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Best practice in heat decarbonisation policy: A review of the international experience of policies to promote the uptake of low-carbon heat supply

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Preface

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The TPA has been part of UKERC since the centre was established in 2004 and is now in its third phase, which started in 2014. The primary objective of the TPA is to provide a thorough review of the current state of knowledge through systematic reviews of literature, supplemented by primary research and wider stakeholder engagement where required.

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Executive summary

Radical decarbonisation of heat supply in the UK will be essential to meeting carbon reduction targets under the Climate Change Act, and delivering on commitments made in the Paris Agreement to limit increases in global average temperature to less than 2°C above pre-industrial levels. Responding to this heat decarbonisation imperative will be particularly challenging in the UK, which has amongst the lowest national share of energy from renewable sources for heating and cooling in Europe.

This report presents the findings of a review of the evidence on policy support for heat supply or infrastructure transitions in different European countries, and sets out to understand how relevant these policy lessons might be to the UK context for achieving radical decarbonisation of heat. The report does not set out to make a judgment about the optimal pathway to low carbon heat, or even the best combination of policies. The review also focuses on heat supply technologies rather than options to improve the energy efficiency of building fabric. Energy efficiency improvements will be of great importance to heat decarbonisation but are not the focus of this particular study. Nevertheless, the review captures integrated policy approaches, where energy efficiency policy forms part of a package of policies supporting the uptake of any particular heat supply technology / infrastructure – for example enhancing thermal efficiency as part of a whole building approach to maximising the performance of heat pumps.

The evidence review evaluates policy experiences to date and is essentially historical in nature. We have focused on two heat supply technologies for which sufficient historic evidence of policies and market evolution is available: heat pumps and district heating. These technologies vary in the extent to which they are currently low carbon where they are deployed in different countries. This variations depends on factors such as the carbon intensity of national electricity grids or the balance between fossil fuel and renewable heat sources. Nevertheless, both heat pumps and heat networks offer significant potential to decarbonise heat supply in the future, and have strongly featured in UK low carbon scenarios to 2050 (Winskel, 2016).

The findings of our review emphasise the importance of contextual factors (ownership structures, degree of liberalisation, energy prices) along with historical context. In many countries early deployment of heat pumps and heat networks started before market liberalisation. Resource endowments such as availability of hydro power or natural gas also have important impacts. This notwithstanding, the findings highlight a number of important lessons, including the role of policy stability, and a policy package which combines finance with information, regulation and standards, and a supportive planning and regulatory framework:

- **Policy stability** promotes industry, consumer and, in the case of district heating, local authority confidence. Where it comes to heat networks, perceived policy stability means banks in Iceland and Denmark compete to loan to district heating projects. In the UK, short-term abruptly changing policies relating to heat network development have created uncertainty and perceived risks for local government and the commercial sector. Similarly, heat pump deployment in Denmark has been adversely affected in the past by varying political support for the environmental agenda, opposition to electric heating, or a lack of recognition of heat pumps as legitimate technologies for delivering renewable energy.
- A range of **incentives, taxation and subsidies** have proved successful in different markets. Fossil fuel or carbon taxation has been successful in building stable low-carbon heat markets in Sweden and Denmark. Subsidies for replacing oil and electric heating can also be effective in stimulating demand both for heat pumps and heat networks. Investment grants appear to be particularly important for heat networks where energy markets have been liberalised (and where district heating markets are less developed). The lesson from a number of heat pump markets in the 1980s and 1990s is that the success of incentives also depends on having standards in place for manufacturing, installation and maintenance which are strong enough to maintain the reputation of the heat pump industry. For example, an initial surge in the German heat pump market following the introduction of a tax credit scheme saw a crash in the mid-1980s, attributed in part to poor installations, a lack of maintenance and low installer experience. The German experience and that in other countries also indicates that markets can recover once effective quality control measures are in place.
- **Information, regulation and standards** are each key to policy effectiveness. Enhancing the reputation of the industry through standards and regulations has helped tackle low consumer awareness and confidence in countries with high uptake of low-carbon heat. In market leading European countries such

as Switzerland and Germany, policies to increase technical standards, promote heat pumps and implement information campaigns have been successfully deployed in combination with subsidies to stimulate the widespread take-up of heat pumps. In the case of heat pumps, the success of public subsidy support and promotion depends upon technical standards being established in the first place. National heat pump associations and test centres to monitor heat pump performance have been instrumental for increasing quality assurance. For heat networks, price regulation may also play a role in reassuring consumers.

- **Planning and regulatory frameworks** are helpful for giving heat network developers confidence that they will secure a high enough percentage of the local heat market to justify the initial capital expenditure in liberalised energy markets. Strong planning policy is a feature of most large-scale heat network development. For example, zoning has been introduced in Denmark, supported by mandatory connection to heat or natural gas networks, and banning of heat pumps in collective supply areas, while subsidisation of heat pumps has been increased outside collective supply areas.

The UK context: The review assesses how transferable these international experiences are for expanding the future provision of renewable heat in the UK. Approximately 85% of UK households are connected to mains gas, while customer surveys have reported high levels of satisfaction with gas central heating systems and a lack of willingness to consider alternatives. European countries with some of the highest heat pump sales per capita over the last decade have achieved such deployment in the absence of indigenous natural gas production. Such countries have exploited their own resources for the supply of heating in buildings. For example, Sweden and Switzerland generate significant proportions of their electricity from hydro-power, which provides a low carbon source of electricity for heat pumps. Sweden and Finland have plentiful supplies of indigenous biomass which they use extensively as a source of fuel for heat networks.

However a group of 'middle ground' countries possess a more mixed portfolio of gas heating, heat pumps and heat networks. For these countries the presence of strong policies appears to have played a central role in creating a diversified mix. For example, recent policy in Germany has an explicit focus on replacing gas grids with heat networks. Germany and Italy have over 20 million natural gas customers and have also sold half a million or a million heat pumps respectively from 2005 to 2013. Irrespective of context a successful approach is likely to combine subsidies, carbon taxes, planning policy, regulation and strong support for certification, skills and product standards.

Overall the review indicates that there is strong historical precedent for the multi-decadal heat system transition that the UK is likely to need if the aspirations of the Climate Change Act are to be realised. Early deployment of heat pumps and heat networks in leading countries took place as a response to the oil crises in the 1970s. In the decades that followed a combination of incentives, planning, regulation and taxation of conventional fuels/systems brought forward a transformation of heat provision. Policies do not always succeed, several countries experienced booms, busts and recoveries. Nevertheless, it is clear that with sustained policy support over a period of 3-4 decades it is possible to bring about a profound shift in the means by which heating is provided.

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1 Introduction and purpose

During 2015 the UK Energy Research Centre (UKERC) Technology and Policy Assessment (TPA) Theme consulted widely over prospective topics for future TPA reviews. This process indicated that a rapid assessment of the available evidence on best practice in international policies aimed at deploying low carbon heat technology in order to draw lessons for UK policy on heat decarbonisation, would be both timely and relevant to UK policy.

Radical decarbonisation of heat supply in the UK will be essential to meeting carbon reduction targets under the Climate Change Act (Chaudry et al., 2015, Eyre and Baruah, 2015), and delivering on commitments made in the Paris Agreement to limit increases in global average temperature well below 2°C above pre-industrial levels (EC, 2016). Responding to this heat decarbonisation imperative will be particularly challenging in the UK, which has amongst the lowest national share of energy from renewable sources for heating and cooling in the EU (Eurostat, 2015). The UK's high penetration of relatively cheap natural gas for supplying heat to buildings is an important constraint on the deployment of renewable heat technologies and infrastructure (Chaudry et al., 2015, Eyre and Baruah, 2015, Hannon, 2015).

The UK also has some of the least energy efficient housing stock in Europe (ACE, 2013). Since by far the majority of the UK's existing homes will still be in use in 2050, heat decarbonisation in the residential sector will need to be delivered predominantly as a retrofit, rather than new build solution (Hannon, 2015, MacLean et al., 2016). This review focuses on heat supply technologies rather than options to improve the energy efficiency of building fabric. Nevertheless, the review captures integrated policy approaches, where energy efficiency policy forms part of a package of policies supporting the uptake of any particular heat supply technology / infrastructure – for example enhancing thermal efficiency as part of a whole building approach to maximising performance of heat pumps.

Options for supplying heat to residential and non-residential buildings include combined heat and power, district heating or heat networks, electrification of heating and heat pumps, hybrid heat pumps (operating in combination with gas boilers), and repurposing of the gas grid for use with hydrogen or biogas. The report focuses on heat pumps and district heating, because these options have been widely deployed in several countries and a large evidence base on policies is available. Future UKERC research will consider gas grid repurposing and other options.

Low-carbon heat options often involve financial and non-financial barriers to their uptake. Effective policies are likely to be ones that address or recognise the relevant barriers and are designed to overcome them. These barriers include the issues associated with the infrastructural transitions that are required – such as installing district heating, replacing natural gas boilers or the roll-out of heat pumps which may require electricity distribution network upgrades.

UK consumer research has identified a number of issues around residential consumer uptake of low carbon heating technologies in general:

- Most UK residential consumers have gas central heating, and say they would choose this technology in future (ETI, 2015 , DECC, 2013a).
- Gas condensing boilers are seen as familiar, proven and trusted, and most consumers state that in an emergency they would be their only choice from lower carbon technologies (DECC, 2013a).
- Heating replacements often need to be completed quickly when current systems are at or near the end of their life (ETI, 2015); 70% of consumers say they would consider pre-emptive replacement only if their current system needs considerable repairs (DECC, 2013a).
- Renovation work may provide an alternative opportunity to replace heating systems, and consumers may consider pre-emptive replacement if low-carbon heating offered a better alternative to their current system (ETI, 2015). Off-gas consumers are overall less satisfied with their current heating systems (DECC, 2013a).
- Most consumers say that increases in gas price or the availability of feed-in tariffs for renewable heat would not influence their choice of heating technology, but the availability of an up-front grant may influence the choice of heating technology (DECC, 2013a).
- 43% in of surveyed residents in high-density urban areas were positive about heat networks (DECC, 2013a).

- Alternative heating technologies also need to be easy for consumers to control (ETI, 2015).

This project sets out to evaluate the relative effectiveness of different policy approaches to support heat supply or infrastructure transitions internationally. The research seeks to identify lessons from the international policy experience and assess how relevant these policy lessons might be to the UK context for achieving radical decarbonisation of heat. However, this report does not set out to make a judgment about the optimal pathway to low carbon heat, or even the best combination of policies. In the early phase of scoping the review, it became apparent that evaluating the relative effectiveness of international policies supporting renewable heat technologies is a multifaceted problem, with a lack of clear metrics or criteria to measure policy success or failure and determine the transferability of international experiences to the UK.

Heat pumps and district heating vary in the extent to which they are currently low carbon where they are deployed in different countries, depending on, for example, the carbon intensity of national electricity grids or the balance between fossil fuel and renewable heat sources. Nevertheless, both heat pumps and heat networks offer significant potential to decarbonise heat supply in the future, and have strongly featured in UK low carbon scenarios to 2050 (Frontier Economics, 2013, Winskel, 2016). Many scenarios envisage combining heat pumps to maximise efficiency with use of decarbonised electricity. Heat networks have the flexibility to supply heat from a variety of different sources. This is useful for a low carbon energy system transition, enabling district heating to deliver heat from various forms of low carbon energy, such as biomass, waste and, depending on national grid carbon intensity, electricity (e.g. heat pumps or electric boilers).

1.1 Project aim and objectives

The main aim of the research is to conduct a rapid evidence review of the international experience of policies and policy packages aimed at boosting take-up of low-carbon heat technology. This review includes both the international experience with heat system change and also policies from the UK and the Devolved Administrations. The overarching research question is:

What policies and other factors have driven change/transformation in heat delivery technologies, fuels and infrastructure?

The research aims to address the following sub-questions:

- What are the factors which determine the success of the policy (including addressing barriers, other regulatory issues, market structure and historical factors)?

- What is the impact of external factors (for example, high fossil fuel prices, heat density, or availability of natural resources)?

- How are the outcomes affected by the aims of the policy?

- Would this policy (or aspects of the policy) work within the contemporary UK energy market context? What are the lessons for UK policy?

- Is there evidence to indicate which is the most suitable delivery/engagement agent, or of the advantages of a particular configuration of national and local action?

Chapter 2 describes the review process used to investigate the evidence base. Chapter 3 examines the historical evidence on heat pumps and Chapter 4 is focused on heat networks. Chapter 5 concludes.

2 Approach to identifying and evaluating evidence

In order to provide a timely contribution to inform thinking associated with the UK strategy for heat, a rapid review was required. This was carried out in the summer of 2016. Initial findings are reported in the Committee on Climate Change Report 'Next steps for UK heat policy' (CCC, 2016). A first task was to carry out a *rapid evidence assessment* (REA) to establish what evidence is available in general about policy options employed or discussed internationally to encourage the decarbonisation of heat supply, and what this literature contains.

Given the short timescales available and the status of the study as an REA, evidence has been identified through keyword searches of two databases: Elsevier Science Direct (for academic literature) and Google (for grey literature), using Boolean combinations of relevant terms. Google was employed as a first step in identifying grey literature and specific websites which host relevant material.

For the database searches, technology/infrastructure keywords were combined with policy, policy evaluation and market deployment keywords identified from a preliminary search of literature related to renewable heat technologies and policy (see Table 2.1). Returned results were filtered for relevance based on their title and abstract. If this is not sufficient to determine relevance, further inspection of the main text was performed. The criteria for relevance was that, in relation to change/transformation in heat delivery technologies, fuels and infrastructure, the document considers some or all of the following:

- policy approaches used internationally to deliver heat supply/infrastructure transitions;
- metrics that the success of these policies can be measured against;
- contextual information that may have influenced the success of particular policy approaches in particular geographical regions or at previous points in history.

Table 2.2 Keywords used to identify relevant literature in Science Direct and Google

Keyword categories			
Technology / infrastructure	Policy	Policy evaluation	Market deployment
biogas AND heat "biomass gasification" biomass AND heat "combined heat and power"/ CHP "district heating" "electric heating" "fuel cell" AND heat "heat electrification" "heat pump" "heat networks" hydrogen AND heat "natural gas" micro-CHP "renewable heat"	policy education grant incentive label loan marketing promotion R&D RD&D regulation standards subsidy/subsidies feed-in support	evaluation assessment effectiveness success failure analysis impact	uptake deployment "roll out" installation development implementation growth expansion adopt/adoption market

Following the filtering of retained search results, key descriptive information from each of the relevant results were captured, namely:

- Country / geographic region;
- Technology / technologies / infrastructures targeted;
- Customer segment targeted (residential/commercial/public sector);
- Policy intervention(s), aims and details;
- Agents involved in policy delivery;
- Study methodology;
- Metrics to assess policy effectiveness;
- Findings on policy effectiveness;
- Factors influencing policy effectiveness (including contextual/external and historical factors);
- Transferability to UK context.

The geographic scope of the evidence considered was limited to European countries in order to permit a sufficiently in-depth analysis of national markets and policy success factors in the time available. During our rapid evidence review, we did not find extensive examples of metrics used to explicitly or implicitly judge policy effectiveness with respect to heat pumps or heat networks. For heat pumps, a common metric used in the literature reviewed was sales or number of installations, which can be normalised by the number of households in a country or presented as a per capita equivalent. Metrics used to represent the deployment of district heating include the total heat capacity of systems in a given country (e.g. in MWth) and the proportion of national populations supplied by heat networks. In general therefore, our assessment of policies relies upon a qualitative evaluation of the relevant material extracted, with reference to quantitative indicators of progress in technological deployment where data has been obtained for this study.

Chapters 3 and 4 set out the findings of our policy assessment with respect to heat pumps and district heating. Both chapters first address key policy mechanisms which have been implemented in support of, or have otherwise impacted upon, each technology. The effect of the sequencing of these policies and how they combine, or have been implemented as part of a policy package, is then discussed, with reference to selected national case studies. Each chapter goes on to consider the role and importance of delivery agents and the extent to which the international examples and case studies presented might be transferable to future UK policy to support renewable heating technologies and infrastructure. Chapter 5 provides an overall discussion and conclusions.

3 What works to support the deployment of heat pumps?

3.1 Introduction: markets, actors and context

Drawing on the review of international literature, this chapter sets out findings on what works and what doesn't work in relation to policies which support the wider uptake of heat pumps. Taking Europe as an example, the progress of heat pump markets, as expressed by sales of heat pumps, is very mixed. On this basis, mature markets can be identified, e.g. France, Germany, Switzerland, Sweden, Austria and Norway, while the UK (alongside The Netherlands, Czech Republic, Poland and others) can be considered as a developing market, with low levels of market penetration and relatively high potential for growth (Zimny et al., 2015). Key actors in the formulation and implementation of policies to support heat pumps include government, utilities, trade associations, installers, manufacturers, the building sector and research institutes (Hannon, 2015, Kiss et al., 2014, Zimny et al., 2015).

A number of contextual factors influence the effectiveness of policies designed to expand heat pump deployment. European heat pump market leaders, such as Finland, Sweden and Switzerland, do not possess domestic natural gas reserves and have very limited proportion of households with connections to the natural gas grid. Several countries with high heat pump penetrations also benefit from large hydro power resources. By contrast the UK and Netherlands have both significant conventional gas reserves and very high penetration of gas connections (Frontier Economics, 2013). Both have limited hydro resources and very low penetration of heat pumps. However, the picture for several countries is much more mixed, and some including France, Germany and Italy combine both a high penetration of natural gas connection and high deployment of heat pumps. The review therefore seeks to assess both the effectiveness of policy and the relationship between policy and contextual factors, including natural resource endowments.

Our review of the international experience indicates that policy interventions which are particularly crucial in shaping the take-up of heat pumps relate to subsidies and policy stability, and attempts to improve information provision, raise standards and expand the skills base. As a precursor to our review of European policies, section 3.2 first considers the impact of policies implemented in the UK on the uptake of heat pumps. Section 3.3 elaborates on the effectiveness or otherwise of interventions in different European countries, with reference to examples from the literature identified. In section 3.4, the sequence, combination and stability of policies are considered with reference to three country case studies: Austria, Sweden and Germany. Section 3.5 explores the different contextual factors which influence the effectiveness of policies identified in our review, and how transferable the policy experience in other European countries might be to the UK.

3.2 UK policy experience

The UK's heat pump market remains small and relatively immature in comparison to leading European markets. From 2010 to 2013, there were 18,185 sales of heat pumps per year in the UK, representing less than one heat pump sale for every 1,000 households – in contrast to Sweden and Finland, where more than 20 heat pumps were sold for every 1000 households over the same period of time (Eurostat, 2016, EHPA, 2014).

Approximately 19,000 microgeneration systems were fitted through the Low Carbon Buildings Programme (LCBP) from 2006 to 2011 – mainly solar hot water and solar PV, but also air-source and ground-source heat pumps, wind turbines and biomass boilers. This scheme offered an up-front grant which covered a proportion of the installation cost (varying by technology). For domestic installations, householders were also required to meet a range of other energy efficiency and insulation criteria. The grant was paid once the system had been installed (Bergman et al., 2009).

The UK's Energy Act 2008 created provision for the Renewable Heat Incentive, which aims to contribute to climate change targets by incentivising the deployment of renewable heat (Donaldson and Lord, 2014). However, the Renewable Heat Incentive (RHI) for residential installations was delayed on several occasions after initially being scheduled for 2011, until its eventual introduction in 2014. The Government therefore introduced another grant scheme – Renewable Heat Premium Payments (RHPP) – which were available from 2011 to 2014. These payments subsidised some of the cost of installing heat pumps and other small scale heating technologies in residential buildings. Nevertheless, the RHPP underspent its allocated budget, and together with delays to the RHI undermined market confidence and supply chain development (Connor et al., 2015, Hanna, 2014).

An evaluation of the early effectiveness of the RHI has been recently published by the Department of Energy and Climate Change. This evaluation includes a survey of household owner-occupiers, who in many cases indicated that they would not have installed renewable heat technologies (including heat pumps) if the RHI had not been available (DECC, 2016). Moreover, non-financial barriers continue to constrain the uptake of heat pumps in the UK (Balcombe et al., 2014, Staffell et al., 2010), due to such factors as a lack of space for thermal stores or the 'hassle factor' involved in installing heat pump units, underfloor heating and new radiators for low-temperature distribution systems.

Ongoing financial incentives such as the RHI require stability and continuity of policy support in order to maximise their effectiveness in stimulating the uptake of renewable heating technologies. A lack of policy stability impacts adversely upon industry confidence. On the one hand, the majority of Microgeneration Certification Scheme installers surveyed by DECC (2016) 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 degression mechanism had impacted negatively on the renewable heat market (DECC, 2016). The DECC consultation on interim cost control for the RHI in March 2012, shortly after the scheme was introduced, also risked undermining consumer confidence (Donaldson and Lord, 2014).

Another important challenge for heat pumps 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 (Balcombe et al., 2014, Connor et al., 2015, Frontier Economics, 2013). Separate studies have demonstrated that the performance of heat pumps installed in households may be compromised by poor installation standards ([EST], 2010, Miara et al., 2011, Energy Saving Trust, 2010).

In 2008, the Microgeneration Certification Scheme (MCS, 2015) was introduced as a quality assurance scheme for microgeneration products and installers, and covers ground source and air source heat pumps. Each installation company was inspected on an annual basis by one of a number of certification bodies who were accredited through the MCS. Interviews with installers of heat pumps and other microgeneration technologies conducted by (Hanna, 2014) revealed some flaws in the operation of the MCS, in terms of its effectiveness in protecting against poor installation practices. For example, installers were able to self-select installations for MCS inspectors to visit – rather than inspectors selecting installations at random from a complete record of heat pumps fitted by a particular company.

3.3 Discussion of policies supporting heat pumps

The sections that follow discuss policies that we have identified as being important to the development of national heat pump markets in our review of different European countries. Section 3.3.1 examines the design and relative effectiveness of both direct subsidies (such as grants, tax breaks and ongoing incentives) and indirect taxes (such as fossil fuel taxes). Sections 3.3.2 to 3.3.4 evaluate success factors relating to technical standards, promotional campaigns and building regulations respectively. We find that generally each area of policy discussed separately in these subsections is not mutually exclusive; rather, many policy measures have been implemented as part of a wider and integrated package of policy support. The nature of this integration is examined in further detail in three country case studies which are presented in boxes 3.1 to 3.3 below.

3.3.1 Subsidies, taxes and energy prices

The high capital costs of heat pumps compared to some incumbent heating options is a key barrier to market growth (Frontier Economics, 2013, Gaigalis et al., 2016, Giambastiani et al., 2014). Government interventions designed to overcome high initial costs of installation and equipment, such as investment subsidies, grants and tax exemptions, can be effective in stimulating deployment (Frontier Economics, 2013, Gaigalis et al., 2016). In several countries, capital grants covering a proportion of installation costs and tax breaks on labour costs have been two of the most common financial incentives supporting the uptake of heat pumps (Table 3.1).

Table 3.1 Examples of financial incentives for heat pumps in selected European countries[1]

Country	Instrument Type	Data	Notes
Austria	Grant	€1000 – €2200	Minimum seasonal COP[2] = 4 / 4.5
Finland	Tax reduction	60% of labour costs	Maximum €3000
France	Tax reduction	40% of labour costs	Maximum €8000
Germany	Grant	€450 – €1200 for ASHPs[3] €900 – €2400 GSHPs[4]	SPF > 3.7 for ASHPs SPF > 4.2 for GSHPs
Ireland	Grant	€2000 – €3500	Retrofit only
Italy	Tax reduction	55% of total cost, deducted in equal instalments over 5-years	High SPF[5] requirements
Netherlands	Grant	€500/kWth	Maximum €1000
Norway	Grant	€1100	Air-air systems excluded
Sweden	Tax reduction	50% of labour costs	Maximum €5000

<u>Notes to Table 3.1</u>

1. Table 3.1 has been adapted from Frontier Economics (2013), except for Austria where the data has been extracted from Kranzl et al. (2013).
2. COP = Coefficient of Performance.
3. ASHPs = air source heat pumps.
4. GSHPs = ground source heat pumps.
5. SPF = Seasonal Performance Factor.

Investment subsidies introduced by the federal government in different regions of Austria typically covered 15% to 30% of the total costs of investment. An agreement reached between the federal government and the regions in 2009 (Art. 15a-Agreement, 2009), requires heat pumps to achieve a minimum level of performance – a mean seasonal COP (Coefficient of Performance) of 4 – in order to be eligible to receive a subsidy (Kranzl et al., 2013).

In addition to covering part of the costs of heat pump installations and products, there are some examples of investment subsidies which incentivise heat pumps as a replacement for conventional forms of heating, such as oil heating or electric heating. Investment subsidies have been implemented in Sweden to incentivise the replacement of direct electric heating with heat pumps or bio-energy heating in multi-family households. These subsidies covered a percentage of the total installation costs and were capped at a fixed amount (Sandstrom, 2000). Relatively recent investment subsidies in Austria have also combined an incentive for the replacement of fossil fuel heating with minimum performance standards: these subsidies provided €1500 or €2200 for switching from fossil fuel heating to heat pumps performing at a minimum seasonal COP of 4 and 4.5 respectively (Kranzl et al., 2013).

However it is important to note that investment subsidies have had their problems and the use of subsidies to promote heat pumps has its critics. In 1993, the Swiss government introduced subsidies for installing heat pumps in retrofits (at a value of 10% of the total installation cost) as part of a heat pump promotion programme (see section 3.3.3). However, these subsidies were discontinued after two years as an impact assessment survey revealed that 85% of those surveyed would have installed heat pumps even if the subsidy had not been available (Delta, 2013).

An evaluation of the success of a household subsidy programme in Norway introduced in 2003, in which householders received 20% of the initial investment costs for air-to-air heat pumps and wood pellet stoves, concluded that subsidies for new technologies risk promoting products which are not yet sufficiently mature and lack the quality and extent of technological support structures that exist in more mature markets (Bjørnstad, 2012).

In addition to investment subsidies, carbon taxes have been present in several European countries for the past 25 years. Finland was the first country to adopt a carbon tax in 1990, followed by the Netherlands in the same year, Norway and Sweden in 1991 and Denmark in 1992. A decade later, the UK introduced the Climate Change Levy, in 2001, and carbon floor price in 2013 (Ares and Delebarre, 2016). However whilst UK carbon taxes apply to fuels for power generation they are not levied on final consumption of gas by small scale and domestic end users. In several of these countries there is evidence that the presence of carbon taxes on domestic fuels also contributed strongly to the adoption of heat pumps, particularly where this was combined with the use of higher carbon oil-fired heating systems. An official in the Division for Energy at the Swedish Ministry of Environment and Energy, contacted in the course of the project, placed particular emphasis on the role of carbon taxes in the growth of heat pumps in Sweden[1].

There is also discussion in the literature about the interaction between subsidy, energy taxes and fossil fuel price movements. High oil prices were one driver of early market growth of heat pumps in Austria, France, Sweden and Switzerland in the 1970s and early 1980s, while declining oil and natural gas prices also contributed to a crash in heat pump markets in the mid-1980s in France, Germany, Sweden and Switzerland (Kiss et al., 2014, Zimny et al., 2015). The relationship between oil prices, financial incentives and heat pump installations in Austria has been studied by (Kranzl, 2007, Kranzl et al., 2013). In Austria in the late 1970s / early 1980s, the peak in oil price was followed by a rapid increase in hot water heat pump installations, while a significant decrease in annual heat pump installations in the late 1980s and 1990s coincided with consistently low oil prices (Kranzl, 2007). Between 2000 and 2009, the number of heat pump installations in Austria increased at a rate of approximately 15% per year, a trend which can be attributed to policy instruments which provide economic incentives as well as rising oil prices during this period (Kranzl et al., 2013).

Swedish and German experiences in the mid-1980s also suggest that the success of subsidy support depends upon standards of manufacturing, installation and maintenance being sufficient to maintain the reputation of the

[1] E-mail communication with Björn Telenius, Head of Section, Division for Energy, Ministry of Environment and Energy, Sweden, 19 August 2016.

heat pump industry (see Case Studies 3.2 and 3.3). We therefore consider these issues in more detail in section 3.3.2.

3.3.2 Technical standards and the skills base

There are a number of different non-financial barriers to the increased uptake of heat pumps, such as technological performance and the availability of information and advice about heat pump technologies that customers can trust (Balcombe et al., 2014). A comparative review of European heat pump field trials reveals that heat pump performance is highly variable for similar products, due to variations in standards of design, installation and operation (Gleeson and Lowe, 2013). In the UK, the Microgeneration Certification Scheme was set up to ensure that installers and products meet required standards, while support from the RHI is conditional on heat pumps and installers being accredited through this scheme (Balcombe et al., 2014).

The establishment of test facilities in Switzerland in the 1970s and Sweden in the 1980s was important for raising the technical standards of heat pumps and providing quality assurance for subsidies introduced in the 1990s. These test centres have observed significant improvements in heat pump performance (measured in terms of COP) between the early 1990s and the mid-2000s. Together with quality labels introduced in Switzerland in 1998 and Sweden in 2005, the test centres helped to redress the poor image of heat pumps during the 1980s market crash when installation and product standards were insufficient (Kiss et al., 2014).

In 1993, a procurement programme was launched in Sweden by NUTEK (the Swedish Agency for Economic and Regional Growth) to develop and commercialise innovative ground source heat pumps (GSHPs) (Zimny et al., 2015). 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 (Kiss et al., 2014).

Countries where GSHPs markets are more advanced, such as Austria, Germany, Sweden and Switzerland, have published higher numbers of technical standards, e.g. 8 standards between 1995 and 2005, and 7 standards between 2007 and 2008 (Rizzi et al., 2011). Countries with greater sales of GSHPs are also beginning to introduce 'contractor certifications and quality awards' to reduce the risk of the industry and consumers being compromised by poor quality products and installations. In December 2012, the European Union requested that member states should introduce certification schemes (or equivalent) for GSHP installers (Rizzi et al., 2011).

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 (Delta, 2013, EHPA and Delta, 2013). 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. 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' (Delta, 2013). 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 (EHPA and Delta, 2013).

3.3.3 Consumer engagement

The review identified a number of examples of marketing, promotion or information campaigns which aim to raise awareness of heat pumps and build consumer confidence. Nevertheless, the reviewed literature is somewhat limited on details of what such promotion actually involved, let alone on what its impact was. We discuss several forms of marketing which have taken place in countries with higher uptake of heat pumps in comparison to the UK.

Promotion of heat pumps may be carried out by different actors, such as government, utilities, industry associations, manufacturers and installers. Evaluating the impact of promotion in terms of its success in increasing sales of heat pumps is difficult even on a case by case basis, not least due to the implementation of several different policies (e.g. technical standards, subsidies) in tandem with marketing activities. For example, the Danish Energy Agency's recent promotional strategy combines a number of different policy instruments – an information campaign, subsidies and heat pump trials, in an effort to increase heat pump installations from 25,000 per year in 2011 to 200,000 per year in 2020 (EHPA and Delta, 2013).

One of the most extensive examples of how heat pump promotion can be integrated with other policy instruments is the programme initiated and funded by the Swiss Federal Office of Energy (SFOE), which represented part of an overall drive to achieve greater independence from oil (Delta, 2013, EHPA and Delta, 2013). This programme also included a short-lived subsidy for retrofit installations which was not demonstrated to be a key driver for growth in the heat pump market (see section 3.3.1). The SFOE established the Swiss Heat Pump Association (FWS) in 1993. The FWS combined multiple actors – including manufacturers, energy suppliers and government entities – and was tasked with country-wide heat pump promotion and co-ordination of marketing (Zimny et al., 2015). The Swiss promotion programme established the Heat Pump Test Facility, WPZ, in 1993, with SFOE heat pump field trials commencing in 1996. These were linked to the public dissemination of independent performance data from the test centre and field trials in an effort to raise consumer and installer confidence. Installation quality was bolstered through a new installer certification scheme and standardised training for installers provided by the FWS. Another element of this quality assurance drive was the creation of the DACH quality label (now EHPA quality label), which set minimum standards for heat pumps (Delta, 2013).

A notable feature of the marketing and awareness-raising strategy employed by the Swiss heat pump promotion programme is that information dissemination took place in each Swiss region (Canton) through community events involving municipal utilities, installers and manufacturers, as well as local communities. In addition, some companies, such as manufacturers, carried out more direct advertising through TV advertising (Delta, 2013). In the UK, the low public awareness of heat pumps and the lack of capacity of installers to carry out significant marketing activities has been previously highlighted by (Hanna, 2014). Overall, the success of the Swiss promotion programme can be expressed by the rise in heat pump sales from less than 3,000 per year in 1993 to approximately 7,000 per year in 1998, at the same time as oil prices were falling and might, all other factors being equal, be expected to lead to a decline in heat pump sales (Delta, 2013).

In Germany, utilities and energy agencies have led information campaigns to make consumers more aware about heat pumps. For example, the marketing activities of the NRW Energy Agency and the RWE utility have been linked to sustainable heat pump market growth in the German region of North Rhine-Westphalia (Delta, 2013). NRW have produced radio adverts and engaged with communities by attending local trade fairs and setting up information dissemination events in town halls, similar to the community marketing approach evident in Switzerland. RWE's information campaign from 2005 to 2010 was motivated by their objective to encourage customers to switch from gas or oil to electricity (Delta, 2013). 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 (EHPA and Delta, 2013). In other respects, this online service performs a similar function to the online installer database provided by the Microgeneration Certification Scheme database in the UK.

3.3.4 Building regulations

The review identified some examples of building regulations which have facilitated or supported heat pump markets in Europe. This section presents a brief discussion of building regulations and their impact on heat pump uptake.

These regulations may take the form of minimum requirements for the installation of renewable energy in buildings. Such requirements can be effective in stimulating the deployment of heat pumps, particularly if they target heat specifically (Frontier Economics, 2013). In 1997, Zurich (followed by most other Swiss cantons) introduced a requirement for the share of non-renewable hot water and space heating in new buildings to be restricted to 80% of useful energy demand. The remaining 20% could be met by installing extra insulation, heat pumps, biomass or solar hot water. As heat pumps could be installed cost-effectively, this regulation created a strong incentive for deployment of heat pumps (Kiss et al., 2014).

In 2009, the German EEWärmeG (renewable energy heat law) set out requirements for 50% of calculated heat load in new residential buildings to be supplied by renewables. A year later, in the state of Baden-Württemberg, an additional requirement was introduced whereby boiler replacements in existing residential properties had to source 10% of heat demand from renewables (Frontier Economics, 2013).

National and regional building regulations for minimum energy efficiency requirements in new buildings contributed to a booming GSHP heat market in Italy. As most GSHPs on the market require operation with low temperature heating systems to achieve optimal performance, they have therefore been easier to install in new build properties (Rizzi et al., 2011).

Sweden supported the early deployment of heat pumps through interest free loans, income tax breaks and building regulations. The 1975 Swedish building code (Svensk Bygg Norm - SBN) required that buildings with ventilation heat losses in excess of 50MWh should be fitted with a heat recovery system. Subsequently, the 1980 SBN incorporated an exhaust ASHP as an acceptable solution for residential water heating (Zimny et al., 2015). More recent 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 in new buildings, and tighter building envelopes have tended to require controlled ventilation due to greater ventilation losses (Zimny et al., 2015).

3.4 Sequences, co-ordination and stability of policy support

3.4.1 Sequence and combination of policies

The discussion of different policy instruments in section 3.3 has revealed the integrated nature of much policy support for heat pumps in leading European markets. It is for this reason that this section explores the sequence and combination of policies, with reference to selected national case studies: Austria, Sweden and Germany. These countries were selected because they have some of the highest levels of heat pump deployment in Europe (in absolute terms or per capita), and because a sufficient level of information was gathered through our review in order to assess the history of their policies and market development in detail.

The case study boxes presented in this chapter provide an account of how sales of heat pumps decreased sharply in the mid-1980s in Austria, Sweden and Germany. These are examples of European countries where early significant deployment of heat pumps took place following the oil crises in the 1970s. Austria, Sweden and Germany all experienced a recovery and growth in heat pump sales during the 1990s, in particular due to concerted attempts by governments and industry to bolster the reputation of the technology through a combination of heat pump promotion, information campaigns, and technical standards.

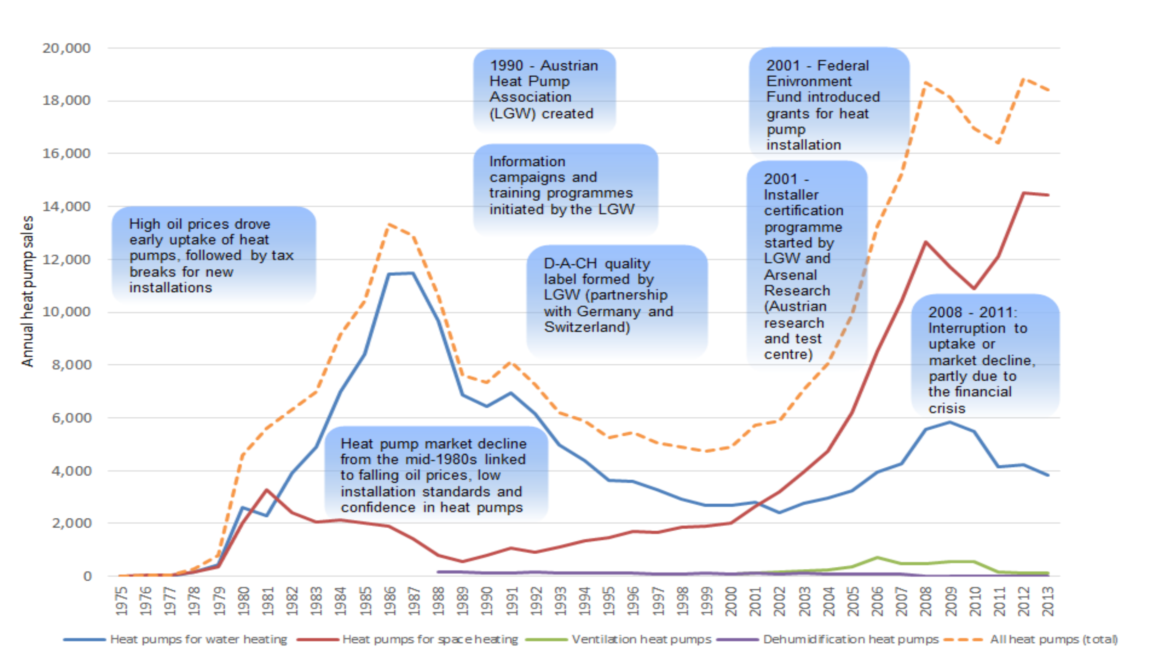
The case studies also highlight the important role of co-operation between different delivery agents in the heat pump industry, and particularly the pivotal role played by the formation of heat pump associations and their subsequent activities. In 1993, the German heat pump association (IWP Heat Pump 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 (Zimny et al., 2015).

The Austrian Heat Pump Association (LGW) was formed in 1990, and initiated installer training programmes and quality assurance through the DACH quality label, as well as an information campaign (Zimny et al., 2015). This is similar to the origin and nature of the heat pump promotion programme in Switzerland, which also involved that country's heat pump association and was linked to quality assurance initiatives (Section 3.3.3). The Swiss Heat Pump Promotion Group (or Swiss heat pump association) was a partnership between 'engineers, contractors, manufacturers, energy-suppliers and government organizations' set up in 1993 in order to promote heat pumps at a country scale (Zimny et al., 2015).

Case study 3.1: Sequence and combination of policies in Austria

The evolution of the heat pump market in Austria, as expressed by annual heat pump sales (Figure 3.1), follows the pattern observed in other leading European heat pump markets, such as Sweden, Germany and France. Initially the take up of heat pumps in Austria comprised systems for hot water heating, and was driven by the oil crises of the 1970s and the resultant spike in oil prices. The domestic production of electricity in Austria has been dominated by hydropower (Zimny et al., 2015), and heat pumps offered a viable, low carbon alternative to heating oil. These early drivers were followed by the introduction of tax breaks for new heat pump installations (Eunomia, 2016). However, installation standards and consumer confidence in the technology were not sufficient at this time to allow the emerging market to withstand the fall in oil prices from the mid-1980s, causing the heat pump market to crash. In 1990, the Austrian Heat Pump Association (LGW) was formed and instigated an information campaign, installer training programmes and quality assurance through the DACH quality label. Nevertheless, Austrian heat pump sales did not begin to recover until 2001, a year in which there were several different policy developments. For one, the Federal Environment Fund was introduced, which subsidised the installation of heat pumps (Eunomia, 2016). Technical standards and quality assurance were further bolstered through the introduction of an installer certification scheme by LGW, and the establishment of a heat pump research and test centre called Arsenal Research. Figure 3.1 suggests that in 2008, the global recession may have contributed to a short-term fall in annual heat pump sales in Austria, although the heat pump market subsequently recovered in 2012. In 2009, sales were affected by the slowdown in building construction due to the high share of heat pumps installed in new buildings. The decrease in heat pump sales at this time has also been linked to the Austrian oil industry launching a programme to support heating oil boilers (Kranzl et al., 2013).

Figure 3.2 Austria: heat pump support policies and market development, 1975-2013

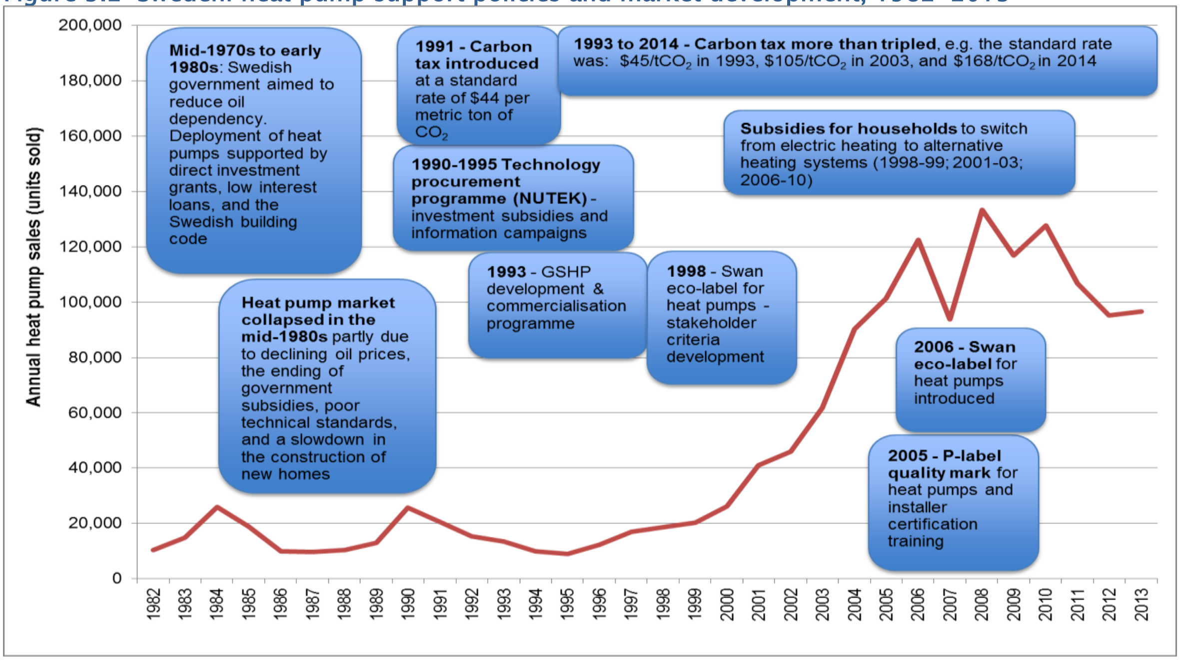


Sources for chart text: EHPA (2009), (Zimny et al., 2015), Eunomia (2016). *Source for chart data:* (Biermayr et al., 2014)

Case study 3.2: Sequence and combination of policies in Sweden

In Sweden, high oil prices helped to drive the early market growth of heat pumps in the 1970s and early 1980s – as with other leading heat pump markets (Figure 3.2). Sweden also supported the early deployment of heat pumps through direct investment grants and low interest loans (Sandstrom, 2000, Johansson, 2014), and the Swedish building code (Kiss et al., 2014, Zimny et al., 2015). 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 (Kiss et al., 2014, Zimny et al., 2015). In the initial stages of heat pump deployment in Sweden, standards and performance of heat pump installations were questionable. Several types of heat pumps fitted in the early 1980s were registered with technical malfunctions. New policy instruments were implemented in Sweden in the early 1990s which focused on technical improvements and increasing quality assurance (Kiss et al., 2014). In 1993, Sweden initiated a procurement programme to develop and commercialise innovative GSHPs led by NUTEK – the Swedish Agency for Economic and Regional Growth (Zimny et al., 2015). After this time, the heat pump market in Sweden has been supported through technical standards and certification – for example the Swan label (an eco-label for heat pumps) in 1998, the P-label quality mark for heat pumps in 2005, a standard for the installation of geothermal systems and installer certification training (Kiss et al., 2014 Zimny, 2015 #90). In addition, there have been further information campaigns about energy efficiency and alternative, lower carbon heating technologies such as heat pumps (Zimny et al., 2015). From 1998 to date subsidies for heat pump installations in domestic buildings have been available for discrete periods but not on a continuous basis, tending to last between one and four years, followed by a break of a year or two before new subsidies have been introduced (Zimny et al., 2015). Now, the Swedish heat pump market is considered to be mature, with at least one in two homes in Sweden fitted with a heat pump (Eurobserv-er, 2015).

Figure 3.2 Sweden: heat pump support policies and market development, 1982-2013

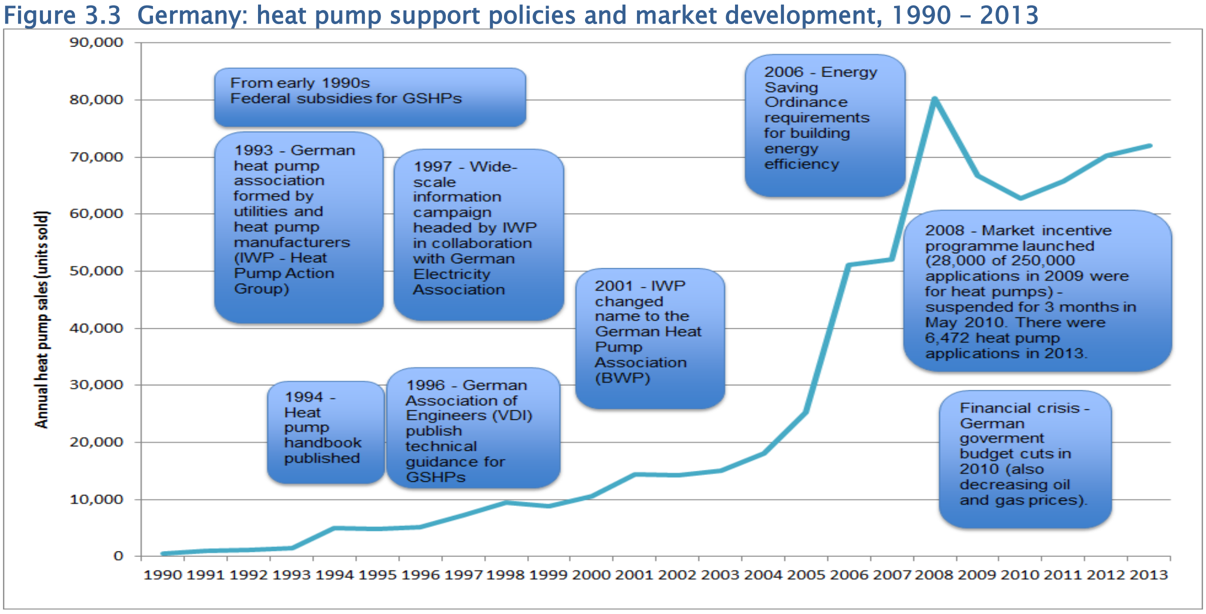


Sources for chart text: Sandstrom (2000) Kiss et al. (2014), Johansson (2014), Zimny et al. (2015).
Sources for chart data: for 1982-1995, heat pump sales data received by email from Swedish Heat Pump Branch, 2 September 2016; for 1994-2013, the data source is EHPA (2014).

Case study 3.3: Sequence and combination of policies in Germany

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 (Sanner, 2016, Zimny et al., 2015). 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 (Zimny et al., 2015). The steady growth in heat pump units sold in Germany during the 1990s (Figure 3.3) 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, and the information campaign led by the IWP several years subsequently. In addition, federal subsidies were provided for GSHPs, with the federal government, states and energy suppliers promoting and encouraging the use of this technology (Zimny et al., 2015). These promotion and quality assurance activities were important to the steady recovery of the German heat pump market in the 1990s, aided by an accumulation of knowledge and higher quality products, as well as a general increase in energy prices. But it nevertheless took at least a decade for a significant acceleration in heat pump sales to occur (Zimny et al., 2015). In fact, the rapid increase in annual heat pump sales observed in 2006 has been linked both to regulations governing building energy efficiency (Energy Saving Ordinance) and an increase in the standard VAT rate from 16% to 19% in 2007 (Eunomia, 2016). 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 (MAP) in 2007. 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 MAP (Eunomia, 2016, Zimny et al., 2015). 57,000 heat pumps for space heating were sold in Germany in 2015, with increased MAP funding leading to a tripling of applications to the scheme (EHPA, 2016).

Figure 3.3 Germany: heat pump support policies and market development, 1990 – 2013



Sources for chart text: (Zimny et al., 2015) Eunomia (2016). *Source for chart data:* EHPA (2014).

3.4.2 Policy stability

Policy stability is important to the successful development of heat pumps. For example, Austria has benefited from the long-term stability of policy and financial support for heat pumps and other renewable heat technologies over 25 years, and similar long-term stability of (and familiarity with) delivery agents (Eunomia, 2016). As noted in section 3.3.2, in Sweden and Switzerland, continuous government and private sector R&D programmes were essential for the ongoing technical development of heat pumps, whether the heat pump market was experiencing phases of boom, bust or consolidation (Kiss et al., 2014).

Some commentators on the Swedish experience suggest that policy stability has been highest for carbon taxes rather than in provision of direct support for heat pumps. The carbon tax in Sweden has sustained over two decades and more than tripled since its introduction in 1991. However, subsidies supporting heat pumps have been available for discrete periods of one to four years at a time (Zimny et al., 2015). Some analysts argue that the effectiveness and impact of these subsidies is debatable and they have come at significant expense to the Swedish government (Kiss et al., 2014). Kiss et al. (2014) also claim that uncertainties about how long investment subsidies would last and the level of support they would offer may have compromised manufacturers' long-term investments in heat pump technology.

The account of a technical expert at the Swedish heat pump association (SVEP), challenges the notion that investment subsidies are an explanation for the high deployment of heat pumps in Sweden (relative to other European countries)[2]. This account indicates that as investment subsidies for heat pumps have been limited to discrete and short-lived periods of time, they have led to booms and busts of installation activity. It is suggested that the widespread uptake of heat pumps, particularly in small dwellings, is more likely to be due to substantial fossil fuel taxes and tax deductions for the costs of labour required for heat pump installation. The economics of heat pumps in Sweden also benefit from relatively cheap electricity and higher costs for

[2] E-mail communication with Jan-Erik Nowacki, Technical expert – heat pumps, Swedish Heat Pump Branch (SKVP), 2 September 2016.

district heating due to privatisation[2]. Sweden has by far the highest carbon tax in Europe. 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). Despite this it is clear that the availability of subsidies for heat pumps, together with measures to improve installation quality played a significant role in Sweden as elsewhere.

Denmark represents an example of how low policy prioritisation for heat pumps and shifting policy support affected the heat pump market. The first oil crisis of 1973/1974 led to considerable efforts in Denmark to reduce the country's oil and gas imports and decrease energy consumption. Up to this time, approximately 200 heat pumps had been fitted in single-family homes, most of which were either performing poorly or inoperable. In 1974, the Ministry of Trade funded a DKK 1.4 million R&D programme for heat pumps. That same year, the first mass-manufactured heat pump reached the Danish market (Nyborg and Røpke, 2015).

The Danish Energy Agency (DEA) was established in 1976 to oversee the new drive towards energy independence, through a national energy plan which included the following elements: to shift from oil to coal, nuclear power and other alternative energy sources; develop a national gas grid using North Sea natural gas; and conduct comprehensive heat planning across all counties and municipalities. An oil tax was introduced in Denmark in 1977, which together with the second oil crisis of 1979 caused substantial increases in the price of household heating fuel. Since oil boilers were the dominant form of heating in Danish households, there was a strong incentive to switch to cheaper heating sources (Eunomia for DECC, 2016). A decade-long R&D programme on heat pumps was also started in 1980 (Nyborg and Røpke, 2015).

In 1981, a new subsidy was implemented by the DEA, which covered 20% of the cost of installing various renewable energy technologies, including heat pumps. At the same time, the DEA funded the setting up of test stations for each supported technology, including a dedicated heat pump test centre located at the Technological Institute. This helped to standardise heat pumps and reduce the risk of subsidies being spent on lower quality products. However, grassroots organisations such as the Organisation for Renewable Energy (ORE) and the Organisation for Nuclear Power (ONP), which were influential in lobbying politicians, were generally opposed to heat pumps on the grounds that they required electricity from fossil fuels as an input, and also doubted their potential to save energy. In addition, the Ministry of Environment was concerned about the possibility of GSHPs contaminating groundwater. This resistance to heat pumps may explain why the subsidy for heat pumps was reduced to 10% of the costs of installation in 1982, whereas the equivalent subsidies for other renewable energy technologies were increased to 30% (Nyborg and Røpke, 2015).

Mandatory connection was introduced in 1982 for households in areas with collective supply from district heating or natural gas. While in the early 1980s, electricity, oil and coal taxes were increased significantly as a response to declining oil prices, natural gas was not taxed. Sales of heat pumps were increasing at this time, but experienced a sharp fall in the mid-1980s (e.g. decreasing from 2,000 sales in 1982 to several hundred in 1986). This market collapse can be explained by variable installation standards and subsidies, unsatisfactory promotion and the volatility of oil and electricity prices (Nyborg and Røpke, 2015).

In the late 1980s, regulation and taxation combined to project a negative image of electricity and dis-incentivise the uptake of heat pumps, particularly as the majority of Danish electricity production at this time continued to be from centralised coal power stations (Energinet.dk, 2016a, Energinet.dk, 2016b). Thus, in 1988 electric heating was banned, and electricity taxes were increased again in 1989. Although the heat pump test station had been established in 1981, almost a decade later the Danish heat pump manufacturers' organisation (AMHP) acknowledged that marketing of heat pumps to the public was inadequate, and was failing to communicate their potential as a renewable technology that could reduce carbon dioxide emissions. In 1993, the Danish Energy Agency withdrew heat pump subsidies in areas supplied by district heating or natural gas, while increasing subsidies for heat pumps outside collective supply areas from 10% to 15% of installation costs. The Energy Agency also supported an installer quality assurance scheme (VPO) in the same year. Heat pump deployment was further hindered by a new CO_2 tax in 1994 which raised tax on electricity, while tax on heating oil remained unchanged and natural gas continued to be tax free (Nyborg and Røpke, 2015).

In 2001, a new conservative Danish government pursued a sharp break from the environmental policies of the previous government by scrapping the renewable energy subsidy law and decommissioning renewable energy test stations (this affected both subsidies supporting heat pumps and the heat pump test station). While the heat pump station continued to operate, it did so on a much smaller budget based on voluntary user-finance (Nyborg and Røpke, 2015).

Political opposition to heat pumps was removed in 2008, when the government announced a reversal of previous opposition to environmentally sustainable energy policy. The penetration of renewable and energy efficient power production had been steadily increasing since the early 1990s, so that by 2008 wind power and local CHP plants together contributed approximately 40% of electricity production in Denmark ((Energinet.dk, 2016). The new government vision was underpinned by fossil fuel independence and green growth. An information campaign was launched to promote the replacement of run-down oil burners with energy efficient heat pumps. This was followed in 2010 by the introduction of a subsidy scheme to support the replacement of oil heaters with heat pumps, solar hot water or district heating (Nyborg and Røpke, 2015).

3.5 Context and transferability to the UK

3.5.1 Contextual factors

Across different European countries, there are a range of contextual factors which may help or hinder policies aimed at supporting the deployment of heat pumps. These contextual factors include climate and the production and availability of natural gas and clean electricity for heating. They can also include competition with other incumbent forms of heating, such as oil and direct electric as well as natural gas heating, or with district heating networks, variations in building stock, typical heating systems (high temperature / low temperature), and temporal variations in oil and gas prices.

Figure 3.4 shows a division of Europe into three climate condition areas from European Commission guidelines in March 2013 for calculating renewable energy production from heat pumps. The colder (blue), average (green) and (warmer) climate zones represent climate conditions based on temperature and global solar irradiation typical of Helsinki, Strasbourg and Athens, respectively (EC, 2013 , Zimny et al., 2015). The north of the UK falls into the same zone as northeast France and western Germany, while the south of the UK is in an identical zone to the southwest of France and much of the southern Mediterranean.

Figure 3.4 European climate condition zones

Source: Zimny et al. (2015)

The EU Renewable Energy Sources Directive sets out the portion of heat delivered as renewable energy from heat pumps. Based on this Directive, Gleeson and Lowe (2013) calculate that for the EU, heat pumps need to have a seasonal performance factor (SPF) of greater than 2.88 in order to produce renewable heat. The current mean performance of air source heat pumps does not meet these standards, although this could change with greater penetration of renewables into the electricity grid, or improvements in heat pump design, installation and performance (Gleeson and Lowe, 2013).

The influence of contextual factors upon the capacity of countries to take up heat pumps is complex. In Table 3.2, different European countries are ranked according to heat pump sales per 1000 households, and compared in relation to contextual data on climate, natural gas production and number of gas customers in each country. In general, no definitive relationship is indicated between climate and national heat pump sales per capita. Tentative observations can be made with respect to the production of natural gas, the number of natural gas customers and climate condition zones. The three countries with the highest total heat pump sales per 1000 households are Sweden, Finland and Estonia[3], which do not produce any natural gas at all, have the least number of natural gas customers and are all in the 'cold' climatic zone. The UK and Netherlands have both the highest indigenous production of natural gas and amongst the lowest number heat pump sales per household. Despite this, Germany and Italy also have a significant level of natural gas production and have high levels of household gas connections while selling over half a million or a million heat pumps respectively from 2005 to 2013 (EHPA, 2014). This suggests that while heat pumps are likely to be more attractive to households in countries which do not have extensive natural gas connections, other factors including policies also play a key role.

In Sweden and Switzerland, the uptake of heat pumps has been facilitated by the abundant supply of low carbon electricity supply from hydro-electricity and nuclear power, as well as the lack of domestic gas reserves (Frontier Economics, 2013). The availability of clean electricity in Sweden and Switzerland has allowed heat pumps to be viewed favourably by policy makers (Kiss et al., 2014). Similarly France combines a high penetration of nuclear generation and of electric heating, with relatively high penetration of heat pumps. In contrast, as described in section 3.4.2, heat pumps faced strong political opposition in Denmark, particularly when fossil fuels dominated electricity production during the 1980s and 1990s (Nyborg and Røpke, 2015).

Table 3.3 Contextual factors and heat pump deployment across Europe: climate, natural gas production and availability

Country[1]	European climate	Indigenous production of natural	Number of natural gas customers[3],	Total number (1000s) of	Average annual heat pump sales,	Average annual heat pump sales,

[3] Norway had a higher annual average from 2010 to 2013 – 34 heat pump sales per 1,000 households – but was not included in Table 3.2 due to a lack of data on natural gas production and number of natural gas customers.

	condition zone (s)	gas, 2013 (TWh, gross calorific value)[2]	2013 (1000s)	private households, 2013	2010-2013 (Absolute numbers)	2010-2013, per 1000 households
Finland	Colder	0.0	34	2,571	64,885	25.2
Sweden	Colder	0.0	40	4,632	106,502	23.0
Estonia	Colder	0.0	52	556	12,607	22.7
Denmark	Average	56.0	420	2,339	27,364	11.7
France	Warmer / average / colder	3.7	11,301	27,804	136,831	4.9
Italy	Warmer / average / colder	81.9	22, 941	25,518	119,658	4.7
Austria	Colder	14.5	1,351	3,722	17,405	4.7
Spain	Warmer / average	0.5	7,473	18,212	62,014	3.4
Portugal	Warmer / average	0.0	1,354	4,007	12,805	3.2
Switzerland	Average / colder	0.0	423	7,970	21,248	2.7
Germany	Average / colder	115.8	21,179	39,411	67,755	1.7
Belgium	Average	0.0	3,226	4,645	7,693	1.7
Czech Republic	Colder	1.6	2,860	4,583	6,773	1.5
Netherlands	Average	796.4	7,152	7,549	8,616	1.1
Poland	Colder	49.4	6,810	13,660	11,629	0.9
Ireland	Warmer	1.8	655	1,707	1,392	0.8
United Kingdom	Average / warmer	424.2	23,003	27,611	18,185	0.7
Lithuania	Colder	0.0	559	1,310	620	0.5

Slovakia	Colder	1.0	1,503	1,811	738	0.4
Hungary	Colder	19.2	3,468	4,106	813	0.2
Column data source(s)	*EC (2013), Zimny et al. (2015)*	*Eurogas (2014)*	*Eurogas, 2014 #170@@author-year}*	*Eurostat (2016), Office (2016)*	*EHPA (2014)*	*EHPA (2014), Eurostat (2016)*

Notes to Table 3.2

1. Norway has not been included in Table 3.2 because no data is available from Eurogas (2014) for indigenous production of natural gas or number of natural gas customers.

2. Indigenous production of natural gas figures 'are best estimates available at the time of publication' (Eurogas, 2014).

3. 'Number of natural gas customers are counted by number of meters, and include domestic as well as non-domestic (industrial, commercial and other) customers, except Germany for which the number of domestic customers is equivalent to the number of dwellings supplied with natural gas for heating' (Eurogas, 2014).

Overall, it is difficult to draw unequivocal conclusions about contextual factors. The absence of an extensive natural gas supply to households and availability of low cost and low carbon electricity correlate strongly with high heat pump penetrations. However a group of 'middle ground' countries possess a more mixed portfolio of gas heating, heat pumps and heat networks. For these countries the presence of strong policies in the form of carbon/energy taxes, effective regulation and planning appear to have played a central role in creating a diversified mix.

3.5.2 Transferability to the UK

The review indicates that policy continuity and effective policy packages involving government, industry and consumers play a key role in heat pump deployment. Policies also need to integrate technical standards, quality assurance and information dissemination. Investment subsidies to cover the up-front costs of heat pump installation can form part of these packages but may have an adverse impacts if they are short-lived or lead to booms and busts in heat pump sales. There is also strong evidence that fiscal policies can help promote heat pumps if they indirectly constrain competition from incumbents – through taxes on fossil fuels.

In Austria, Denmark and Germany, fossil fuel taxes have been the most significant driver of heat pump deployment according to (Eunomia, 2016). This is reinforced through some of the evidence presented in our review, particularly in the cases of Sweden and Denmark. Since Germany possesses a substantial proportion of households connected to the gas grid (42%), it can provide an instructive comparison to the UK. In particular, the operating costs of fossil fuel heating systems are higher in Germany due to the fossil fuel tax in place there (Eunomia, 2016).

Our review does not specifically consider technological cost reduction or learning rates as metrics of policy success. However, in Switzerland and Sweden, the cost of heat pumps has decreased over time as these markets have become more mature (Kiss et al., 2014). Conversely, costs are likely to be higher in less mature markets such as the UK. As installation costs represent a significant proportion of costs related to heat pumps, there is potential for significant cost reduction in the UK under a scenario in which policies guide the UK heat pump market towards increased competition and maturity (Eunomia, 2016).

Overall the review suggests that if the UK is to develop policies to increase the use of heat pumps it is likely to be instructive to focus on the experience in countries with a diverse mix of gas and heat pumps. Whilst countries with a radically different context (particularly gas connection levels and electricity mix) might not offer such direct analogies, specific lessons may still apply. The experience of several countries in taking steps to improve the quality of heat pump installations is a clear example. The review also suggests that irrespective of context a successful approach is likely to combine subsidies, carbon taxes, regulation and strong support for certification, skills and product standards.

3.6 Summary of main findings

Our findings on policies to support the deployment of heat pumps include:

- Markets for heat pumps vary in their relative maturity across Europe, but we need to be aware of the different contexts in which these markets have developed, for example the availability of alternative heating systems, particularly natural gas. A key success factor for heat pumps is policy stability, which promotes industry and consumer confidence.

- In the UK, high consumer satisfaction with gas central heating systems means that in recent surveys many consumers say they would be unwilling to consider alternatives. Across Europe, heat pumps have been widely deployed where natural gas networks are less extensive, as gas heating is typically cheaper than alternatives. Off-gas consumers in the UK may be more willing to consider alternative heating technologies.

- In market leading European countries, policies to promote heat pumps, implement information campaigns and increase technical standards have been successfully deployed in combination with subsidies to stimulate the widespread take-up of heat pumps. Low consumer awareness and confidence forms a barrier to the uptake of heat pumps; enhancing the reputation of the industry through standards and regulations have been key in overcoming this barrier in countries with high levels of uptake of these technologies.

- Swedish, German and Danish experiences in the early to mid-1980s suggest that success of public subsidy support depends upon standards of manufacturing, installation and maintenance being sufficient to maintain the reputation of the heat pump industry. Some leading European heat pump markets (e.g. Germany, Sweden and Switzerland) experienced a recovery and growth in heat pump sales from the early 1990s, in particular due to concerted attempts by governments and industry to boost the reputation of heat pumps through a combination of promotion, information campaigns, subsidies and technical standards.

- Heat pump deployment in Denmark was affected by varying political support for the environmental agenda, opposition to electric heating, or lack of recognition of heat pumps as a legitimate form of renewable energy. There is similarity between the UK and Denmark since in both countries subsidy programmes supporting renewable heat technologies have been delayed or terminated, adversely impacting on market confidence.

It is important to determine the balance between policies which incentivise heat pumps and those which support the development of district heating. In

Denmark, policies have included mandatory connection to district heating or natural gas networks, a ban of heat pumps in collective supply areas and increased subsidisation of heat pumps outside collective supply areas. Chapter 4 considers heat networks in detail and returns to this interaction issue.

4 What works to support the deployment of district heating?

4.1 Introduction

Drawing on the review of international literature, this chapter sets out findings on what works and what doesn't work in relation to policies which support the wider uptake of heat networks, also known as district heating (DH). As in the case of heat pumps the literature indicates that there is a wide range of variation in the penetration of district heating across Europe. In the UK to date, district heating has achieved very little deployment compared to other countries in Europe. In Denmark, Sweden and Finland, 50-60% of buildings are supplied by district heating; by contrast, district heating supplies perhaps 1% of buildings in the UK (Ecoheat4EU, 2011ae). Barriers to the development of district heating in the UK are fairly well known, and are described by DECC (2013g), Frontier Economics (2015) and others.

There are important differences between heat pumps and heat networks, with the latter requiring a higher degree of regional or urban coordination and planning. Nevertheless the review reveals important similarities related to policy continuity, financial support and the quality of the consumer experience. As with Chapter 3, this chapter provides a brief review of the UK experience (section 4.2) before assessing the international experience in terms of individual policies (section 4.3). In section 4.4, the sequence, combination, stability and flexibility of policies are considered with reference to two country case studies: Sweden and Norway. Section 4.5 explores the different contextual factors which influence the effectiveness of policies in other countries and the extent to which they might be transferable to the UK policy context.

4.2 UK policy experience

In the UK, short-term and abruptly changing policies relating to district heating development have created uncertainty and perceived risks for local government and the commercial sector (Webb et al., 2014). UK grant programmes have triggered some limited 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 (Hawkey, 2012). The perceived uncertainty of UK energy policy in general can also raise concerns about future risks to district heating (DECC, 2015).

A number of UK policies have focussed on funding feasibility assessments for district heating rather than infrastructure development: the Low Carbon Pioneer Cities Heat Networks Project, Heat Networks Delivery Unit (HNDU), and the London DEMaP project. Specialist support from either DECC or ARUP was provided along with funding, and the role of specialist support to local authorities is discussed further below.

The HNDU successfully attracted a large number of applications (234 from 121 Local Authorities), of which 201 were successful; most Local Authorities working on heat networks applied for this central government funding, and it may have helped to raise the profile and perceived credibility of district heating. However, while these projects are still at an early stage, their further development appears to be highly uncertain: many Local Authorities expect it will be challenging to secure funding for the capital costs of development and to pay for further external support (e.g. for commercial skills training). In addition, some projects may require public investment to go forward since they offer marginal rates of return (DECC, 2015). This concern appears to be supported by the experience of the district heating scheme in Birmingham, operated as a public private partnership, where the focus on profitability has meant separate public funding was been required to meet local objectives by extending the network to supply multi-storey public housing (Hawkey et al., 2013).

By contrast, the London DEMaP project, which was succeeded by the Decentralised Energy Project Delivery Unit (DEPDU), has driven actual network deployment. By project closedown in 2015, ten out of ‘more than 20’ supported projects had progressed to procurement and delivery, with ‘many others in the pipeline’ (Kirk, 2015). DEPDU provided Local Authorities and other district heating sponsors with financial assistance and specialist support from the consultancy ARUP to support project commercialisation (UNEP, 2015). In some cases, the availability of support from DEPDU leveraged other funding for additional feasibility studies (Board, 2013).

Multiple stages of funding are desirable to support heat network deployment (UKERC, 2016), and DEPDU appears to have been successful in offering support beyond the stage of feasibility assessments. DEPDU was 90% funded by the European Investment Bank on the condition that this would be repayable if projects failed to leverage significant additional capital investment. To reduce this risk, only projects with a high chance of being delivered were prioritised for development (Board, 2013). It seems likely that this model would not be able to support many of the projects identified following the support of the HNDU, if these cannot attract private capital. In addition, some projects supported by DEPDU consisted of extensions to existing networks of supply of new-build areas, and capital cost and financial risk may be reduced when connecting new-build areas to district heating rather than retrofitting (Ecoheat4EU, 2011ae).

In Scotland, investment support for infrastructure development is available and the majority of funded schemes are already in operation. The District Heating Loan Fund provides loans of up to £400,000 covering up to 100% of the cost of developing district heating schemes, which are repayable with 3.5% interest over 10 years; technical support is also offered where appropriate. In addition, the Warm Homes Fund can support district heating projects that use renewable heat to provide affordable warmth to homes, and offers grants of up to £20,000 and loans of up to £5million. Together this support has funded 26 DH schemes, of which 22 were operational at the time of evaluation. Half of respondents would likely not have taken action without the support scheme, and the remainder may have taken some action but using the support scheme reduced risks to project delivery (Fawcett); a similar finding was reported for the Low Carbon Pioneer Cities Heat Networks Project (Ambrose et al., 2015).

Although a high number of individual schemes have been developed as a result of capital support available in Scotland, they appear to be relatively small in scale, with 835 households newly connected to district heating in total (a single project supported by DEPDU, Royal Free Hospital in Gospel Oak, provided heat to over 1,500 residents). It is unclear at his stage of the review whether this was due to the nature of schemes Local Authorities prioritised for development, or limitations of the policy support. Suggestions to improve the scheme include additional technical support, such as a best practice guide, which could increase confidence to develop larger schemes; offering higher loan amounts for larger projects to be delivered; and marketing DH more widely to larger potential customers, such as housing associations and facilities managers (Fawcett).

The planning and regulatory framework supporting district heating is generally relatively weak in the UK, which is suggested as a major factor inhibiting its development (Toke and Fragaki, 2008). UK policy requires only voluntary appraisal of the use of waste heat from, for example, thermal electricity generation, and it has been suggested that UK lobbying contributed to weakening the EU Energy Efficiency Directive to replace mandatory use of waste heat with a requirement for business case analysis (Hawkey and Webb, 2014).

There are perhaps some exceptions with a stronger planning framework, but these are limited to specific areas of the UK. At one point planning regulations required new developments in Milton Keynes to connect to district heating (Hawkey and Webb, 2014). The Greater London Authority developed an Opportunity Area Planning Framework supporting district heating, which also requires connection to existing or planned heat networks (Nine Elms on the South Bank, 2016).

Relatively little UK evidence has been identified to date on specific policies to support customer connection to district heating. The evidence so far reviewed included one example that evaluated residential consumer acceptance of district heating: at the Wyndford estate in Glasgow, replacement of old electric storage heaters with district heating plus external wall insulation lead to substantial increases in satisfaction amongst the 10% of residents interviewed. Heat metering and billing was sometimes confusing, however, with some residents finding it difficult to understand how their use of heating and hot water related to what they paid (Webb et al., 2014).

More generally, early customer liaison was identified as a key success factor for District Heating Loan Fund projects (Fawcett), but many projects funded through the HNDU expected it to be challenging (DECC, 2015). In particular, it can be difficult to coordinate multiple larger consumers, which may have differing needs, and mistrust a communal solution (Hawkey, 2012).

4.3. Policies to support the deployment of district heating

4.3.1 Financial support – investment subsidies

District heating is capital intensive, and has uncertain returns unless established as a monopoly. This points to an important potential role for financial support for investment (Andrews et al., 2012). Investment subsidies may be provided as a grant or loan, and ongoing financial support may be provided in various ways. The review to date has identified international evidence on the role of investment subsidies and ongoing financial incentives. These are discussed in turn in the following sub-sections.

Investment grants are considered to be a general good-practice support measure, but not typically suitable for countries with highly developed district heating markets (Ecoheat4EU, 2011ae). Stakeholders from countries where district heating is less developed see investment grants for network development as highly important (Werner, 2011).

In the majority of cases, investment subsidies were not involved in the extensive development of district heating seen in Denmark and Sweden. However, most development took place before energy market liberalisation, with district heating companies owned and/or controlled by municipalities, and risk reduced through planning and regulation of heat supply (Toke and Fragaki, 2008, Ericsson, 2009). Danish municipalities have also reduced risk by guaranteeing loans to district heating developers (Andrews et al., 2012).

Some evidence has been identified of investment subsidies for district heating development in pre-liberalisation contexts. In pre-liberalisation Germany, investment subsidies were provided by the Future Investment Programme (ZIP) I and II which followed the 1970's oil shocks. On average 35% of investment costs was distributed to district heating utilities to promote the expansion of CHP and district heating; connected load increased by around 14,000 MW, and employment also increased (Ecoheat4EU, 2011a). In Sweden, two waves of investment subsidies for biomass CHP took place before and after energy market liberalisation in 1996, with the aim of increasing biomass CHP generation in the context of the planned closure of nuclear generators. These had a relatively small direct impact on national electricity generation, but may have helped to raise the profile of CHP (Ericsson, 2009).

Investment subsidies have been widely involved in the development of district heating post-liberalisation, although Prague's district heating system is unusual and noteworthy because much of its development took place under free market conditions with no subsidy or grant, although the project was started under a planned economy (Andrews et al., 2012). In Norway, investment subsidies have been the most important measure for expanding district heating. Support for district heating has been given to all new district heating plants, including investments of 30 million Euros in 2008 and 59 million Euros in 2009 (Ecoheat4EU, 2011a).

The district heating development in Rotterdam, Netherlands, received a central government grant of 27 million Euros linked to avoided CO_2 and NOx. It was developed by a municipally owned company and also received 38 million Euros in municipal equity as well as having 150 million Euros of loans underwritten; these figures reflect municipal support approximately tripling after the closure of a local waste incinerator meant increased capital investments in more extensive heat networks were necessary for the project to be delivered (Hawkey and Webb, 2014).

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 DH (Ecoheat4EU, 2011a). Under the German CHP Act in 2013, single payments totalling €110 million were used to fund 1,017 district heating systems with a total length of 423 km (Gailfuss, 2016).

There is also some evidence that investment subsidies can stimulate expansion of district heating in countries where it is already well established. Funding from central government supported the development of less traditional heat networks in post-liberalisation Sweden, including smaller networks, expansion into less heat dense areas of one and two family homes, and greater use of industrial waste heat that was less local to heat demand areas and so required relatively extensive heat networks. It played a particularly important role in improving the economics and raising legitimacy of industrial waste heat to supply district heating. District heating competed with other types of projects to secure this funding, which was available for local projects to address environmental issues, employment and greenhouse gas emissions (Ericsson, 2009).

Between 2006 and 2010, Swedish subsidy programmes were directed to individual consumers. A subsidy for replacement of oil boilers in one or two family homes had high uptake and resulted in more rapid replacement, but was criticised for poor cost-effectiveness. 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 around 80% shift to district heating, although with significant variation between regions depending on local feasibility (Ericsson, 2009).

The way funding is administered may influence its effectiveness. For example, in an Italian support scheme, selected DH plants received a set percentage of allowable investment costs as a one-off grant; 70% of available funds were allocated, and only 32% of selected projects are currently in operation (rising to 49% if failed projects are excluded) (Aste et al., 2015). Payments were made after completed work was verified, in some cases many years after work began, and the support mechanism could be improved by simplifying and clarifying the application process and criteria and reducing the time involved (Aste et al., 2015). In addition, policies may need to offer sufficient levels of funding to have larger scale impacts. Investment subsidies for heat networks under the German CHP Act were at one time limited to 20% of total investment, which may be too low (Ecoheat4EU, 2011a). Also in Germany, the Market Stimulus Package for Renewable Energy Sources (MAP) focussed on small and medium enterprises and relatively small projects or investment levels. Ecoheat4EU (2011a) suggests that the MAP should be expanded to cover installations or enterprises of any size.

In general, investment grants may be more effective at reducing perceived risk because they do not require ongoing political support (Ecoheat4EU, 2011ae). Investment subsidies could also reduce the total funding required if funded organisations apply high discount rates to future funding (Frontier Economics, 2015). Nevertheless, grants have been criticized for reducing developer accountability and leading to less well designed systems (Thorsteinsson and Tester, 2010). In Iceland, geothermal exploration and drilling has been funded by government loans that convert to grants if no resource is identified (Thorsteinsson and Tester, 2010), and the logic of providing grants rather than loans could perhaps also apply to funding for feasibility assessments.

4.3.2 Ongoing incentives and carbon/energy taxes

Some international evidence was identified of financial incentives provided by schemes that increase the revenue that can be gained from CHP electricity generation, or tax alternative forms of heating (Ericsson, 2009, Toke and Fragaki, 2008).

In Sweden, tradable certificates for renewable electricity supported biomass CHP and were often the most important factor in deciding to invest in CHP. This has resulted in an increase in CHP for DH, which previously decreased after the development of nuclear generation (Ericsson, 2009).

Denmark promoted CHP generation from the beginning of DH deployment. The 'triple tariff' paid to CHP operators was based on the time of electricity generation, with higher tariffs being paid during peak times. Aggregators allow CHP operators to access similar markets and prices as large generators, and the triple tariff has now been more or less replaced by trading on the spot market. Danish CHP-DH typically incorporates additional thermal storage which supports this flexibility (Toke and Fragaki, 2008).

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. Investment support for heat storage is also continued, which can support more flexible operation of CHP to help balance renewable generation (Toke and Fragaki, 2008).

As 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 (Gailfuss, 2016). Aste et al. (2015) note that CHP increases overall economic viability as well as energy efficiency of DH, but report some evidence in Italy of inefficient heat dumping as a result of perverse incentives that excessively reward electricity generation, and suggest that incentives should be optimised to maximise environmental benefits.

As with heat pumps, carbon or energy taxes levied on incumbent heating options can also incentivise heat network development. They may also have a significant impact on the fuels used to provide networks with heat. Oil was taxed from the start of district heating development in Denmark in the 1970s, and the level of taxation was raised after oil prices fell in the 1980s, which allowed CHP systems to be run profitably (Toke and Fragaki, 2008). Denmark now has one of the highest energy taxes in Europe (Oñate et al., 2014). Taxes in Sweden were introduced after the initial development of DH, and have mostly been responsible for changing the fuel used to meet shifting policy objectives: first reducing oil use, and more recently increasing the use of biomass. District heating infrastructure has been able to rapidly respond to changing energy policy in this way (Ericsson, 2009). In Norway, there are taxes on fuel oil and electricity (the main alternative heating sources), but there is a tax deduction for electricity used for district heating, while waste incineration, the main heat source for district heating, is tax exempt (Ecoheat4EU, 2011a). Germany taxes fossil fuels and CHP plants, which are the main heat source for district heating, and are exempt from this tax if their load factor is over 70%. Large power stations are also exempt from this tax, so the tax exemption for CHP provides no advantage for electricity generated from CHP, but it nonetheless provides a significant advantage for district heating over individual oil and gas heating (Kerr., 2008).

4.3.3 Heat planning

Planning frameworks supporting or mandating district heating in certain areas can reduce the financial risk of developing district heating projects (Ecoheat4EU, 2011ae). Andrews et al. (2012) contend that since district heating is capital intensive, and inherently risky in a free market, projects will only be developed if developers are confident they will access a high percentage of the heat market. They propose that for district heating to be economically attractive 60% of the heat market in the development area must be connected. Building regulations can play a role as well as zonal heat planning.

Andrews et al. (2012) also suggest that European countries with high levels of district heating have greatly reduced 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. Heat planning is generally perceived as a highly useful policy by stakeholders across a range of countries, but there is some tension between prescriptive planning and consumer choice (Werner, 2011). This challenge is illustrated by the example of Germany, which has a framework for very strong heat planning, but which is little used as it can be unpopular; this is discussed further below.

Denmark and Sweden employed relatively prescriptive planning pre-liberalisation, when most district heating development took place. Municipalities' responsibilities and powers regarding heat planning have decreased following energy market liberalisation, and heat planning has become less widely used. In Denmark, local authorities are required to produce local heat plans that identify existing and future heat demands of buildings and current and potential heat sources, and assess which heat sources are most socio-economically cost-effective and locally appropriate. The Danish Heat Law of 1979 required local authorities to oblige new buildings to connect to DH, and electric resistance heating was banned in areas supplied by district heating, obliging many buildings to connect (Toke and Fragaki, 2008, Oñate et al., 2014). From 2000, local heat plans in Denmark no longer required binding planning, and local authorities may decide whether or not to require certain buildings to connect to district heating (Chittum and Østergaard, 2014); the extent to which this power is used varies considerably (Oñate et al., 2014).

Planning was also a key part of district heating development in Sweden (Oñate et al., 2014). Heat networks were initially managed by municipalities, and then transferred into municipal ownership (Ericsson, 2009). Subsequently, some of these DH systems were sold to large national or international utilities, which in the late 2000s accounted for 42% of energy supplied to district heating (Ericsson, 2009).

In 1977, Swedish municipalities were required by law to develop local energy plans. The law has been criticised for a lack of clarity on exactly what the plans should include, and a lack of sanctions for municipalities not producing them; about 27% of municipalities did not have a plan in 2006. Also, the law does not give municipalities any authority to influence other actors, for example by mandating the use of district heating. Nonetheless, in pre-liberalisation Sweden, some municipal energy companies refused to supply electricity for heat in areas with existing district heating. In post-liberalisation Sweden, customers are free to disconnect from district heating and use alternative heating sources, although district heating suppliers are granted monopolies on district heating supply. Although local authorities are not able to mandate the use of district heating, they are able to require new building developments to be connected to district heating. However, this power is not always used. Alternatively, municipalities may suggest district heating supplies a new development where this is viable, and facilitate communication between developers and the district heating supplier (Ericsson, 2009).

Germany has the potential for a very strong planning framework, particularly post-liberalisation. 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 district heating infrastructure. A number of municipalities have used mandatory heat planning, but it accounts for only 12% of district heating in the country (Ecoheat4EU, 2011a). It can be unpopular and this may account for it being relatively little used, but increasing public involvement in the process could help to promote acceptance (Ecoheat4EU, 2011a).

Norway also has a fairly strong planning framework, although customers are not obliged to use district heating. The Planning and Building Act, introduced in 1985 (Norwegian Ministry of Local Government and Modernisation, 1985), obliges municipalities to consider district heating feasibility as part of spatial planning, and they may choose to create local heat plans that support district heating. The Energy Act requires district heating companies to produce detailed development plans, including evidence of customer commitments to connect, in order to obtain a license; in turn, the license grants them a concession to supply district heating in a given area. If that area is also covered by a local heat plan supporting district heating, the district heating company is able to require all customers to connect to, though not use, district heating (Ecoheat4EU, 2011a).

4.3.4 Regulations relating to building energy efficiency and the use of waste heat

District heating is technically compatible with energy efficient buildings, and supplying low energy buildings can also support the use of lower temperature heat including from renewable sources (Andrews et al., 2012). However, there can be economic challenges if heat demand decreases (Ericsson, 2009). The Planning and Building Act 2010 in Norway required all buildings above 500m^2 to have a minimum 60% of their net heating demand supplied by means other than direct electric heating or fossil fuels; for buildings under 500m^2, the minimum requirement was 40% (Ecoheat4EU, 2011a).

In Germany, the Act on the Promotion of Renewable Energies in the Heat Sector (EEWärmeG) aimed to increase the share of renewable energy in final energy consumption for space and water heating, and cooling, to 14% by 2020. DH is covered if heat is produced by a substantial share of renewables, at least 50% CHP, or a combination of both (Ecoheat4EU, 2011a).

The objective of the German Energy Saving Ordinance (EnEV) (amended in 2009) was to reduce primary energy demand for heating and hot water in buildings by 30%. This could be delivered through CHP DH in combination with insulation, or other measures (Ecoheat4EU, 2011a), while minimum insulation levels were also required (Ecoheat4EU, 2011a). 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. However, they have also led to a decrease in heat demand over time, while the level of heat demand has become less certain because the legislation has changed 'on a regular basis’ (Ecoheat4EU, 2011a).

Regulations requiring the use of waste heat can also promote the development of district heating (Hawkey and Webb, 2014), and coordinated planning with waste management can provide heat sources for district heating through municipal solid waste incineration or biogas production (Ericsson, 2009).

Regulations on the use of waste heat initiated DH development in Norway and the Netherlands. In Norway, this related to EFW, and in the Netherlands, to industrial waste heat. However, there could be concerns in that sources of waste heat may be far from settlements, requiring more capital investment (Ericsson, 2009), and further local co-dependency and risk introduced – as seen in a case in Netherlands described by Hawkey and Webb (2014), where one waste heat source withdrew, and another closed down.

In Sweden, available waste heat from industry was an important factor behind DH development in some towns. Subsidies were important for developing the more extensive networks necessary to recover waste heat. From 2002, a ban on landfill of combustible waste encouraged the uptake of energy from waste as a heat source for DH, although this appears to relate principally to existing networks (Ericsson, 2009).

4.3.5 Technical standards, price regulation and consumer protection

In Sweden, the Swedish District Heating Association had an important role in setting technical standards for performance and interoperability. Technical standards also benefited the emerging industry by reducing the risk of becoming locked into obsolete infrastructure with no replacement parts available, disseminating knowledge and helping to ensure pipes performed consistently well, and possibly reduced the price of pipes (Ericsson, 2009).

Price regulation can increase consumer confidence in district heating (Andrews et al., 2012), and this may be particularly important where planning has created monopoly operation (Ecoheat4EU, 2011ae). Prior to liberalisation in Sweden, cost-based pricing was mandatory and district heating companies were prohibited from making profits. Price regulation ended with liberalisation and district heating tariffs now vary significantly between areas. This is likely to reflect different costs in different areas, but also different approaches to cost setting and expected profits: some suppliers set prices according to cost (although information on costs is not transparent), and some consider the price of alternative heating; while large utilities may expect much higher rates of return than municipal district heating companies (Ericsson, 2009).

In Sweden, 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 (Oñate et al., 2014). Third party access for heat to networks has been discussed, but may reduce district heating operational efficiency (Oñate et al., 2014) and increase costs through increasing risk and administrative burden, which could cancel out the benefits of competition (Ericsson, 2009). It could also make it more difficult to coordinate district heating planning and management with, for example, local waste management (Ericsson, 2009).

In 2005, Reko quality certification was introduced for district heating with the intention of increasing consumer confidence. Certification includes a requirement for price transparency. Reko certification soon became widespread but in 2008 a new District Heating Law came into force mandating price transparency for district heating and directing contract conditions. An Independent District Heating Board was set up as part of the Swedish Energy Agency to mediate disputes between energy companies & customers, and energy companies and industries supplying waste heat (Ericsson, 2009).

In Germany, the Ordinance on General Conditions for the Supply of District Heating was established in 1980 and continues today (Ecoheat4EU, 2011a). It provides a framework of standard business conditions and contracts for the supply of DH to all customers other than industrial customers. This aims to offer customer protection, but also benefits the district heating industry through providing greater legal certainty around the business. Actors from the district heating industry see the Ordinance as important for further development of district heating (Ecoheat4EU, 2011a). Although likely due to factors other than the Ordinance, it is interesting to note that in a survey conducted by AGFW (the German Energy Efficiency Association for District Heating, Cooling and Combined Heat and Power) comparing consumer attitudes to district heating, gas, oil, and other forms of heating, district heating has a higher rate of overall satisfaction, is considered to have the fairest pricing and has highest customer loyalty (Ecoheat4EU, 2011a).

District heating operators may also choose to provide price guarantees to reassure users. A district heating marketing campaign in Sweden (targeting detached homes, which have little DH supply) offered fixed prices for heat for five years (Mahapatra and Gustavsson, 2009). A government grant was available to encourage residential consumers to switch from electrical resistance heating to district heating, heat pumps or biomass boilers, but the marketing campaign was identified as key since consumers subsequently preferred district heating in particular (Mahapatra and Gustavsson, 2009). Other than fixed heat prices, success factors identified for the campaign included a two year guarantee on installations, with removal of existing heating and installation of components for district heating offered as a package; the district heating company arranged for a bank to offer attractive loans to residents for costs not covered by the government grant; and the high use of interpersonal communication, such as numerous local meetings to present the offer, and use of a demonstration vehicle parked locally to show prospective customers how district heating is operated in the home (Mahapatra and Gustavsson, 2009).

4.4 Applying policies to support the deployment of district heating

4.4.1 Policy stability and flexibility

In general, policy stability was identified as a key success factor for district heating development, including in Iceland (Thorsteinsson and Tester, 2010) and Denmark, where perceived policy stability means banks compete to loan to district heating projects (Chittum and Østergaard, 2014). Evidence has been identified of policies being changed to improve their effectiveness for a variety of reasons: to target policies more closely to meet policy objectives; and to respond to changing policy objectives over time.

Since stability is an important success factor for district heating policy, it seems reasonable that any changes to policy will be more effective if these do not increase uncertainty for district heating market actors. As well as providing ongoing support to projects that began under previous forms of the policy, consulting district heating market actors as well as other stakeholders to inform policy design may increase the effectiveness of support measures (Ecoheat4EU, 2011a). Following energy market liberalisation in Sweden some district heating has come under the ownership of national/international utility companies, rather than municipal energy companies, and it is uncertain whether this has resulted in a decrease in investment (Ericsson, 2009).

In addition to national energy policy promoting district heating, the design of specific policies can influence stability for projects. The Norwegian Energy Fund includes a mechanism to transfer unused funds from previous years; this flexibility creates funding certainty for major capital intensive projects with long and often uncertain delivery times. The Energy Fund also receives new funds each year from returns on national deposits and a small charge on electricity bills, which creates certainty for industry and helps Enova (a public enterprise which provides investment support for district heating) to fund large projects (Enova, 2015).

German policies relating to building efficiency can also promote district heating, but as requirements are regularly reviewed and tightened this creates long term uncertainty for heat demand (Ecoheat4EU, 2011a).

In Germany, policies have been changed to improve their effectiveness, and to align policies on CHP with those on renewable generation. To improve policy effectiveness, the 2009 amendment to the CHP Act addressed some limitations of the 2002 policy by removing size restrictions on CHP plants eligible for support, and introducing investment subsidies for heat networks to provide a sink for surplus heat from CHP. It also gave electricity from CHP dispatch priority equal to renewables (Kerr., 2008). The most recent amendment to the CHP Act in 2016 followed an evaluation of the Act in 2014 (Gailfuss, 2016). Changes in 2016 that aim to improve policy effectiveness are that larger CHP plants over 10MWe have the amount and duration of bonus payments decided in advance of construction, to reduce uncertainty, while smaller CHP plants up to 2kW will now receive investment subsidies to reduce the administrative burden (Gailfuss, 2016). Other changes in 2016 better align the Act with wider energy policy. Coal CHP will no longer be supported. Bonus payments will no longer be made when electricity prices are negative, and electricity from CHP plants over 100kW must either be consumed by the plant owner or marketed directly; these changes should result in CHP electricity generation taking a somewhat more active role in the electricity system and integrating with renewable generation (Gailfuss, 2016).

In Norway, investment support and other polices have been increasingly targeted over the years in response to policy evaluation and cost analysis of possible policy targets. Investment support initially supported the most rapid deployment of district heating. Investment support was later diversified to target different heating plants, including smaller plants, greater use of renewable heat, and demonstration projects for more innovative technologies. Policies aimed at end consumers were introduced following the decision to support conversion of direct electric heating to water based central heating where this is relatively easy to do, in order to allow further expansion of district heating (Enova, 2012).

4.4.2 Sequence and combination of policies

The deployment of district heating faces multiple barriers (DECC, 2013g) suggesting that packages of policies may be more successful than single policies in encouraging its deployment. There is also some evidence that different types of policies can address the same barrier: financial support and heat planning can both reduce the risk of making a large capital investment when future demand is uncertain. This makes it interesting to consider the sequence and combination of policies employed in countries which have achieved district heating deployment which was targeted by policy.

This subsection discusses some suggestions on how the sequence and combination of policies may influence the uptake of district heating, considering the two country case studies presented in boxes 4.1 and 4.2 and other relevant evidence reviewed in section 4.3.

Firstly, we consider the role of price regulation in liberalised markets, and how this is affected by other policies. In Sweden, where DH has already been developed, heat networks became established prior to the liberalisation of the market, and the loss of price regulation following liberalisation has caused concern because DH represents a natural monopoly and is an established and straightforward heating technology for many people to use. In response, requirements for pricing transparency and contract conditions were introduced (Ericsson, 2009) (Oñate et al., 2014).

In other countries where DH has not yet been developed, and heat planning is used to support DH infrastructure development, it might be appropriate to use price regulation or other consumer protection alongside this. For example, the Norwegian Energy Act in 1991 included price regulation for protecting the customer, due to the connection obligation in the Planning and Building Act (Ecoheat4EU, 2011a).

Another question is whether it is more effective to target heat sources or network development. Both funding and planning/regulatory requirements can target either the development of heat networks including customer substations, the use of certain heat sources, or both. Germany and Denmark promoted the use of CHP before the use of district heating. In Denmark, the 1976 Electricity Supply Act stipulated all new electricity production must be in the form of CHP, and ongoing financial support for CHP was also introduced. The expansion of CHP plants provided low cost heat for district heating (Toke and Fragaki, 2008). The Danish Heat Law of 1979 required municipalities to plan heat supply considering current and potential future heat sources, and allowed for connection to district heating to be mandated for new buildings and direct electric heating to be banned in district heating supply areas. This ensured that district heating development followed CHP development.

In Germany, the 2002 CHP Act initially supported only CHP through a system of bonus payments, but was amended in 2009 to include investment subsidies for district heating to provide a sink for waste heat from CHP, which suggests that the development of CHP itself was not sufficient to drive development of DH networks. The German Market Stimulus Package for Renewable Energy Sources (MAP) aims to increase investment in renewable heat sources, and provides funding for heat network in addition to the heating technologies themselves. Heat networks are relatively expensive, so it is suggested that supporting their development can also help to promote the development of the heating technologies (Ecoheat4EU, 2011a).

Overall, based on the evidence reviewed, promoting the use of specific heat sources might be a trigger of change from business as usual, but may not necessarily be sufficient due to high costs and risks of developing networks. There can also be barriers to promoting the use of specific heat sources. The use of waste heat may introduce greater risk, since it relies on industry or waste incinerators providing waste heat remaining involved in the project; this was an issue in the development of district heating in Rotterdam (Hawkey and Webb, 2014). The use of waste heat may also involve considerably higher investment costs if longer heat networks are required to carry heat from where it is produced to areas of heat demand (Ericsson, 2009).

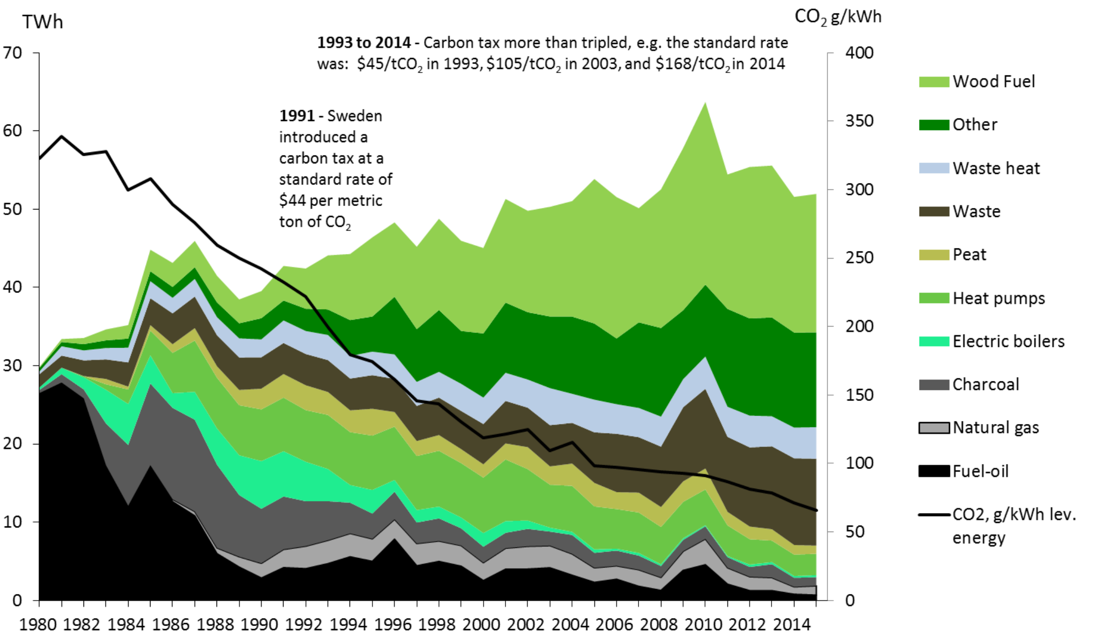
Case study 4.1: Sequence and combination of policies in Sweden

Nearly all Swedish towns have a district heating system (Ericsson, 2009). District heating is the dominant form of heating in multi-family houses and premises, comprising 50% of total heating demand in Sweden in 2012 (Sköldberg and Rydén, 2014). 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). Most district heating development took place before energy market liberalisation, and district heating companies were first managed and then owned by municipalities. 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. From 1977 municipalities were required to develop local energy plans addressing energy efficiency and energy security; the requirements for these plans have been modified over the years (Ericsson, 2009).

The use of CHP fell following the expansion of nuclear power generation, but has since risen along with electricity prices, planned closure of nuclear generation, and the promotion of biomass CHP. In 1991, a carbon tax was introduced, which has been gradually increased. This resulted in a considerable decrease in the use of fossil fuels and increased use of biomass (see Figure 4.1), alongside two investment subsidy programmes for biomass CHP between 1991 and 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. Consumer subsidies to replace oil boilers and direct electric heating drove some additional uptake of district heating between 2006 and 2010, and some district heating companies actively promoted these opportunities to customers (Ericsson, 2009, Mahapatra and Gustavsson, 2009).

Cost-based pricing 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. 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 (Oñate et al., 2014). 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 Law 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.

Figure 4.1 Sweden: energy sources used for district heating production, 1980–2015,and carbon taxes



Source: Sverige (2016)

Case study 4.2: Sequence and combination of policies in Norway

District heating installed capacity in Norway more than tripled between 1999 – 2009, a growth rate that is unique in Europe (Ecoheat4EU, 2011a). Figure 4.2 illustrates how fuel consumption for the production of district heating has increased by almost four times between 1995 and 2015, with energy from waste being the main source of this growth. District heating has been developed or is planned in most larger Norwegian towns, and more than 60 companies have been granted licenses for DH (Norwegian Ministry of Petroleum and Energy, 2015). In 2012, district heating consumption totalled 4.2 TWh (Norwegian Ministry of Petroleum and Energy, 2015), and in 2011 district heating supplied 6% of multi-family buildings and 2% of all residential buildings (Buildings Performance Institute Europe, 2016).

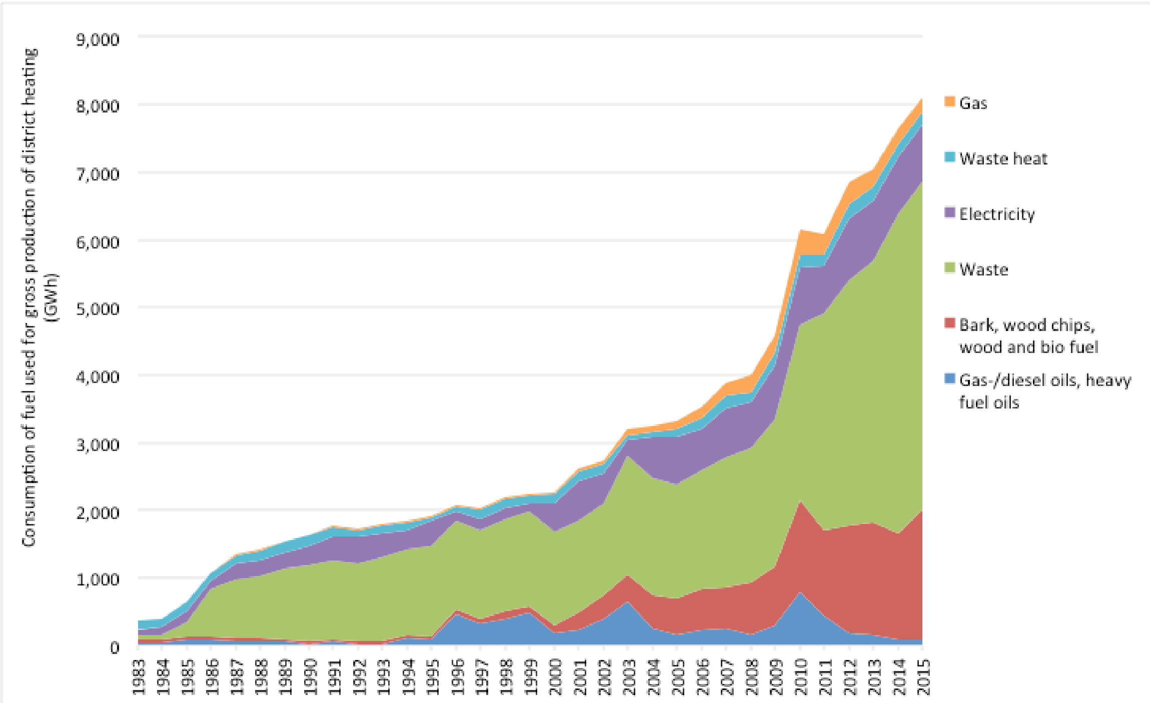
The earliest period of district heating development in Norway was the 1980s (Ecoheat4EU, 2011a). From 1985, the Planning and Building Act allowed connection to district heating to mandated in district heating license areas (Norwegian Ministry of Local Government and Modernisation, 1985). Electricity has been taxed since 1951, and fuel oil since 1991 (Ecoheat4EU, 2011a).

Alongside energy market liberalisation in 1991, price regulation and standards were introduced as part of district heating license conditions. Price regulation requires that district heating prices do not exceed the price of residential direct electric heating (the dominant form of heating in Norway) in that locality (Norwegian Ministry of Petroleum and Energy, 2007).

In the 1990s Norway experienced an energy crisis as the result of large variations in hydropower generation. This led to a new national energy strategy and the creation of Enova, a public enterprise for support of environmentally friendly energy projects, in 2001, and this was followed by new climate-related aims in 2002 (Becidan et al., 2015). The main objective of Enova’s programmes for district heating and heating plants is to increase Norway’s energy security by reducing dependency on hydropower for electric heating (Enova, 2015).

From 2002 to 2007, Enova provided investment support for major plants for heat production and distribution. To allow more rapid deployment, there was a focus on supplying buildings with existing water based central heating. In 2007, Enova carried out an evaluation of support measures and the potential for and barriers to district heating. This identified significant potential for additional conversion to district heating, with the most important barrier being the lack of infrastructure inside and outside buildings. In 2009, Enova carried out an analysis of the costs of converting buildings to water based central heating (Enova, 2012). A landfill ban on biodegradable waste was announced in the early 2000s and came into force in 2009. This resulted in more energy from waste plants being built (Enova, 2012). Municipal solid waste incineration is the main heat source for district heating, providing 34% of heat (Ecoheat4EU, 2011a). From 2008, Enova provided more targeted investment subsidies. This included support tailored to investment in renewable heat, including a large solar thermal demonstration plant, and support for the installation of central heating where this is relatively straightforward (Enova, 2012). A consumer advice service and direct subsidies to consumers, which cover conversion to water based central heating amongst other technologies, were later introduced (Enova, 2015).

Figure 4.2 Fuel types used for district heating production in Norway, 1983 – 2015



Source: Statistics Norway (2016)

4.5 Context and transferability to the UK

4.5.1 Contextual factors

The preceding discussion has set out to assess the effectiveness of policies supporting the deployment of heat networks across different national contexts in Europe and under different market structures (i.e. pre-/post-liberalised national economies). In order to understand how transferable these policy experiences might be to the design of policy for heat network development in the UK, it is first necessary to consider the various contextual factors that have hindered or facilitated the increased development of DH in a particular country or market context.

In Table 4.1, contextual factors relating to natural gas production and availability are compared to the number and capacity of district heating systems, and the percentage of citizens connected to district heating, in different European countries. As with heat pumps, it is notable that, of the countries shown, both the UK and Netherlands produce the largest amounts of indigenous natural gas, while they are within the lowest three countries in terms of residents connected to DH (2% and 4% respectively). Conversely, four of the six countries where at least 50% of citizens are connected to district heating do not produce any natural gas (Estonia, Lithuania, Sweden and Finland). On the other hand, both Denmark and Norway have domestic natural gas resources and Germany has a high level of natural gas connections to households. As with heat pumps, the interaction of natural resource endowments, climate, policies and energy prices is complex.

In Sweden and Denmark, most DH development took place prior to energy market liberalisation. In Scandinavian countries such as Sweden, Denmark and Norway, DH was developed in the absence of extensive natural gas heating, whereas in the UK, heat supply from natural gas is relatively cheap and convenient. Nevertheless, electric heating was replaced by DH in the former countries, and consumers may prefer established heating technology in general.

The need for different policy support packages may depend on the context and the objectives for district heating development. For example, EcoHeat4EU suggested that investment subsidies are not appropriate in contexts where district heating is highly developed, but it played an important role in expanding district heating into less traditional areas in Sweden, particularly in improving the economics and legitimacy of the use of industrial waste heat (Ericsson, 2009). Similarly, UK district heating projects developed under DEPDU were able to attract considerable private funding, and this scheme focussed on projects that could be developed in this way, but the extension of district heating in Birmingham to supply multi-family public housing required public funding as the private district heating company did not see it as financially attractive.

Table 4.1 Contextual factors and district heating deployment across Europe: natural gas production and availability, and residential space heating demand

Country[1]	Indigenous production of natural gas, 2013 (TWh, gross	Percentage of natural gas customers per private	Total heat demand for domestic space	Number of District Heating systems	Total installed District Heating	Percentage of citizens served by District Heating (%)

	calorific value)[2]	household[3], 2013 (%)	heating (TJ)		capacity (MWth)	
Denmark	56	18.0	131,187	394		63%
Estonia	0	9.4	N/A	230	5,406	62%
Lithuania	0	42.7	25,500	357	9,920	57%
Poland	49.4	49.9	431,853	317	56,521	53%
Sweden	0	0.9	289,080			52%
Finland	0	1.3	198,500	400	23,270	50%
Czech Rep.	1.6	62.4	172,070	666	22,958	38%
Slovakia	1	83.0	N/A	2,350	15,793	35%
Austria	14.5	36.3	205,030		10,300	24%
Hungary	19.2	84.5	N/A	214	8,377	15%
Germany	115.8	53.7	1,664,400 (2012)	3372 (plants)	49,691	12%
France	3.7	40.6	1,050,000	501	21,230	7%
Italy	81.9	89.9	741,763	200	8,056	6%
Netherlands	796.4	94.7	270,000	400	5,850	4%
Switzerland	0	5.3	182,400	153	2,466	4%
United Kingdom	424.2	83.3	N/A	2,000	335	2%
Column data source(s)	Eurogas (2014)	Eurogas (2014), Eurostat (2016) Office, 2016 #172@@author-year}	*Euroheat & Power (2015)Euroheat (2015)*	*Euroheat & Power (2015)Euroheat (2015)*	*Euroheat & Power (2015)Euroheat (2015)*	*Euroheat & Power (2015)Euroheat (2015)*

Notes to Table 4.1

1. Norway has not been included in Table 4.1 because no data is available from Eurogas (2014) for indigenous production of natural gas or number of natural gas customers.

2. Indigenous production of natural gas figures 'are best estimates available at the time of publication' (Eurogas, 2014).

3. The ratio of natural gas customers to private households is an overestimate in most cases as it includes non-domestic customers of natural gas: 'Number of natural gas customers are counted by number of meters, and include domestic as well as non-domestic (industrial, commercial and other) customers, except Germany for which the number of domestic customers is equivalent to the number of dwellings supplied with natural gas for heating' (Eurogas, 2014).

4.5.2 Transferability 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. Norway could be considered to be more relevant to the UK context according to the following criteria: it does not have a significant history of district heating; it has recently introduced policies advocating district heating; it was early in the liberalisation of electricity markets; and there is homogeneity in heating technology, which is mostly provided by direct electric heating (Hawkey and Webb, 2014).

DH deployment in Germany can also be instructive in designing policy to expand DH in the UK. A significant proportion of heating in Germany is supplied by natural gas (43% in 2013 – (Euroheat & Power, 2015) and in larger cities natural gas is the main competitor to district heating: a 2009 incentive scheme[4] in the German state of North Rhine-Westphalia aimed to stimulate the replacement of gas grids with district heating grids (Ecoheat4EU, 2011a). It is also interesting that the share of district heating has grown by about 1% per year for the past 15 years, despite a very low rate of new buildings and a continuous decrease in heat demand due to successful energy efficiency policy (Ecoheat4EU, 2011a).

In Denmark and Sweden, DH was developed widely pre-liberalisation (Chittum and Østergaard, 2014, Oñate et al., 2014), while regulation may not be possible to the same extent in a liberalised market such as the UK, where most UK local authorities lack the capacity to coordinate development. An additional

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[4] Programme for Rational Energy Use, Renewable Energy Sources and Energy Saving.

feature which has facilitated the deployment of DH in Denmark and 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 (Ericsson, 2009). Meanwhile, public acceptance of community-wide solutions in Denmark and Sweden might represent an example that the community energy movement can follow in the UK.

There is evidence that district heating markets can become self-sufficient and operate without subsidies. District heating in Iceland received important early support from the Icelandic Energy Authority, including funding from the Iceland Energy Fund, but as the industry developed utility companies began to take a major role in both the development of district heating and exploration for new geothermal resources (Thorsteinsson and Tester, 2010). Similarly, in Denmark banks compete to fund district heating projects, making interest rates generally below 1% (Chittum and Østergaard, 2014). However, the district heating market is already highly developed in each of these examples, while Iceland benefits from an abundant, indigenous resource in geothermal energy (Gipe, 2012). In Denmark, competition to fund district heating projects may be explained by stable national energy policy, publically underwritten loans, and heat planning, but also by the technology being proven and trusted, an effective skills base being available, and district heating companies having clear roles and responsibilities and efficient decision making (Andrews et al., 2012). Some of these factors could be directly influenced by policy, but others relate to the extent to which district heating is already established. In Denmark, subsidies for district heating were in place until 2000 (Oñate et al., 2014).

In other countries, it is not clear that the district heating industry is becoming self-sufficient. Both Norway and Germany have increased financial support to counteract external changes that could have a negative impact on district heating development. In Norway, support was increased in response to the 2008 global financial crisis increasing the rate of return sought by developers (Ecoheat4EU, 2011a). Periods of low power prices can reduce willingness to invest in district heating (Enova, 2015), and means increased financial support is needed (Enova, 2013, Enova, 2014). This is because price regulation in Norway links district heating prices to the costs of electric heating. In Germany, the 2016 amendment to the CHP Act introduced bonus payments for existing gas CHP in the municipal sector which had previously ceased to receive them, as falling power prices may otherwise mean they cannot operate economically (Gailfuss, 2016). It seems possible that changes in the operation of district heating to support changing policy objectives, for example as part of a low carbon transition, could also involve further subsidies. For example, as mentioned above, changing financial incentives and to some extent investment subsidies were used to drive changes in district heating in Sweden such as increased use of bio-CHP, to support changing energy policy objectives (Ericsson, 2009). Furthermore, renewable heat sources such as geothermal may have relatively high investment costs (Thorsteinsson and Tester, 2010), and if heat demand falls as a result of efficiency measures, this may make it more difficult for district heating to operate economically (Ericsson, 2009).

There is some evidence that providing lower levels of support could actually make district heating deployment more expensive. Short term and frequently changing policies in the UK meant that development costs were temporarily driven up, rather than supply chains and skills bases becoming more developed (Hawkey, 2012). If fewer customers are connected to district heating, it can make the costs per customer higher and increase prices (Ecoheat4EU, 2011a).

4.6 Summary and policy recommendations

Our findings on policies to support the deployment of district heating include:

- Historical and contextual factors have played an important role in district heating development, and current support measures may in fact have little bearing on the district heating market shares seen in different countries.

- Policy stability is a key success factor: in Iceland and Denmark, perceived policy stability means banks compete to loan to district heating projects. In the UK, short-term abruptly changing policies relating to DH development have created uncertainty and perceived risks for local government and commercial sector.

- International evidence suggests that funding is likely to be necessary to support district heating deployment in liberalised markets. Investment subsidies were not involved in the extensive development of district heating seen in Denmark and Sweden. However, most development took place before energy market liberalisation, with district heating companies owned and/or controlled by municipalities, and risk reduced through planning and regulation of heat supply. Financial support may enable the development of district heating since it is capital intensive. Grants reduce risk to a greater extent than loans, but may reduce developer accountability and lead to less well designed systems.

- Ongoing financial support is likely to be less effective at reducing the risks associated with building heat networks, but could play a role in shaping future evolution of district heating such as the heat sources used. Enabling CHP to trade directly in electricity markets could help to improve the business case for investment, and promote a role for CHP in providing balancing to the UK electricity system.

- Carbon and energy taxes on alternative heating sources can also play an important role. For example, heating oil was taxed from the start of district heating development in Denmark in the 1970s, and this tax was raised after oil prices fell in the 1980s, allowing CHP systems to be run profitably. Denmark now has one of the highest energy taxes in Europe.

- District heating schemes may need to access a high proportion of the heat market in the area they supply to operate economically. Countries with high levels of district heating have greatly reduced 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.

- UK policies have had limited impact on developing Local Authority capacity. In countries with extensive district heating deployment, local authority roles and responsibilities and spatial planning tools have been much more clearly established.

- Technical standards and price regulation can increase consumer confidence in district heating, and subsidies to consumers could also support uptake. Direct marketing by district heating companies can also be successful, at least in some contexts.

5 Discussion and overall conclusions

Our review of European policies supporting renewable heat deployment has revealed extensive experience of heat system transformation, particularly in Northern and Western Europe. In Denmark, Sweden and Finland, 50-60% of buildings are supplied by district heating; by contrast, district heating supplies perhaps 1% of buildings in the UK. In France, Italy and Sweden approximately 1 million heat pumps or more were sold in each country between 2005 and 2013, compared to 100,000 in the UK.

Our review has revealed that contextual factors are very important - ownership structures, degree of liberalisation, energy prices and so on. In many countries early deployment of heat pumps and heat networks started as a response to the oil crises in the 1970s, before market liberalisation. Resource endowments such as availability of hydro power or natural gas also have important impacts. Nevertheless there are important lessons for UK policy and a number of common themes have become apparent from our review of the international policy experience which apply to both heat networks and heat pumps.

A key success factor for both heat pumps and heat networks is policy stability, which promotes industry, consumer and, in the case of district heating, local authority confidence. With respect to district heating, in Iceland and Denmark, perceived policy stability means banks compete to loan to district heating projects. In the UK, short-term abruptly changing policies relating to DH development have created uncertainty and perceived risks for local government and the commercial sector. Heat pump deployment in Denmark has been affected by varying political support for the environmental agenda, opposition to electric heating, or a lack of recognition of heat pumps as a legitimate form of renewable energy.

In this review, we have examined the role of incentives, taxation and subsidies. The experiences of leading European heat pump markets in the mid-1980s suggest that the success of public subsidy support depends upon standards of manufacturing, installation and maintenance being sufficient to maintain the reputation of the heat pump industry. For example, a tax credit scheme was introduced in Germany in 1979 to support energy saving initiatives in buildings, which included heat pumps. This scheme was eventually compromised by a crash in the number of heat pumps sold in Germany during the mid-to-late 1980s. This crash has been attributed to various factors, including lower oil and natural gas prices, the bad reputation of heat pumps acquired by poor manufacture of heat pump systems or poor installation practices, lack of maintenance, lack of installer experience and overselling of products.

There is clear evidence from Sweden and Denmark that high and increasing levels of carbon/energy tax applied to conventional heating options have provided a strong driver toward expanding low carbon heat markets in these countries. In Denmark, oil was taxed from the start of district heating development in the 1970s, and this tax was raised after oil prices fell in the 1980s, allowing CHP systems to be run profitably. Denmark now has one of the highest energy taxes in Europe.

Capital funding appears to be of particular importance to the deployment of heat networks in liberalised economies. Investment grants are considered to be a general good-practice support measure, but not suitable for countries with highly developed district heating markets. Stakeholders from countries where district heating is less developed see investment grants for network development as highly important.

Financial support may enable the development of district heating since it is capital intensive. Grants reduce risk to a greater extent than loans, but may reduce developer accountability and lead to less well designed systems. The nature of the funding can influence the types of projects that are viable, for example, projects which meet local social or environmental objectives but offer low rates of return may be unattractive to private investors and reliant on public finance.

Conversely, investment subsidies were not involved in the extensive development of district heating seen in Denmark and Sweden. However, most development took place before energy market liberalisation, with district heating companies owned and/or controlled by municipalities, and risk reduced through planning and regulation of heat supply.

Information, regulation and standards represent a critical influence upon policy effectiveness in the deployment of heat pumps and district heating. For example, issues associated with poor performance have affected sales and perceptions of heat pumps but this can be remedied. Low consumer awareness and confidence forms a barrier to the uptake of both technologies; enhancing the reputation of the industry through standards and regulations has been key in overcoming this barrier in countries with high uptakes of these technologies. For district heating, price regulation may also play a role in reassuring consumers. In market leading European countries such as Switzerland and Germany, policies to increase technical standards, promote heat pumps and implement information campaigns have been successfully deployed in combination with subsidies to stimulate the widespread take-up of heat pumps.

Planning and regulatory frameworks supporting or mandating district heating in certain areas can reduce the financial risk of developing district heating projects. Since district heating is capital intensive, and inherently risky in a free market, projects may only be developed if developers are confident they will access a high percentage of the heat market. The planning and regulatory framework supporting district heating is generally relatively weak in the UK, which is likely to be a major factor inhibiting its development.

European countries with high levels of district heating have greatly reduced 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 a willingness to invest for relatively low rates of return. Regulation has been used in Denmark to facilitate such zoning of technology types through mandatory connection to DH or natural gas networks, and banning of heat pumps in collective heat supply areas, while subsidisation of heat pumps has been increased outside collective heat supply areas.

The review assesses how transferable these international experiences are for expanding the future provision of renewable heat in the UK. Approximately 85% of UK households are connected to mains gas, while customer surveys have reported high levels of satisfaction with gas central heating systems and a lack of willingness to consider alternatives. European countries with some of the highest heat pump sales per capita over the last decade have achieved such deployment in the absence of indigenous natural gas production. Such countries have exploited their own resources for the supply of heating in buildings. For example, Sweden and Switzerland generate significant proportions of their electricity from hydro-power, which provides a low carbon source of electricity for heat pumps. Sweden and Finland have plentiful supplies of indigenous biomass which they use extensively as a source of fuel for heat networks.

However a group of 'middle ground' countries possess a more mixed portfolio of gas heating, heat pumps and heat networks. For these countries the presence of strong policies appears to have played a central role in creating a diversified mix. For example, recent policy in Germany has an explicit focus on replacing gas grids with heat networks. Germany and Italy have over 20 million natural gas customers and have also sold half a million or a million heat pumps respectively from 2005 to 2013. Irrespective of context a successful approach is likely to combine subsidies, carbon taxes, regulation and strong support for certification, skills and product standards.

Overall the review indicates that there is strong historical precedent for the multi-decadal heat system transition that the UK is likely to need if the aspirations of the Climate Change Act are to be realised. Early deployment of heat pumps and heat networks in leading countries took place as a response to the oil crises in the 1970s. In the decades that followed a combination of incentives, planning, regulation and taxation of conventional fuels/systems brought forward a transformation of heat provision. Resource endowment and relative energy prices are important and policies do not always succeed, several countries experienced booms, busts and recoveries. Nevertheless, it is clear that with sustained policy support over a period of 3-4 decades it is possible to bring about a profound shift in the means by which heating is provided.

6 References

ACE. 2013. *Fact-file: The cold man of Europe.* [Online]. Available: www.ukace.org/wp-content/uploads/2013/03/ACE-and-EBR-fact-file-2013-03-Cold-man-of-Europe.pdf [Accessed 11 May 2016.

ANDREWS, D., KROOK RIEKKOLA, A., TZIMAS, E., SERPA, J., CARLSSON, J., PARDO-GARCIA, N. & PAPAIOANNOU, I. 2012. Background Report on EU-27 District Heating and Cooling Potentials, Barriers, Best Practice and Measures of Promotion. Brussels: European Commission Joint Research Centre.

ARES, E. & DELEBARRE, J. 2016. *The carbon price floor* [Online]. House of Commons Library. Available: http://researchbriefings.parliament.uk/ResearchBriefing/Summary/SN05927 [Accessed 20 December 2016.

ASTE, N., BUZZETTI, M. & CAPUTO, P. 2015. District heating in Lombardy Region (Italy): Effects of supporting mechanisms. *Sustainable Cities and Society,* 14, 43-55.

BALCOMBE, P., RIGBY, D. & AZAPAGIC, A. 2014. Investigating the importance of motivations and barriers related to microgeneration uptake in the UK. *Applied Energy,* 130, 403-418.

BECIDAN, M., WANG, L., FOSSUM, M., MIDTBUST, H., STUEN, J., BAKKEN, J. & EVENSEN, E. 2015. Norwegian Waste-to-Energy (WtE) in 2030: challenges and opportunities. *Chemical Engineering Transactions,* 43, 2401-2406.

BERGMAN, N., HAWKES, A., BRETT, D. J. L., BAKER, P., BARTON, J., BLANCHARD, R., BRANDON, N. P., INFIELD, D., JARDINE, C., KELLY, N., LEACH, M., MATIAN, M., PEACOCK, A. D., STAFFELL, I., SUDTHARALINGAM, S. & WOODMAN, B. 2009. UK microgeneration. Part I: policy and behavioural aspects. . *Proceedings of the ICE - Energy,* 162 22-36.

BIERMAYR, P., EBERL, M., ENIGL, M., FECHNER, H., KRISTÖFEL, C., LEONHARTSBERGER, K., MARINGER, F., MOIDL, S., STRASSER, C., WEISS, W. & WÖRGETTER, M. 2014. *Innovative energietechnologien in Österreich marktentwicklung 2013* [Online]. Bundesministerium für Verkehr, Innovation und Technologie. Available: http://www.nachhaltigwirtschaften.at/e2050/e2050_pdf/201426_marktentwicklung_2013.pdf [Accessed 16 December 2016.

BJØRNSTAD, E. 2012. Diffusion of renewable heating technologies in households. Experiences from the Norwegian Household Subsidy Programme. *Energy Policy,* 48, 148-158.

BOARD, I. P. 2013. *Decentralised Energy Project Delivery Unit* [Online]. Available: https://www.london.gov.uk/moderngov/documents/s24068/07%20ELENA%20DEPDU%20-%20Cover%20Report.pdf [Accessed 28 October 2016.

BUILDINGS PERFORMANCE INSTITUTE EUROPE. 2016. *Data hub for the energy performance of buildings* [Online]. Available: http://www.buildingsdata.eu/episcope-data/results [Accessed 19 December 2016.

CCC. 2016. *Next steps for UK heat policy* [Online]. Committee on Climate Change. Available: https://www.theccc.org.uk/publication/next-steps-for-uk-heat-policy/ [Accessed 20 December 2016.

CHAUDRY, M., ABEYSEKERA, M., HOSSEINI, S. H. R., JENKINS, N. & WU, J. 2015. Uncertainties in decarbonising heat in the UK. *Energy Policy,* 87**,** 623-640.

CHITTUM, A. & ØSTERGAARD, P. A. 2014. How Danish communal heat planning empowers municipalities and benefits individual consumers. *Energy Policy,* 74**,** 465-474.

CONNOR, P. M., XIE, L., LOWES, R., BRITTON, J. & RICHARDSON, T. 2015. The development of renewable heating policy in the United Kingdom. *Renewable Energy,* 75**,** 733-744.

DECC 2013a. Homeowners' willingness to take up more efficient heating systems. . London: Department of Energy and Climate Change.

DECC 2013g. Research into barriers to deployment of district heating networks. London: Department of Energy and Climate Change.

DECC 2015. Evaluation of the Heat Networks Delivery Unit - Interim report covering wave 1 research. London: Department of Energy and Climate Change.

DECC. 2016. *Renewable Heat Incentive evaluation* [Online]. Department of Energy and Climate Change. Available: https://www.gov.uk/government/collections/renewable-heat-incentive-evaluation [Accessed 7 June 2016.

DELTA 2013. Delta-ee report for the Danish Energy Agency. Policy measures for heat pump market growth. . Delta Energy and Environment.

DONALDSON, R. & LORD, R. 2014. Challenges for the Implementation of the Renewable Heat Incentive - An example from a school refurbishment geothermal scheme. *Sustainable Energy Technologies and Assessments,* 7**,** 30-33.

EC. 2013 *Commission delegated regulation (EU) No 811/2013 of 18 February 2013.* [Online]. Brussels: European Commission. Available: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R0811&from=EN [Accessed 16 December 2016.

EC. 2016. *Paris Agreement.* [Online]. European Commission. Available: http://ec.europa.eu/clima/policies/international/negotiations/paris/index_en.htm [Accessed 11 May 2016.

ECOHEAT4EU. 2011a. *Country-by-country database* [Online]. Intelligent Energy Europe. Available: http://ecoheat4.eu/en/Country-by-country-db/Overview/ [Accessed 2 November 2016.

ECOHEAT4EU. 2011ae. *Ecoheat4EU Executive Summary Report* [Online]. Intelligent Energy Europe. Available: http://ecoheat4.eu/en/upload/Ecoheat4EU%20Summary%20Report%20%28publishable%29.pdf [Accessed 24 October 2016.

EHPA. 2009. *History of the European quality label for heat pumps: From DACH to EHPA and Long term experiences with heat pump tests.* [Online]. European Heat Pump Association. Available: http://www.ehpa.org/uploads/media/EHPA_Newsletter_10_2_02.pdf [Accessed 24 October 2016.

EHPA 2014. European Heat Pump Market and Statistics Report 2014 European Heat Pump Association.

EHPA. 2016. *Heat pump sales in Germany - 2015: only a slight decline given challenging market conditions* [Online]. European Heat Pump Association. Available: http://www.ehpa.org/about/news/article/heat-pump-sales-in-germany-2015/ [Accessed 16 December 2016.

EHPA & DELTA 2013 Unleashing the opportunity - European best practice in building successful heat pump markets. Brussels: European Heat Pump Association.

ENERGINET.DK. 2016a. *Electricity generation* [Online]. Available: http://www.energinet.dk/EN/KLIMA-OG-MILJOE/Miljoerapportering/Elproduktion-i-Danmark/Sider/Elproduktion-i-Danmark.aspx [Accessed 16 December 2016.

ENERGINET.DK. 2016b. *Fuels* [Online]. Available: http://www.energinet.dk/EN/KLIMA-OG-MILJOE/Miljoerapportering/Sider/Braendsler-forbrug-og-sammensaetning.aspx [Accessed 16 December 2016.

ENERGY SAVING TRUST 2010. Getting warmer: A field trial of heat pumps. . London: Energy Saving Trust.

ENOVA. 2012. *Annual report 2012* [Online]. Available: https://www.enova.no/innsikt/rapporter/resultatrapport-2012/in-english/in-english/616/1411/ [Accessed 19 December 2016.

ENOVA. 2013. *Annual report 2013* [Online]. Available: https://www.enova.no/innsikt/rapporter/resultatrapport-2013/in-english/in-english/780/1752/ [Accessed 19 December 2016.

ENOVA. 2014. *Annual report 2014* [Online]. Available: http://viewer.zmags.com/publication/40751ba7#/40751ba7/1 [Accessed 19 December 2016.

ENOVA. 2015. *Annual report 2015* [Online]. Available: http://viewer.zmags.com/publication/9513c0bc#/9513c0bc/1 [Accessed 19 December 2016.

ERICSSON, K. 2009. *Introduction and development of the Swedish district heating systems – Critical factors and lessons learned* [Online]. Lund University. Available: http://www.res-h-policy.eu/downloads/Swedish_district_heating_case-study_(D5)_final.pdf [Accessed 24 October 2016.

ETI. 2015 *Smart Systems and Heat – Consumer challenges for low carbon heat* [Online]. Energy Technologies Institute. Available: https://s3-eu-west-1.amazonaws.com/assets.eti.co.uk/legacyUploads/2015/11/3501-Consumer-Insights.pdf?dl=1 [Accessed 24 October 2016.

EUNOMIA 2016. Drivers of growth and cost changes in European renewable heat technologies. Report by Eunomia to the Department of Energy and Climate Change.

EUROBSERV-ER. 2015. *Heat pumps barometer* [Online]. Available: https://www.eurobserv-er.org/pdf/2015/EurObservER-Heat-Pumps-Barometer-2015-EN.pdf [Accessed 16 December 2016.

EUROGAS. 2014. *Eurogas statistical report 2014* [Online]. Available: http://www.eurogas.org/uploads/media/Eurogas_Statistical_Report_2014.pdf [Accessed 16 December 2016.

EUROHEAT & POWER. 2015. *2015 Country by country – Statistics Overview (2013 data)* [Online]. Available: http://www.euroheat.org/wp-content/uploads/2016/03/2015-Country-by-country-Statistics-Overview.pdf [Accessed 21 December 2016.

EUROSTAT 2015. Share of energy from renewable sources for heating and cooling.

EUROSTAT. 2016. *Number of private households by household composition, number of children and age of youngest child* [Online]. Available: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=lfst_hhnhtych&lang=en [Accessed 16 December 2016.

EYRE, N. & BARUAH, P. 2015. Uncertainties in future energy demand in UK residential heating. *Energy Policy,* 87**,** 641-653.

FAWCETT, J. 2015. *Evaluation of the District Heating Loan Fund (DHLF) - Final report* [Online]. Databuild. Available: http://www.energysavingtrust.org.uk/sites/default/files/reports/Heat%20-%20District%20Heating%20Loan%20Fund%20-%20Evaluation%20Final%20Report%20-%20EST-004-15%20%20%20_0.pdf [Accessed 24 October 2016.

FRONTIER ECONOMICS 2013. Pathways to high penetration of heat pumps. Report prepared for the Committee on Climate Change. London: Frontier Economics.

FRONTIER ECONOMICS 2015. Research on district heating and local approaches to heat decarbonisation. Annex 1: overcoming barriers to district heating. London: Frontier Economics.

GAIGALIS, V., SKEMA, R., MARCINAUSKAS, K. & KORSAKIENE, I. 2016. A review on Heat Pumps implementation in Lithuania in compliance with the National Energy Strategy and EU policy. *Renewable and Sustainable Energy Reviews,* 53, 841-858.

GAILFUSS, M. 2016. *Germany's new CHP Act explained* [Online]. PennWell Corporation. Available: http://www.decentralized-energy.com/articles/print/volume-17/issue-1/features/germany-s-new-chp-act-explained.html [Accessed 19 December 2016.

GIAMBASTIANI, B. M. S., TINTI, F., MENDRINOS, D. & MASTROCICCO, M. 2014. Energy performance strategies for the large scale introduction of geothermal energy in residential and industrial buildings: The GEO.POWER project. *Energy Policy,* 65, 315-322.

GIPE, P. 2012. *Iceland: A 100% renewables example in the modern era* [Online]. Available: http://reneweconomy.com.au/iceland-a-100-renewables-example-in-the-modern-era-56428/ [Accessed 21 December 2016.

GLEESON, C. P. & LOWE, R. 2013. Meta-analysis of European heat pump field trial efficiencies. *Energy and Buildings,* 66, 637-647.

HANNA, R. F. 2014. *Installer businesses and renewable energy uptake in homes* . Ph.D., University of Surrey.

HANNON, M. J. 2015. Raising the temperature of the UK heat pump market: Learning lessons from Finland. *Energy Policy,* 85, 369-375.

HAWKEY, D. & WEBB, J. 2014. District energy development in liberalised markets: situating UK heat network development in comparison with Dutch and Norwegian case studies. *Technology Analysis and Strategic Management,* 26, 1228-1241.

HAWKEY, D., WEBB, J. & WINSKEL, M. 2013. Organisation and governance of urban energy systems: district heating and cooling in the UK. *Journal of Cleaner Production,* 50, 22-31.

HAWKEY, D. J. C. 2012. District heating in the UK: A Technological Innovation Systems analysis. *Environmental Innovation and Societal Transitions,* 5, 19-32.

JOHANSSON, P. 2014. *The evolution of the Swedish heat pump industry – an efficient use of development resources?* [Online]. Available: https://cleantechfunding.org/2014/03/26/the-evolution-of-the-swedish-heat-pump-industry-an-efficient-use-of-development-resources/ [Accessed 16 December 2016.

KERR., T. 2008. *CHP/DHC country scorecard: Germany* [Online]. International Energy Agency. Available: https://www.iea.org/media/topics/cleanenergytechnologies/chp/profils/geermany.pdf [Accessed 19 December 2016.

KIRK, P. 2015. *Decentralised energy for London programme close event* [Online]. Available: http://www.londonheatmap.org.uk/Content/uploaded/documents/02DEPDUHow_we_did_it.pdf [Accessed 18 May 2016.

KISS, B., NEJJ, L. & JAKOB, M. 2014. Heat pumps: a comparative assessment of innovation and diffusion policies in Sweden and Switzerland. *In:* GRUBLER, A. & WILSON, C. (eds.) *Energy technology innovation: Learning from historical successes and failures. .* Cambridge: Cambridge University Press.

KRANZL, L. 2007. Quantitative and economic assessment of the direct fiscal measures. Study of the Austrian case. . *Report in the frame of the IEE project REFUND+.* Vienna.

KRANZL, L., KALT, G., MÜLLER, A., HUMMEL, M., EGGER, C., ÖHLINGER, C. & DELL, G. 2013. Renewable energy in the heating sector in Austria with particular reference to the region of Upper Austria. *Energy Policy,* 59, 17-31.

MACLEAN, K., SANSOM, R., WATSON, T. & GROSS, R. 2016. *Managing heat system decarbonisation: comparing the impacts and costs of transitions in heat infrastructure.* [Online]. Imperial College London. Available: http://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/icept/Heat-infrastructure-paper.pdf [Accessed 12 May 2016.

MAHAPATRA, K. & GUSTAVSSON, L. 2009. Influencing Swedish homeowners to adopt district heating system. *Applied Energy,* 86, 144-154.

MCS. 2015. *The Microgeneration Certification Scheme* [Online]. Available: http://www.microgenerationcertification.org/ [Accessed 19 July 2015.

MIARA, M., GUNTHER, D., KRAMER, T., OLTERSDORF, T. & WAPLER, J. 2011. Heat pump efficiency - Analysis and evaluation of heat pump efficiency in real-life conditions. Freiburg: Fraunhofer Institute for Solar Energy Systems.

NINE ELMS ON THE SOUTH BANK. 2016. *VNEB Opportunity Area Planning Framework* [Online]. Available: http://nineelmslondon.com/downloads [Accessed 12 December 2016.

NORWEGIAN MINISTRY OF LOCAL GOVERNMENT AND MODERNISATION. 1985. *Planning and Building Act (1985): Act of 14 June 1985 No. 77 the Planning and Building Act* [Online]. Available: https://www.regjeringen.no/en/dokumenter/planning-and-building-act/id173817/ [Accessed 19 December 2016.

NORWEGIAN MINISTRY OF PETROLEUM AND ENERGY. 2007. *Acts and regulations* [Online]. Available: https://www.regjeringen.no/en/dokumenter/Acts-and-Regulations-/id106724/ [Accessed 19 December 2016.

NORWEGIAN MINISTRY OF PETROLEUM AND ENERGY. 2015. *Facts 2015: energy and water resources in Norway* [Online]. Available: https://www.regjeringen.no/contentassets/fd89d9e2c39a4ac2b9c9a95bf156089a/facts_2015_energy_and_water_web.pdf [Accessed 19 December 2016.

NYBORG, S. & RØPKE, I. 2015. Heat pumps in Denmark—From ugly duckling to white swan. *Energy Research & Social Science,* 9**,** 166-177.

OFFICE, S. F. S. 2016. *Private households by size 2015: definitive data* [Online]. Available: https://www.bfs.admin.ch/bfs/en/home/statistics/population.gnpdetail.2016-0513.html [Accessed 16 December 2016.

OÑATE, V. G., KESSELS, K. & SIX, D. 2014 Best-practices for district heating implementation in Belgium: Policy analysis and benchmark from countries with high market penetration. . *2014 IEEE International Energy Conference (ENERGYCON).* Dubrovnik, Croatia.

RIZZI, F., FREY, M. & IRALDO, F. 2011 Towards an integrated design of voluntary approaches and standardization processes: An analysis of issues and trends in the Italian regulation on ground coupled heat pumps. *Energy Conversion and Management,* 52 3120-3131.

SANDSTROM, B. 2000. Swedish experience with subsidies for heat pump installations. . *European Heat Pump News.* European Heat Pump Association.

SANNER, B. 2016. Shallow geothermal energy – history, development, current status, and future prospects *European Geothermal Congress 2016.* Strasbourg, France.

SKÖLDBERG, H. & RYDÉN, B. 2014. *The heating market in Sweden – an overall view* [Online]. Värmemarknad Sverige. Available: http://www.varmemarknad.se/pdf/The_heating_market_in_Sweden_141030.pdf [Accessed 21 December 2016.

STAFFELL, I., BAKER, P., BARTON, J. P., BERGMAN, N., BLANCHARD, R., BRANDON, N. P., BRETT, D. J. L., HAWKES, A., INfiELD, D., JARDINE, C. N., KELLY, N., LEACH, M., MATIAN, M.,

PEACOCK, A. D., SUDTHARALINGAM, S. & WOODMAN, B. 2010. UK microgeneration. Part II: technology overviews. *Proceedings of the ICE - Energy,* 163**,** 143-165.

STATISTICS NORWAY. 2016. *Statistikkbanken* [Online]. Available: https://www.ssb.no/statistikkbanken/ [Accessed 20 December 2016.

SVERIGE, E. 2016. *Tillförd energi för produktion av fjärrvärme 1980 - 2015* [Online]. Available: http://www.svenskfjarrvarme.se/Statistik--Pris/Fjarrvarme/Energitillforsel/Tillford-energi-utveckling-1980-2012/ [Accessed 19 December 2016.

THORSTEINSSON, H. H. & TESTER, J. W. 2010. Barriers and enablers to geothermal district heating system development in the United States. *Energy Policy,* 38**,** 803-813.

TOKE, D. & FRAGAKI, A. 2008. Do liberalised electricity markets help or hinder CHP and district heating? The case of the UK. *Energy Policy,* 36**,** 1448-1456.

UKERC. 2016 *Meeting report: heat networks and governance.* [Online]. UK Energy Research Centre. Available: http://www.ukerc.ac.uk/publications/meeting-report-heat-networks-and-governance.html [Accessed 19 May 2016.

UNEP. 2015. *District energy in cities - unlocking the potential of energy efficiency and renewable energy* [Online]. United Nations Environment Programme. Available: http://www.unep.org/energy/portals/50177/DES_District_Energy_Report_full_02_d.pdf [Accessed 2 November 2016.

WEBB, J., HAWKEY, D., TINGEY, M., KERR, A., LOVELL, H., MCCRONE, D. & WINSKEL, M. 2014 *Heat and the city - Exploring affordable, low carbon community heating in cold climate cities* [Online]. Edinburgh: University of Edinburgh. Available: http://www.heatandthecity.org.uk/__data/assets/pdf_file/0006/169215/Heat_and_The_City_Brochure_web.pdf [Accessed 2 November 2016.

WERNER, S. 2011. Best practise support schemes. Brussels, Belgium: EcoHeat4EU.

WINSKEL, M. 2016. From optimisation to diversity: changing scenarios of heating for buildings in the UK. *In:* WEBB, J., D., H., LOVELL, H., MCCRONE, D., TINGEY, M. & WINSKEL, M. (eds.) *Sustainable urban energy policy: heat and the city.* London and New York: Routledge.

ZIMNY, J., MICHALAK, P. & SZCZOTKA, K. 2015. Polish heat pump market between 2000 and 2013: European background, current state and development prospects. *Renewable and Sustainable Energy Reviews,* 48**,** 791-812.