute this solely to pricing policy.	Appears to have had few unexpected outcomes.	Unlikely to be compatible with UK consumer protection regulations.
Grants for hydrogen and green gas development	It is too early to make an informed judgement on the efficacy of efforts.	N/A	Institutionally feasible, but would depend on the availability of funds.

Source: Vivid Economics

Box 7. **Interview evidence – Senior advisor heating and cooling, Netherlands Enterprise Agency (RVO.nl)**

Under the 2017 Energy Agenda the Netherlands established an ambitious transition path for low temperature and high temperature heat, with the aim of reaching a near carbon neutral heating sector by 2050. Complementing this national level ambition, around thirty municipalities have made an agreement to go natural gas free by 2050.

Concrete implementation plans will be developed by the recently formed coalition government. In putting together that plan there are concerns in government regarding the cost of renewable heat, and there were no clear solutions to this yet, although the Netherlands may in future use the carbon tax to fund the transitions to renewable heat.

While the strategy has not yet been formalised, some outlines of the plan are beginning to take shape.

- A high electric scenario, including full electric and hybrid electric heat pumps (with both gas and biogas boilers) is an option for existing households.
- The plan will likely disaggregate the housing stock, and set out areas of the existing household stock where district heating is best suited. To the extent that district heating is used, it would be based on a mix of geothermal and biomass, electric, biogas and hybrid heat pumps.
- In new households, all new households should be near energy zero by 2021 (although energy used by new households is already very low). There are proposals for no new households to be connected to the gas grid, or enabling municipalities to regulate these out.
- The interaction with the power system is also considered, and high levels of insulation are used to avoid the peak loads. Hydrogen gas is also being explored as a longer term idea, building on the trials and pilots currently underway.

5 France

France's buildings are heated by a mix of fuels, consisting of gas (42%), oil (21%), electricity (primarily direct electric, 15%), biofuels and waste (12%) and district heating and other sources (10%). However, 30% of households in France rely on electric heating. An innovative policy package consisting of fiscal incentives, loans, targets and a carbon tax have had some success and could hold lessons for other countries.

In summary:

- France is undertaking a heating transition based on a combination of targets, regulations and fiscal policies.
- The country has set ambitious overall targets for a doubling of renewable heat by 2030, as well as ambitious interim targets for 2018 and 2023.
- The approach is beginning to have an effect in the new build sector – France has become a key growth market for heat pumps within Europe, and heat pumps have been installed in almost 40% of new builds.
- Fiscal incentives support the replacement of systems in existing buildings with renewable heating ones.
- However, new dwellings are also turning to gas heating alongside heat pumps (c. 55% of properties).
- France's current strategy and policies may not be sufficient to meet its ambitious goals – it has already had to revise its interim targets for individual renewable heat incentives downwards as it recognised it was unlikely to meet them, and faces challenges in meeting these revised targets.

5.1 Implications of archetypes for the heating and cooling transition

In order to understand the heating transition in France it is important to consider the following:

<u>Endowment and infrastructure</u>

Among European countries, France has an average share of renewables in heating and cooling, with 20% of heating demand in 2015 derived from renewables (compared to a mean of 19% and a median of 22% among the EU 28), a 60% increase since 2005 (from 12%)[138]. This compares to a 5.5% share of renewables in heating and cooling for the UK in 2015.

For all commercial and residential buildings, approximately 15% of total heating capacity is derived from electricity, while France also has a significant share of gas in the fuel mix for heating, supplying just over 40% of total heating demand. However, looking at the numbers of households served by different technologies, around 30% of households are reliant on electric (mostly resistive) heating, while just over 40% of dwellings using gas heating, 18% use oil and coal, roughly 4% each use biomass and district heating, and 3% use heat pumps.

[138] (Eurostat 2017)

France relies on imports of energy or inputs rather than natural endowments to meet its fossil fuel heating needs – the majority of its heat energy consumption. France does not mine uranium domestically, but imports it primarily from Canada and Niger, though almost a fifth of France's nuclear energy is generated from recycled nuclear fuel[139]. France also imports all or almost all (99%-100%) of its natural gas (primarily from Norway and Russia), its oil (primarily from Saudi Arabia and Kazakhstan), and its coal (primarily from Australia and Russia)[140].

In 2016 there were approximately 29.1 million households in France, slightly more than the UK's 28.7 million households. Approximately 63% of dwelling floorspace is France is in owner-occupied homes, with approximately 21% and 16% of floorspace in the private and public rented sectors, respectively – whereas the UK has slightly larger shares of owner-occupied (68%) and public rented (18%) housing, but a smaller private rental share (14%)[141].

Market liberalisation

France has a strong tradition of state involvement in the energy sector, which remains highly concentrated, though the country has undergone a process of privatisation and liberalisation over the past two decades[142]. The French state retains substantial stakes in the previously fully-owned monopoly electricity (EDF) and gas (GDF) companies. France has progressively liberalised its electricity and natural gas sectors to comply with EU directives, eliminating the monopoly rights of EDF and GDF, unbundling transmission and distribution rights and establishing a sector regulator. However, EDF still accounts for the bulk of power generation, and the transmission and distribution networks are fully and near-fully owned by EDF subsidiaries.

Heating profile

France is in a temperate region, though it has four distinct climatic zones that affect its seasonal patterns. Western France has an oceanic climate that moderates annual temperature variations, while central and eastern France has a continental climate with hot summers and cold winters, and south-eastern France has a Mediterranean climate with hot, dry summers and moderate winters. France has a seasonal peak for energy for heating in the winter and cooling in the summer, though this varies within the country, with greater demand for cooling in the summer in the south east.

The fluctuation of demand has implications for France's electricity exports and imports. The country does not utilise all of its nuclear-powered baseload during daily low demand periods and therefore exports electricity during low-demand periods during the day. However, the promotion of less efficient electric heating due to the availability of electricity has led to significant seasonal demand peaks during winter

[139] (World Nuclear Association 2017)

[140] (International Energy Agency 2016b)

[141] (Buildings Performance Institute Europe 2011)

[142] (OECD 2015)

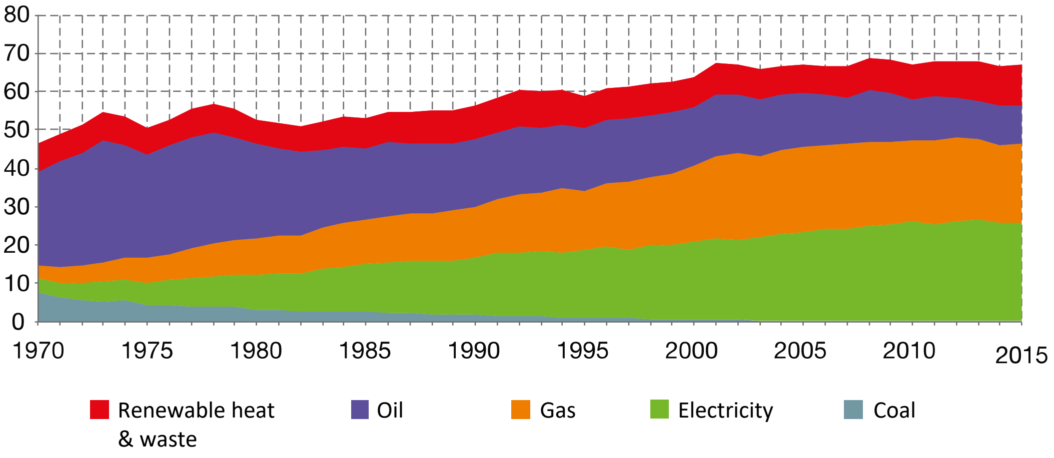
months, when France increases both energy imports and thermal generation to meet demand[143], indicating the value of both interconnectors and flexible alternatives to nuclear generation.

5.2 Decarbonisation trends in the last 10-15 years

Coal and oil were significant in France's energy production in the middle of the twentieth century, but since the 1970s France has seen a huge expansion in its nuclear energy generation capacity and significant reductions in its energy produced from fossil fuels, in both absolute and relative terms. However, France also imports and uses significant volumes of fossil fuels, primarily for use in transportation but also for heating, though the shares of oil and coal in primary energy consumption have also been falling over the past two decades, and down by almost half (from 69% to 35%) in the longer term between 1973 and 2015[144]. Consumption of energy from thermal renewables and waste doubled over the same time period, though natural gas consumption tripled and electricity consumption increased 15-fold.

Limited official data are available on consumption of energy for heat in France, however data for overall residential and commercial consumption of energy indicates near elimination of coal consumption and reductions in oil consumption, as shown in Figure 16. However, while thermal renewables and waste energy consumption has increased since 2000, so too has natural gas and electricity consumption. Nonetheless, data on France's overall renewable energy production indicates that the share of renewable energy produced by heat pumps since 2000 has increased substantially, though remains a small part of the overall energy mix, shown in Figure 17. Looking specifically at 2015 primary consumption of renewable energy for heat, as shown in Figure 18, almost three quarters is from wood biomass, with heat pumps making up the second largest share (at 16%).

Figure 16. **Residential and commercial energy consumption, 1970 – 2015 (Mtoe)**



[143] Interview evidence, ADEME

[144] (Service de l'observation et des statistiques 2017a)

Figure 17. **Evolution of primary production of renewable energy, 2000 – 2015 (Mtoe)**

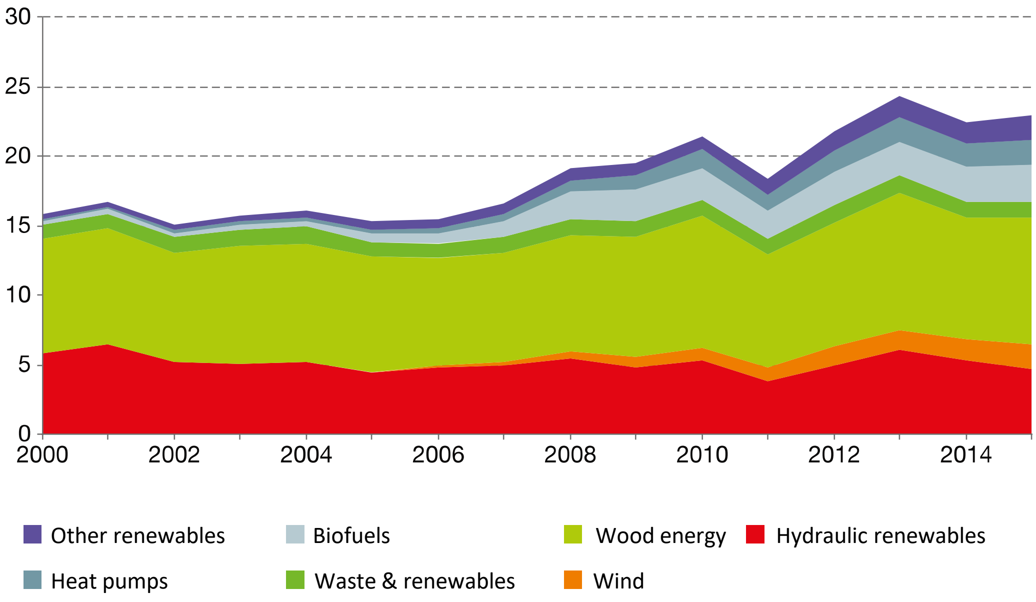
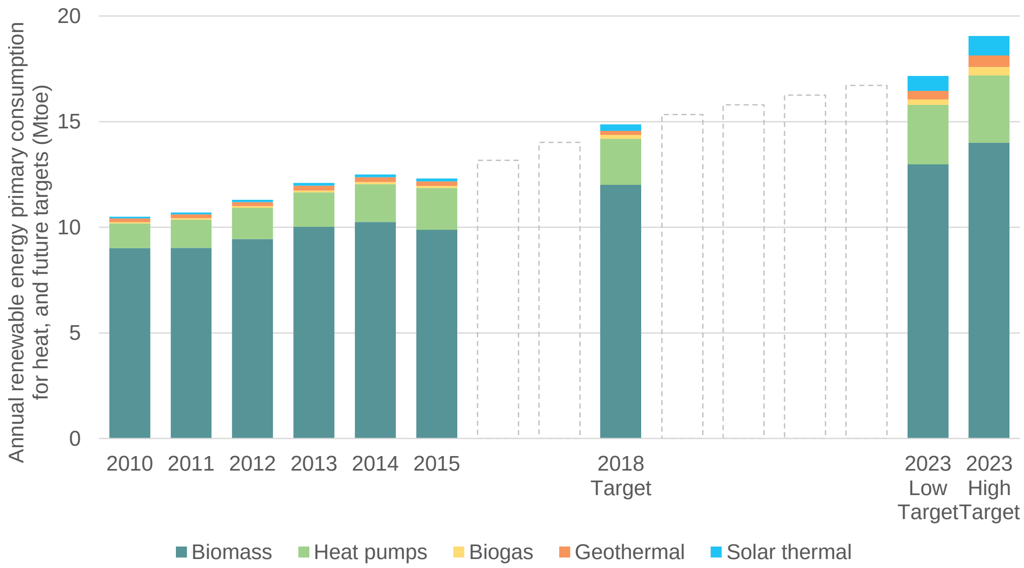


Figure 18. **Primary consumption of renewable energy for heat, 2010 – 2015 and future targets (Mtoe)**



Note: *1 Mtoe ~= 11.6 TWh*

Source: *Figure 16 – Service de l'observation et des statistiques (2017a); Figure 17 – Service de l'observation et des statistiques (2017b); Figure 18 –Vivid Economics, based on Service de l'observation et des statistiques (2015), Service de l'observation et des statistiques (2017b), International Energy Agency (2016b)*

Installation of heat pumps has increased significantly over the past decade, despite weakening sales in the early 2010s. Sale neared 160,000 units per annum in 2008, though this halved to just over 80,000 units per annum in 2010. However, sales have increased in the period since, nearing 190,000 units per annum again by 2015, and France is now one of the largest markets for heat pumps in the EU[145]. Up to 2010, sales were concentrated in air/water heat pumps, but there have been large expansions in installations of domestic hot water heat pumps since 2010 (making up more than half of total sales in 2015).

France is lagging in the deployment of district heating, despite studies indicating that there is significant potential for district heating and that costs would be competitive with electric heating and heat pumps in France[146]. District heating current supplies only around 6% of households, less than half the EU average of 13%[147]. 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.

5.3 Policy and drivers

France has set ambitious targets to transition towards renewables in both overall energy and in heating, with aims to decrease the share of electricity generated from nuclear power to 50% by 2025[148]. This is driven by a recognition of the need to increase the share of modern renewables in its energy mix and a desire to reduce its dependence on nuclear energy. The 2015 Energy Transition Law aims to increase the share of renewables in energy consumption to 32% in 2030, equivalent to a 70% increase in production from 2016. Within the heat sector, the Law sets a goal to double the share of renewables in heat to 38% by 2030[149]. The Law also aims to increase the share of renewables and waste energy supplying district heating five-fold by 2030.

The Decree of 24 April 2016 established a number of specific interim renewable energy goals for 2018 and 2023 under the Energy Transition Law, including plans to substantially increase energy production from biomass, biogas, heat pumps, geothermal heat and solar thermal (see below)[150]. These targets and the strategy for achieving the overall goals of the Law are due to be revised in 2018 – and in fact already reflect a slight decrease in ambition compared to the 2012 National Renewable Energy Plan’s aim of achieving 33% of renewables in heating and cooling by 2020, reflecting an acknowledgement that the previous targets were unlikely to be met. France has also recently released its Grand Investment Plan 2018-2022, which includes plans to invest €4.9 billion in renewable energy development over the period and an aim to increase production capacity of renewable heat networks by more than 50% by 2023[151].

[145](Nille 2015) (Collier, 2018)

[146] (Collier, 2018)

[147] (Collier, 2018)

[148] (Assemblé Nationale 2015)

[149] (Assemblé Nationale 2015)

[150] (La ministre de l’environnement 2016)

[151] (Pisani Ferry 2017)

France has primarily relied on regulatory and fiscal incentives to drive the transition away from direct electric heating and towards renewable heating deployment, across both the residential and commercial sectors. These policies have aimed to limit the installation of electric heating in new builds, while simultaneously subsidising the replacement and retrofitting of 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.

Since 2005 the **Crédit d'Impôt pour la Transition Énergétique** (CITE, Tax Credit for Energy Transition) has supported residential purchases of energy efficient and renewable energy equipment, including boilers with a high energy efficiency rate, thermal insulation works, heating regulation devices, heat pumps. The tax credit provides householder with a rebate 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, applicable to both capital and installation costs for properties that are more than two years old (and excluding new build properties). It is estimated that over 6 million households benefitted from CITE at least once between 2005 and 2011[152].

Since 2009, households have also been able to benefit from a provision of the Finance Law that provides a 0% interest **Eco-loan** up to €30,000 for energy-efficient renovations. Activities covered by the loan include the installation, regulation or replacement of heating or hot water systems, including those using renewable energy.

In the commercial sector, the 2008 **Fonds Chaleur** (Heat Fund) has provided approximately €1.6 billion to support 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). The Fonds Chaleur has an annual budget of €220 million, and aims to support the production of 5.5 Mtoe (64 TWh) of renewable heat by 2020, primarily though supporting biomass, geothermal energy, heat pumps and solar thermal. Between 2009 and 2015, the Fonds Chaleur supported the production of 1.8 Mtoe (21 TWh) of renewable heat[153].

The French Government has also established a savings fund that offers preferential-rate loans for domestic energy saving projects, the **Livret de développement durable et solidaire** (LDDS). The LDDS is a fixed-rate savings account established in 2007, with banks required to allocate a share of the funds raised through these accounts to finance energy-saving projects in older buildings – and in 2016 was expanded to provide for grant financing of social sector organisations. Individuals, households and entrepreneurs are eligible for preferential rate loans for the purchase and installation of renewable energy production equipment, space and water heating equipment using wood or other biomass and heat pumps.

Alongside these demand-side incentives, France has enacted tough regulations on new building developments that have effectively eliminated the installation of direct electric heating in new build

[152] (International Energy Agency 2016c)

[153] (Jacques le Seigneur 2016)

properties. 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. The Régulation thermique is due to be updated in 2018 to reflect advancements in building techniques, and is expected to be expanded to all buildings (not just new buildings) after 2020.

France's **carbon tax** system also plays a role in encouraging the decarbonisation of heat. The taxe intérieure de consommation sur les produits énergétiques (TICPE) applies to CO_2 emissions from the industry, buildings and transport sectors with exemptions for operators covered by the EU emissions trading system, and is payable by fossil fuel distributors or imports. The tax is currently set at €31/tCO_2e, but under the Energy Transition Law this is due to increase to €56/tCO_2e by 2020 and €100/tCO_2e by 2030. There is also a separate tax on natural gas consumption, the taxe intérieure sur la consummation de gaz naturel (TICGN), set at €5.88 per MWh, and added to bills by gas providers, which was initially only applicable to commercial consumers but was expanded to cover households in 2014.. The carbon tax may play an important role in maintaining the relative competitiveness of renewables compared to gas options for new builds and retrofits.

Table 14. **Analysis of key policies - France**

Variable	Incidence	Modality	Duration	Complementary measures
Crédit d'Impôt pour la Transition Énergétique (CITE)	New and existing residential dwellings	Tax credits for purchases of equipment for primary residences (Article 200 of the General Tax Code) to promote both sustainable development and energy conservation	2005 – 2018 (ongoing)	Eco-loan LDDS Régulation thermique
Eco-loan	New and existing residential dwellings	0% loan for energy-efficient renovation	2009 – 2017 (ongoing)	CITE Régulation thermique
Fonds Chaleur	New and existing commercial buildings	Subsidies for project support (40%-80% of costs) and project execution (25%-80% of costs)	2009 – 2017 (ongoing)	Régulation thermique
Livret de développement durable et solidaire (LDDS)	Existing residential dwellings	Preferential loans for energy saving measures	2007 – 2017 (ongoing)	CITE Régulation thermique
Régulation thermique	New residential and commercial buildings	Requirements for minimum energy consumption standards	2012 – 2017 (ongoing)	CITE Eco-loan Fonds Chaleur

Variable	Incidence	Modality	Duration	Complementary measures
Carbon tax	Industry, buildings and transport sectors, excluding those within the EU ETS	Taxation on fossil fuels	2007 – 2017 (ongoing)	CITE Eco-loan Fonds Chaleur LDDS Régulation thermique

Source: Vivid Economics

5.4 Innovative aspects and solutions

The combination of strict regulations on the energy consumption efficiency of new buildings and fiscal support for renewable heat though both subsidised capital costs and subsidised loans has contributed to a substantial increase in heat pump installations in new builds, and to a significant growth market for heat pumps in France in recent years. This approach avoids the need to provide upfront grants and ensures that public funding is only spent on realised projects and avoids risks of upfront grants being allocated to projects that are not completed, but also delivers lump sum incentives after a short and predictable time period (the wait until the next tax submissions are processed). It is also expected that future iterations of the building performance regulations will also cover existing buildings as well as new builds, creating regulatory incentives to drive the adoption of renewable heat in existing buildings.

France's combination of a carbon tax on fossil fuel use along with its fiscal and regulatory policy tools also suggests an innovative approach to incentivising switching towards renewable heat installations, and to manage the risks of households switching to natural gas when moving away from direct electric heating, coal or oil. Evidence from new build installations suggests that this approach has had mixed success so far. However, the anticipated increase in the carbon price between now and 2030 should strengthen the consumer incentive to adopt renewable heat technologies.

5.5 Outstanding challenges

France's targets for expanding renewable heat by 2030 are ambitious, and the country's interim goals have already had to be revised downwards once, and there remain are a number a challenges to realising these goals. Despite the addition of more than 360 ktoe of installed renewable energy capacity on average per year between 2010 and 2015, this falls significantly short of the over 600 ktoe needed annually from 2015 to meet the 2023 'low' targets, or the 850 ktoe needed to meet the 2018 or 2023 'high' targets (as shown in Figure 18). While France has already met its 2018 geothermal target and is on track to meet its 2018 and 2023 heat pump targets (based on average annual additions over the past five years), at historic rates of expansion it would miss all other 2018 and 2023 targets.

In September 2017, the French government made an unexpected announcement that it will phase out the CITE at the end of 2018 (and earlier in 2018 for window and door retrofits). The government aims to replace CITE in 2019 with a premium payable immediately upon completion of works, which aims to reduce the duration of the gap between initial consumer financing of investments and the (re)payment of public subsidies to households[154]. All else being equal, this shift to a premium repayable upon completion should increase the incentive to invest in renewable heat options as it would bring forward the subsidy payment. In practice, the effect of this change will also depend on the structuring and value of the premium relative to the value of the CITE, and on how the transition to and the communication of the new premium is handled.

There has 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[155].

Additionally, individual renewable heat options face challenges at achieving scale. Solar thermal in particular has fallen short of deployment targets, potentially due to remaining questions over installation costs and reliability[156]. There are also concerns that the wood industry is not sufficiently developed to generate sufficient biomass to supply biomass for heating at scale[157].

5.6 Applicability to the UK

There are a number of lessons for the UK from France's heat transition, and some policies and strategies used by France may be relevant to the UK.

Lessons from the heat pump transition in France show 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. The switch to a post-completion 'premium' from 2019 should decrease the gap between upfront investment and subsidy payment, potentially decreasing capital constraints that reduce investment incentives.

In terms of transitioning off a gas grid, France's lessons in switching towards renewable heating in both new builds and existing residential stock demonstrates lessons for the UK. The low price of fossil fuels has made it hard to incentivise existing natural gas users to switch from gas to renewables, at least in advance of the end of the lifespan of existing gas boilers. At the same time, a majority of new builds have installed gas heating, compared to 40% of the existing stock, demonstrating the challenge of promoting renewable alternative to gas heating. However, France's carbon tax 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.

[154] (franceinfo 2017; BFM Business 2017)

[155] (Chabrillat 2017)

[156] (Chabrillat 2017)

[157] (Chabrillat 2017)

Table 15. **Policy applicability - France**

Policy	Effectiveness	Efficiency	Feasibility
Crédit d'Impôt pour la Transition Énergétique (CITE)	CITE has been used by a significant share of French households – 6 million between 2005 and 2011, out of c. 30 million total The heat pump market has expanded significant since the late 2000s, with France one of the biggest growth markets in recent years	Widespread use and effective promotion of esp. heat pumps, but incentivisation of uptake of other renewable heats have been less strong	Feasible for the UK as an alternative to longer time period repayment structures, though may require re-structuring of RHI scheme
Eco-loan	Along with CITE, the Eco-loan has supported the substantial growth in the heat pump market	Appears to have had few unintended consequences, but potential overlap with LDDS loans	Feasible for the UK in principle, with the caveat that zero interest loans would require additional government subsidies
Fonds Chaleur	Has supported the deployment of 1.8 Mtoe (21 TWh) of renewable heat in commercial buildings	Appears to have had few unintended consequences	Feasible for the UK in principle, subject to willingness to provide subsidies for private sector entities
Livret de développement durable et solidaire (LDDS)	Similar to the Eco-loan, the LDDS has supported the substantial growth in the heat pump market	Appears to have had few unintended consequences, but potential overlap with Eco-loan	Feasible for the UK in principle, and shifts obligations for provision of loans to private providers
Régulation thermique	The RT has successfully eliminated inefficient direct heating from new builds	Efficiency of this mechanism will depend on the share of buildings that will move from electric to renewable versus natural gas sources, which has not been clear, and may have been worse without complementary carbon tax support	Strict building regulations may prove effective in the UK, but would need to be calibrated different as UK does not have high installed base of direct electric heating
Carbon tax	Has supported the shift away from some fossil fuels in heating, with limited coal and oil in new builds, but the share of gas expanded in new builds	The carbon tax has increased from EUR 7/tCO_2e at its inception to EUR 31/tCO_2e currently, and will significantly ratchet up to EUR 100/tCO_2e by 2030	Facilitated by public acceptance of high energy prices/taxes – which the UK public might not be willing to accept – while a carbon tax could also have adverse impacts on vulnerable consumers

Source: *Vivid Economics*

Box 8. **Interview evidence – Engineer, International Actions and Surveys, Agence de l'Environnement et de la Maîtrise de l'Énergie (Agency for the Environment and Energy Control, ADEME)**

The large share of electric heating has been driven by historic strategic choices. Heating demand is a key driver of overall energy demand in France, accounting for around 50% of energy demand. Electric heating has played a strong role in France, driven by previous strategic decisions, particularly around nuclear energy. The prevalence of cheap electric power from nuclear was a key driver in initial uptake of electric heating, which benefitted from the goal of minimising reliance on exports. The strength and robustness of the national grid also enabled electric heating uptake.

The Fonds Chaleur is one of the key instruments for driving the transition to renewable heating – but renewables have nonetheless faced challenges competing with gas. The Fonds Chaleur has played a key role in supporting the strong growth in the heat pump market over the past decade. Administrators of the Fonds Chaleur expect the budget allocation for the Fonds Chaleur to increase significantly in the near future, which is seen as a vote of confidence in the fund. The Fonds Chaleur has worked alongside the national carbon tax to incentivise switching from non-renewables – particularly electricity and oil-based heating – to renewable heating, and to mitigate switching to natural gas systems when such changes are made. However, the low cost of gas in recent years has made it more difficult to achieve the Fonds Chaleur's goals, as greater subsidy levels are required for renewables to achieve price-competitiveness with gas systems, making it harder to achieve the renewable heat deployment targets.

France is facing challenges in meeting its national and EU renewable energy targets – but there are positive signs for future developments. France has faced difficulties in meeting its targets, such as the 2020 targets set for France by the EU. However, ADEME expects to see continued growth in the heat pump market over coming years, and expects that solar PV – which has been slow to roll out – will become more cost competitive, and hence more widespread, in the early 2020s. Additionally, while nuclear energy from existing nuclear power generation has low unit costs, renewables are likely to be competitive on costs with new nuclear generation costs, due to very high investment costs. Furthermore, even with low electricity costs, incentives for replacement of electric heating would remain in place to achieve greater energy efficiency in heating. ADEME also note that there is significant potential for district heating in France, with a portion of the expected expansion in the Fonds Chaleur budget expected to be allocated towards promoting district hearing – with potential for solar PV to play a key role in supplying the baseload for district heating.

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Company Profile

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