Working paper. David Hawkey. 27 September 2018

The problem of heat and its solution: dynamics of sustainable heat policy visions in the UK, Denmark and Germany

1 Introduction

The future is uncertain and largely unknowable, yet energy policymakers seek to make decisions in the present on the basis of envisaged futures [REF]. A number of strands of social science research have examined the role of ideas about the future in shaping energy policy, focusing on different aspects of those ideas (such as their combination with interests and filtering through institutions to shape policy outcomes (Kern, 2011) or the ideological dimensions of their content (Jasanoff and Kim, 2013)). Across various aspects of energy policy research has illustrated the performativity of ideas about the future: shepherding debate, justifying action and resource mobilisation and reducing perceived uncertainties (Borup et al., 2006; Delina and Janetos, 2018; Dignum et al., 2018; Eames et al., 2006). Yet while the significance of ideas and discourses about the future is recognised, less is known about how the ideas publicly aired by energy policymakers develop and what shapes and constrains them. The guest editors of a recent special edition of this journal noted this gap, calling for 'papers that explicitly study […] the complex dialectic between the past (or the present) with that of the future of energy' (Delina and Janetos, 2018, p. 6). This paper contributes to filling this gap, focusing on the way sociotechnical legacies in different countries shape policymakers' ideas about the future of heating buildings.

Heat is a complex subject, in cold countries tending to account for a greater share of total final energy consumption than (non-heating consumption of) electricity (Danish Energy Agency, 2017; DECC, 2013; Prognos AG et al., 2014b). The quantity and character of energy consumption for heating is the outcome of various interacting systems that have coevolved over long periods: the ways buildings have been constructed, maintained and upgraded; the various technologies used to convert and distribute energy within buildings; occupancy patterns and standards of thermal comfort; retail costs of energy and disposable incomes; network infrastructures distributing energy to and through settlements; primary energy resources; wholesale markets; extractive industries; etc. (BMUB, 2010; DECC, 2013; Energinet.dk, 2015a) The 'system boundaries' of heat are therefore difficult to pin down, and this means there can be quite different ways of understanding the future of heat, for example corresponding to different emphases on which parts of the system should change, making heat a fruitful domain to understand how energy policy visions are shaped in particular places at particular times.

To examine the social shaping of policymakers understandings of the future, I draw on Hajer's (1997) account of the functioning of discourse in a policy setting. I take an international comparative perspective, comparing the content of visions for sustainable heat in Germany, Denmark and the UK articulated in policy debates, countries selected for their contrasting patterns of energy efficiency and heat supply (Figure 1). The comparative approach helps escape what Jasanoff identifies as the 'intellectual trap of taking as universal […] assumptions that turn out, on investigation, to be situated and particular' (Jasanoff, 2015, p. 24). The paper contrasts the way policy debates framed the future of heat around the end of 2016 when most of the data on which the paper is based were collected – its aim is to illuminate factors shaping the way policymakers understood the future of heat at a particular moment in time. A key issue is the extent to which the future is stabilised within policy communities or itself changes over time. The paper's objective is both to contribute to social science knowledge of how energy futures are constructed, but also to shed light on ways in which national debates about the future of heat could be different to their current form.

The paper is organised as follows. Section 2 discusses STS treatments of visions of the future and establishes the concepts used to analyse the cases. Section 3 outlines the methodological approach and section 4 presents empirical material on debates about the future of heat. Section 5 concludes.

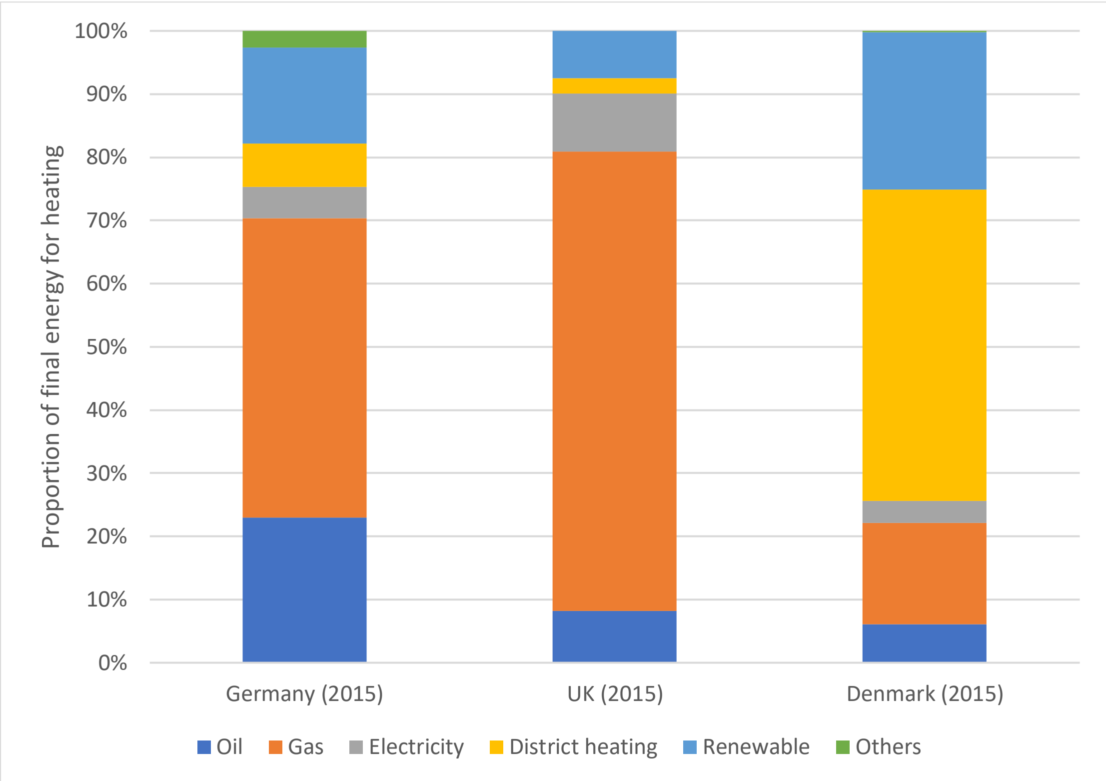

Figure 1. Heat supply for buildings in Germany (BMWi, 2015), UK (Department for Business, Energy and Industrial Strategy, 2017a) and Denmark (Danish Energy Agency, 2017)

2 Theory – shared visions of the future

Hajer's (1997) approach to discourse has been influential across various studies of the role of the future in the present of energy policymaking (Delina and Janetos, 2018; Kern, 2011; Lovell et al., 2009). In particular, Hajer's concept of the 'storyline', 'a generative sort of narrative that allows actors to draw upon various discursive categories to give meaning to specific physical or social phenomena' (Hajer, 1997, p. 56). Hajer identified conditions for a storyline to become hegemonic: discourse structuration, whereby 'the credibility of actors in a given domain requires them to draw on the ideas, concepts, and categories of a given discourse' (p. 60) and discourse institutionalisation, whereby 'a given discourse is translated into institutional arrangements' (p. 61). The idea that a storyline may acquire these powerful attributes has led to an emphasis on understanding how discourse shapes action and decisions (Dignum et al., 2018; Kern, 2011), and analysis of the efforts actors exert to promote storylines that serve their interests (Geels, 2014).

Less interest has been paid to understanding the shaping of storylines, and where this question has been raise it is often asserted that dominant policy storylines reflect the interests of powerful incumbent industrial interests (Geels, 2014; Lovell et al., 2009). For example, Geels (Geels, 2014) suggests that generally 'policymakers and incumbent firms can be conceptualised as forming a core alliance at the regime level, oriented to maintaining the status quo.' In part this emphasis on the capacity of powerful actors to shape the debate reflects assumptions about language, that Hajer explicitly rejects, that it is a medium through which other dynamics play out. For example, Jasanoff (Jasanoff, 2015) contrasts a focus on language with accounts that are 'directly associated with action and performance, or with materialization through technology'. Hajer's argument against this language-as-medium position draws on Foucault's work, which denied the power of powerful actors in modern societies was independent of the discourses in which they are positioned. That is, rather than some actors having power to shape a discourse that then constrains options for others, all actors are constrained by the 'subject positions' in which a shared discourse situates them. In Hajer's terms, 'the influence of a stubbornly resisting actor […] cannot be explained by reference to the importance of his position alone, but has to be given in terms of the rules inherent in the discursive practices, since they constitute the legitimacy of his position,' (Hajer, 1997). Attributing the dominance of a storyline to the power of the actors whom it favours is further complicated by the difficulty obtaining evidence of powerful actors exerting power to shape discourses in their interest, because the visibility of this process would often be counterproductive, undermining the plausibility or legitimacy of the position advanced.

How, then, can we get a handle on the shaping of policy storylines if the interests of powerful actors pose empirical and conceptual challenges as explanatory starting points? Tozer and Klenk (Tozer and Klenk, 2018), in their exposition of contrasting storylines of urban sustainability, briefly offer a form of explanation for different storylines being powerful in different cities. They suggest the detail given to 'carbon neutral' in different cities is shaped by macro flows of energy – that it 'makes sense' that a city where progress has already been made on renewable deployment should flesh out 'carbon neutral' as '100% Renewable', while a city with plans to expand gas CHP and reduce coal reliance would unpack 'carbon neutral' as 'clean energy'. This alignment can be understood in terms of Hajer's concept of 'discursive affinity': the discursive power of storylines derives not from individuals' strategic choices or from internal coherence, but from their similarity with other shared or accepted elements with similar cognitive or discursive structures. In such cases actors ned not even understand the detail of an argument to reach the conclusion that is 'sounds right' (Hajer, 1997) (see also Levidow and Papaioannou's notion of 'discursive resonance' (Levidow and Papaioannou, 2013)).

Thus while not denying a role for individual agency, and differential influence of different actors over storylines, we may nonetheless explore other dimensions of the field of discourse shaping the kinds of storylines which emerge as positions or assumptions policymakers are prepared to take. The microsocial mechanisms by which the resonance between a storyline and other discursive elements is made effective are likely to be myriad, extending over time and multiple interactions. They may take the form of explicit argument linking an aspect of a storyline with a piece of received wisdom, historical precedent, fashionable idea, etc., but they may also operate more subconsciously across various actors. The distribution of these effects over many actors and the fact that actors may not be aware of them poses a challenge to empirical research as informants are not necessarily reliable witnesses of these processes. This is why an international comparative approach is helpful, allowing interrogation of different patterns of alignment between policy storylines and broader discourses, remaining sensitive to the accounts actors give for the plausibility or legitimacy of a given storyline, but not relying on these.

With what might a storyline about the future of heat share a discursive resonance? This paper draws on ideas developed by Bakker et al. (Bakker et al., 2012) who examined the credibility of technology expectations (focusing on hydrogen). Their approach is helpful in establishing categories of discursive resources specifically for technology- and future-oriented storylines. Their categories were (1) current performance and historical trajectory, (2) a forward path used to argue that further performance improvements are feasible, and (3) embedding the technology's future in an account of societal needs. These categories were developed for understanding the credibility of visions of a specific technology, while this paper explores the broader and less clearly delimited domain of the future of heat. Accordingly Bakker et al.'s categories are broadened as follows:

1. the existence of exemplars in the present or the past that actors appeal to in defending the credibility of a vision (which include past episodes of sociotechnical change that are drawn on to argue proposed transitions are feasible);
2. modes of analysis and argument that can be used to project the future, drawing *inter alia* theoretical constructs and calculative devices, which support claims about the future performance, cost and other characteristics of a future scenario;
3. a broader discourse establishing the parameters of a desirable future and a desirable transition (such as environmental, cost, industrial outcomes), and an articulation of the sociotechnical vision as fulfilling those parameters.

The stability of these discursive resources is not guaranteed. They may change for various reasons, including as a consequence of a storyline being adopted (as, for example, in the hype-disappointment cycle (Borup et al., 2006)). This instability suggests two methodological alternatives: to explore the dynamics of storylines over time, investigating their coevolution with changing discursive resources; or to take a snapshot approach, examining the forms of discursive resonance operative at a given point in time. This paper adopts the latter approach.

While Hajer outlined conditions for storylines to become hegemonic, his framework does not require hegemony for storylines to shape policy action. Indeed, Lovell et al. (Lovell et al., 2009) found that between the late 1990s and 2007 various storylines emerged and coexisted in UK energy and climate policy. In cases where storylines are not hegemonic, investigation may nonetheless examine the factors shaping prominent storylines that the investigator identifies.

3 Method

This paper's examination of heat visions focuses on problems and solutions in space heating as expressed in national government policy documents. It draws on two main sets of material. First: analysis of a range of documents connected to these policy debates, including government policy papers, reports and advice to government, analyses conducted by academics and consultants (either commissioned by or targeted at government), official statistics and media reports. Rather than demanding a hegemonic storyline, the investigation selects accounts of the future of heat published by particular departments at particular times. In the UK the focus is on documents published by the Department for Energy and Climate Change and by the Government without attribution to a particular department. In Denmark the focus is on publications by the Danish Energy Agency In addition to tracking the articulation of heat visions this analysis examined the impact of arguments arising from different actors on policy visions. Second: a set of 76 interviews with national and local government officers, industry associations, consultants, analysts and NGOs conducted between 2015 and 2017 as part of a broader comparative study of policy and practice for sustainable heat in the UK, Denmark and Germany. These interviews were used to explore different actors' accounts of the problem of heat and the justifications they offered for different solutions.

4 Results

4.1 Primary energy

This section considers differences across countries in the more general analysis of the future of energy. In particular, this section considers how concerns about environmental damage caused by energy resources is translated into visions for the primary energy resources to be used in future. For a vision of the future of heat to plausibly satisfy the objectives of national energy policy, it must be coherent with the wider shared understanding of the future of primary energy resources.[1]

In all three countries climate change is well established as a central energy policy issue (BMUB, 2010; Danish Government, 2011; DTI, 2003), but from the *undesirability* of greenhouse gasses each country arrives at different positions on what would constitute *desirable* future primary energy resources. Of the three countries the UK's approach countenances the widest range of inputs. Renewables and nuclear power feature in long-range policy visions, as does continued use of fossil fuels with carbon capture and storage (CCS) (UK Government, 2017). Danish policy has the most restrictive primary energy prescription, having set a target to achieve 100%

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[1] This is not to claim visions of future primary energy resources are the *only* overarching issue with which heat visions must be coherent, but it is both a prominent issue in national energy policy debates and one which differentiates the three countries examined in this paper.

renewable energy systems by 2050 (Danish Government, 2012). German energy policy seeks to both reduce the combustion of fossil fuels and eliminate nuclear energy, and emphasises efficiency and renewables as means of achieving these objectives (BMWi, 2016a). The primary energy objectives of national policy can be summarised in the UK as a *source agnostic* approach to reducing GHG emissions, in Germany as *reducing the use of fossil fuels and nuclear power*, and in Denmark as *eliminating fossil fuels*.

4.1.1 Factors shaping the role of different primary energy sources in national visions

National policy primary energy visions are couched in complex discursive processes and are not determined by available energy resources. Nuclear power in the UK, for example, was ruled out in early iterations of energy and climate change policy (DTI, 2003), but was, in the words of then Prime Minister Tony Blair, brought 'back with a vengeance' (BBC News, 2006) in 2006. This followed a campaign by the UK's nuclear industry to position the technology as a solution to both the climate change problem and exposure to international gas markets, at the time perceived to be sensitive to Russian manipulation (Rogers-Hayden et al., 2011). The return of nuclear to UK energy policy was abrupt. Failings in the Government's consultation process were successfully challenged in the court (BBC News, 2007), but the political choice to pursue nuclear nonetheless stood. High politics were also significant to establishing Germany's position on nuclear. Chancellor Angela Merkel's government initially adopted a policy of lifetime extension for existing nuclear plant (perceived by some as a prelude to a policy of new nuclear stations), but the Fukushima disaster accentuated the electoral liability of this policy, particularly in regional elections, leading to its abandonment (Huß, 2014) and consensus across the main political parties against nuclear. The nuclear question in Danish politics has been closed since the 1970s (Hadjilambrinos, 2000).

A continuing role of fossil fuels in high-level visions is not a simple consequence of the availability of indigenous resources. The UK has been a net importer of liquid and gaseous hydrocarbons since 2004 (Bolton, 2013), Denmark in 2015 produced 118% more oil than it consumed (Danish Energy Agency, 2017), and Germany has long been dependent on imported oil and gas (IEA, 2008). In the UK CCS is regularly identified in mainstream system-wide techno-economic analyses as a crucial technology for minimising costs of decarbonisation in the UK (Committee on Climate Change, 2015; Energy Technologies Institute, 2015), and as a means of protecting oil and gas industries in the North Sea, repurposing skills and infrastructure for transport and storage of CO_2 (Scottish Government, 2017a). While oil and gas is also produced in Denmark, the country's geological formations mean sites identified as technically suitable for CO_2 sequestration are onshore whereas the UK has access to offshore sites (Teir et al., 2010). Explorations of CCS in Germany also focused on onshore sites, and in both countries proposed projects met with opposition from communities situated above storage sites who perceived various risks including potential CO_2 leaks or ground movement. CCS took on negative connotations in German and Danish policy debates, leading to the effective abandonment of the technology both through stringent regulation (Fischer, 2015; Lidegaard, 2011) and its absence in national energy scenario analyses (Danish Energy Agency, 2014a; Prognos AG et al., 2014b). Thus CCS in UK energy visions is aligned with accounts of desirable futures in part because it reconciles climate change with a continued role for companies and employees in the oil and gas sector without generating opposition from communities living above storage sites. In Denmark the positive impact on industry is set against opposition to onshore storage. In Germany CCS does not establishes a future for an indigenous industry but does generate community opposition.

While CCS does not feature in mainstream energy visions in Germany, this has not led to as clear a commitment to eliminating fossil fuels as in Denmark. An important factor is the dependence of precarious regional economies on coal mining in Germany (but neither Denmark nor the UK), particularly in the Lausitz area (Becker et al., 2017; Vallentin et al., 2016) which make clear policies for the elimination of fossil fuels by 2050 politically challenging (as illustrated by the scaling back of policies aimed at reducing the role of coal in electricity generation (Appun, 2015; Renn and Marshall, 2016)). This contributes to the German policy framing as *reduction* (versus Danish *elimination*) of fossil fuel consumption.

The role of renewables in high level national framings does correspond with the extent of renewable energy across each country's energy systems – across the three countries the emphasis on renewables in visions is higher in the countries with more renewable deployment. Renewable energy contributions in 2005 (as reported under the 2009 EU Renewable Energy Directive) were 16.5% in Denmark, 7.6% in Germany and 1.5% in the UK, suggesting both that local exemplars can support credible visions and that credible visions can be translated into local exemplars.

Looking specifically at renewable sources for heating, Figure 2 shows each country's targets under the directive, along with baseline penetration and interim outturn for 2014. Drawing on national statistics I have also extrapolated the trajectory of renewable heat deployment between 1999 and 2009 out to 2020 to illustrate the relationship between past dynamics and perceived future potential (c.f. (Bakker et al., 2012)). Danish and German 2020 targets appear broadly achievable with continuation of trends in renewable heat deployment over the first decade of the millennium. In the UK where renewable energy is not central to the heat problem, the 2020 target is considerably more stretching compared with trend. While the proportion of renewable heat achieved in the UK by 2014 exceeded the indicative path the Government had set out when adopting the target, it nonetheless represented less than half of the additional renewable heat required to meet the 2020 level, and leaked ministerial correspondence indicates fears it will not be met (Rudd, 2015). In the UK, therefore, the apparently greater difficulty in deploying renewable heat reinforces arguments that a wider range of primary energy sources are necessary to achieve climate change targets.

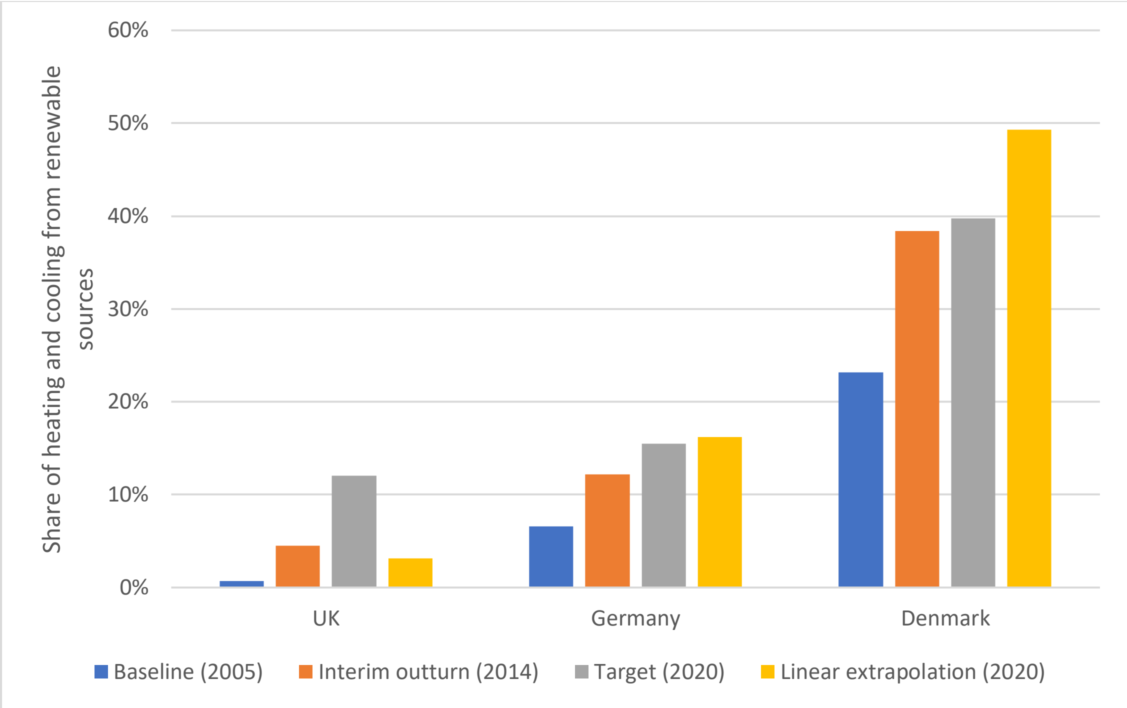

Figure 2. Renewable heat baseline and targets for Denmark, Germany and the UK based on submissions to the EU under the Renewable Energy Directive. For order-of-magnitude comparison with renewable heat trends, a linear extrapolation to 2020 of annual renewable heat production between 1999 and 2009 is also shown, calculated from renewable heat statistics (BMWi, 2016b; Danish Energy Agency, 2017; Department for Business, Energy and Industrial Strategy, 2017b).

4.1.2 Historical exemplars shaping primary energy visions

As well as discursive resources associated with particular primary energy sources, past dynamics of change play a role in supporting the credibility of primary energy futures. National energy histories provide shared templates through which visions of future energy transitions can be understood, debated, and rendered plausible. In the UK, GHG emissions fell 11% from 1990 to 2000, two-thirds of which were a result of the 'dash for gas', when the newly privatised industry invested heavily in CCGTs and reduced the use of coal-fired generation (Winskel, 2002).[2] Thus the most significant sociomaterial exemplar for decarbonisation in the UK was switching between fossil fuels, rather than reducing fossil fuel consumption. Keay (2016) argues this forms a template inside UK government (particularly the Treasury) as a preferred approach. In

[2] Data from Eurostat table env_air_gge

Germany, over the same period, emissions reductions were driven less by fuel switching than by a reduction in aggregate fossil fuel use, bound up with the dynamics of reunification. Economic restructuring and upgrading of coal-fired power generation in the east (Hvelplund and Lund, 1998) meant reduction in primary energy intensity was the most significant contributor to Germany's 17% reduction in GHG emissions from 1990 to 2000 (Schleich et al., 2001). Danish commitments to eliminate fossil fuels echo decisions made in the wake of the 1970s oil crises to phase out the use of oil in heat and power through a combination of switching and efficiency. This phase out has almost been completed: oil represented 87% of primary energy supply for heat and power in 1972; by 2000 this had been cut to 18% and in 2015 the figure was 4% (Danish Energy Agency, 2017). This achievement is often appealed to in Danish policy documents to argue extensive change in energy systems is feasible (Danish Government, 2014).

Each country therefore has a different indigenous history of energy transition, and each is aligned with their current overarching energy vision. The UK's emphasis on decarbonising energy inputs is a form of switching that does not necessarily imply constraints on primary energy input. Germany's emphasis on reducing the use of fossil fuels resonates with the role efficiency played in past decarbonisation. And Denmark's proposal to eliminate the use of fossil fuels by substituting with a more limited range of alternatives, thereby requiring more efficient use of primary inputs, aligns with the progress it made in replacing oil in heat and power production.

4.2 Energy efficiency of buildings

Each country's strategy for energy efficiency is shaped by the broader framing of future primary energy demand. Estimates of energy savings potentials across these strategies are presented in Table 1. The extent of energy savings arising from retrofitting buildings is least ambitious and has the broadest range in the UK. UK strategy countenances energy futures extending from little (if any) reduction in total demand to a reduction of around a third. The upper-end of the UK's range corresponds to the lower end of the German government's target range, and is similar to the Danish government's single estimate. This is in spite of the UK's reputation for an ageing and low efficiency building stock (Association for the Conservation of Energy, 2013; HM Government, 2011), and German and Danish reputations for high levels of efficiency (Danish Government, 2014), illustrating again the content of a policy vision is not simply determined by physical characteristics of energy systems.

Table 1. 2050 energy saving goals presented in national energy efficiency strategies.

Document	Domain	Scenario	Base year	Per capita energy saving by 2050	Total energy saving by 2050[3]
UK: 2012 Energy Efficiency Strategy (DECC, 2012a)	Whole economy	Renewables and energy efficiency	2011	47%	32 – 38%
		CCS and bioenergy	2011	35%	16 – 24%
		Nuclear and less efficiency	2011	21%	-2 – 7%
Germany: 2015 Energy Efficiency strategy of buildings (BMWi, 2015)	Buildings	High renewables	2008	–	36%
		High efficiency	2008	–	54%
Denmark: 2014 Strategy	Buildings	100% renewable	2011	–	35%

[3] Neither the UK's 2012 'Energy Efficiency Strategy' nor the 2011 'Carbon Plan' on which it was based published population estimates for 2050. I have calculated total energy savings on the basis of the Office for National Statistics (ONS) population estimates published in 2011 (the last published before the Energy Efficiency Strategy). The ONS estimated 2010 population as 62.3m and projected a 2035 population of 73.2m. It did not estimate a 2050 population. Here I have extrapolated from the 2035 population using the ONS's 0.6%/year growth rate to 80.0m. The more conservative estimate is based on assuming population in 2050 remains the same as 2035.

for energy renovation of buildings (Danish Government, 2014)	

The relative breadth of energy efficiency scenarios across the three countries reflects both the breadth of supply-side scenarios and the way government analysts project future energy savings. The UK scenarios are based on MARKAL modelling, which takes a carbon-constrained cost-optimisation approach to whole energy systems (DECC, 2012a; HM Government, 2011). This means emissions reductions arising from reducing demand and decarbonising supply are traded-off against each other within the model. The lowest efficiency improvements were associated with the 'high nuclear' scenario, under which the calculated benefits of energy efficiency were low compared to electrification of heat and transport. Conversely, given constraints on the volume and controllability of renewable energy, the renewable scenario emerged with the most significant reduction in energy demand.

By contrast, the 2014 Danish Strategy For Energy Renovation of Buildings begins with the proposition that "energy consumption has to be significantly reduced […] if we are to attain the goal of [100%] renewable energy in a cost effective way" (Danish Government, 2014, p. 4). Rather than subjecting energy efficiency to whole-system cost optimisation calculations the Danish approach began with a multi-stakeholder report into the technical potential for energy savings, from which the Government extracted measures it considered realistic. Thus, while a number of renewable supply-side scenarios were constructed at the same time (Danish Energy Agency, 2014a), the desirable level of energy efficiency was not considered sensitive to supply-side scenarios. Instead of cost-optimisation the Danish strategy focused on future-proofing,

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https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/bulletins/nationalpopulationprojections/2011-10-26 taking 35% improvement in efficiency as required and seeking to ensure opportunities are not missed, particularly non-energy remedial works to ageing building components.

The German government's approach to energy efficiency sits between the Danish and UK in terms of presenting trade-offs and uncertainties. The 2010 Energy Concept proposed an 80% 'order of magnitude' reduction in non-renewable primary energy demand for heating by 2050 against 2008 levels, aligned with the overarching primary energy policy vision (BMUB, 2010). This target was carried forward into the 2015 Energy Efficiency Strategy for Buildings (BMWi, 2015) which estimated the combinations of energy efficiency and renewable supply that could plausibly reach the target. Thus, like the UK analyses, energy efficiency was traded-off against supply options to meet the target, but unlike the UK (and like the Danish approach) the target was specific to buildings and not sensitive to assumed changes in other sectors.

The specificity of long-range energy savings targets across the three countries thus parallels the extent to which they have adopted renewable energy as a desirable supply-side future. The UK's whole-system optimisation approach and breadth of supply-side options contributes a lack of specificity in energy efficiency in an additional way. The UK figures in Table 1 actually refer to economy-wide energy savings rather than specific to heating buildings. While this means the UK figures are not strictly comparable with Danish and German numbers I have presented them together to illustrate the difference in the discursive resources available in energy policy debates. In the UK the extent of future energy efficiency of buildings has not been settled and is subject to continued debate (e.g. Rosenow et al., 2017) both due to the breadth of overarching energy demand scenarios and the fact that these are not presented in building-specific terms.

Differences in the specificity of long-range energy efficiency in heat policy visions corresponds to the specificity of near term heat and energy efficiency policy. As noted above, Danish strategy focuses on ensuring opportunities to thermally future-proof buildings are not missed, framing the long-term upgrade of buildings as a project underway. Germany has a rule-of-thumb annual target for 2% energy renovation across the building stock, itself rendered plausible by the average 2.4% annual reduction in final energy demand for heating between 2002 and 2010 (DENA, 2015). More generally, policy documents in these countries envisage progress toward longer term heat targets being achieved by steady progress (BMWi, 2015; Danish Energy Agency, 2014a). By contrast, decarbonisation of heat in the UK is envisaged not to follow a steady trajectory: the UK Committee on Climate Change (2016) sees heat decarbonisation occurring late relative to other sectors and policy makers argue against setting deployment targets based on steady progress. As one UK government policy officer put it, "[rather than] simply saying that you need to do however many hundred thousand or million homes a year, year on year, for the next however many years [… there] might be reason to believe actually that costs will fall, and therefore in fact you will reduce your costs if you wait to carry out certain types of activities," (interview 2016). Consequently the UK lacks a near-term benchmark for progress towards the long-term solution of the heat problem. This is reflected in the lack of compensatory programmes in response to a number of failed or abandoned policies, including the Green Deal (a pay-as-you-save energy efficiency financing scheme), the Energy Company Obligation (a requirement for suppliers and electricity generators to invest in decarbonisation which was scaled back in 2013), and Consequential Improvements (a policy that would have required renovated homes to be brought up to minimum efficiency standards that was abandoned in 2013) (Rosenow et al., 2017). In the absence of near-term targets for buildings improvements, the failure of these policies has not created effective pressure on UK Government to put new policies in place.

DK has reputation for high standards – when we talk with the rest of the world quote. But this also means it has an industry which can benefit from regulation. And this dynamic is clear in Germany too. So perversely, while having a reputation for poor thermal performance, the pressure for stock upgrade in the UK is less robust [which doesn't mean it is absent, but the case for its lack of robustness is the collapse of policies – cite falling rate of renovation vs DE struggle to raise the rate].

4.3 Energy supply infrastructure

An important factor shaping each country's heat visions is the existing pattern of energy supply infrastructure and conversion technologies. Perceived opportunities for changing energy supply for heat are conditioned by affordances for sociotechnical change. For example, individual-building oil-fired boilers are often targets for policy intervention, both because of the relatively high carbon intensity of oil and because experience indicates these buildings and their owners are relatively easy to convert to renewable energy (e.g. because heating costs are higher than gas, because alternative sources can feed existing internal radiator systems, and because conversion away from oil does not threaten sunk investment in network infrastructure). These effects are illustrated in the Danish transition away from oil since the end of the 1970s: conversion from oil to renewables (predominantly biomass) made a significant contribution in low density areas unsuitable for district heating or gas networks. As illustrated in Figure 3, building-scale renewable heat grew from almost nothing in the mid 1970s to a quarter of all heat supplied, and half of heat for buildings not using district heating.

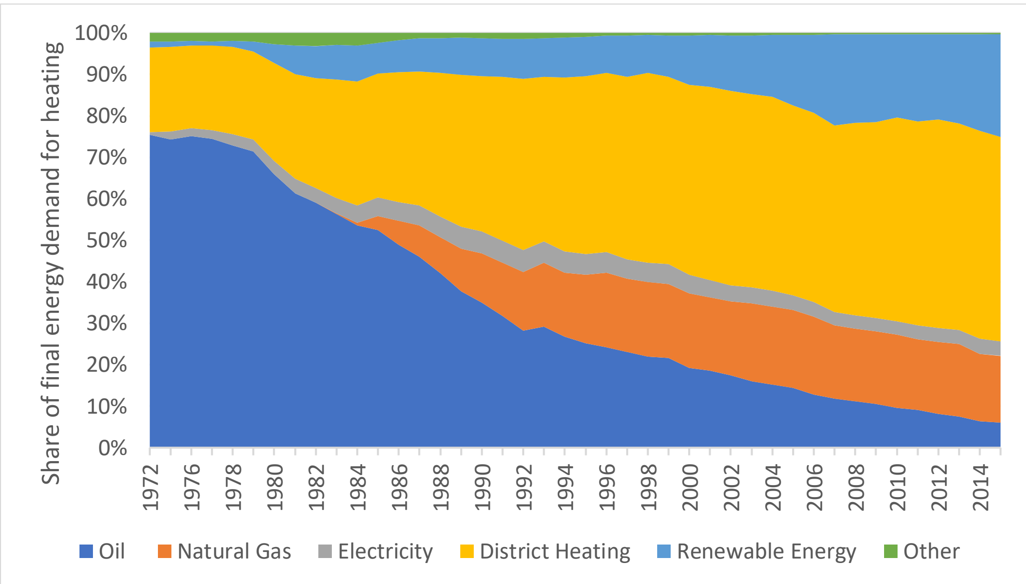

Figure 3. Energy supply for heating in Denmark (source data (Danish Energy Agency, 2017)).

Figure 1 breaks down the supply vectors used for heating buildings across the three countries. Germany has the highest share of heating dependent on oil, and this is where most retrofit deployment of renewable heat has been seen. Between 2008 and 2015 the share of heating using oil fell by six percentage points and the share based on renewables grew by five (BMWi, 2015). This dynamic is projected into the future in scenarios commissioned by the German Government (Prognos AG et al., 2014c) which envisage the decline in oil's share[4] between 2011 and 2030 (from 28% to 11%) making up the bulk of the growth in biomass and heat pumps (from 5% to 26%).

The role of oil in German and Danish deployment of renewables suggests the low share of oil in UK heating contributes to the latter country's challenges in meeting its relatively low renewable heat targets. Whereas near term progress can be made in Germany by conversion from oil, near-term policy on energy supply for heating in the UK is confronted with the prevalence of gas. In Denmark extensive district heating frames opportunities for heat policy. The sections below discuss how these infrastructural legacies shape heat visions, focusing particularly on their role as exemplars for what changes are considered plausible, and the techniques used to extrapolate from the past and the present into the future.

4.3.1 Electrification

Use of electric heating was prohibited under the post-oil crisis heat planning regime in Denmark, and for many years the use of electricity for heating (including the use of heat pumps) was regarded as a wasteful use of a high value commodity (Nyborg and Røpke, 2015). However, electrification of heat has entered Danish policy visions in recent years (Danish Energy Agency, 2014a), carried by a number of arguments. To achieve fossil-free heating by 2050, scenario builders see two principal options: bioenergy or electrification. To date biomass has made up the

[4] Share of building heating by floor area.

bulk of renewable heat deployment, at building scale, in small heat networks (for example using local agricultural products such as straw) and conversion of large coal-fired CHP units to biomass. Building scale and large district heating uses of biomass have led to high import levels (Figure 4). Concerns about biomass imports expressed by interviewees focus on international sustainability (more than exposure of Denmark to international biomass markets) and the role of bio-energy in eliminating fossil fuels from industry and transport.

> *Can we continue importing a lot of biomass or will the whole world change their attitude […]? We're a rich country, we could go onto the world market and buy a share which is larger than we actually should have done. […] But with the long view […] it's not that we need to be self-sufficient, […] we actually believe and base out assumption that* ***everybody*** *would like to have biomass to do the difficult energy things […] We are blessed with lots of wind in Denmark. So it's not biomass for Denmark, that's much more problematic in other countries, Hungary, Romania, which don't have a lot of wind […] but they have a lot of use of biomass. So keep the biomass for those areas which don't have a lot of wind. (Interview, SDM, environmental NGO, 2016).*

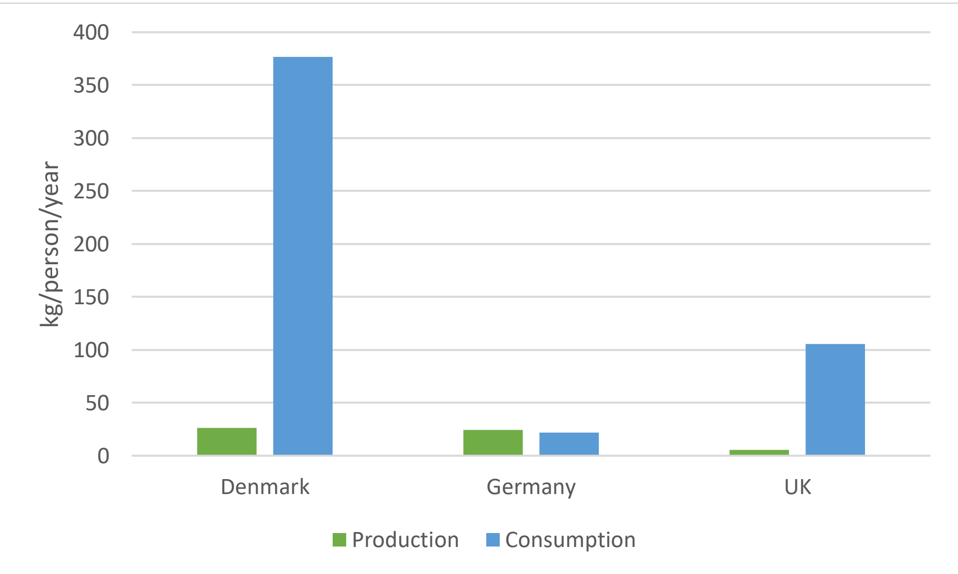

Figure 4. Biomass pellets annual production and consumption in 2015. Biomass data from Eurostat table 'for_basic'. Population data from Eurostat table 'tps00001'. Consumption calculated as sum of production and imports minus exports. Note the moderately high amount of imports to the UK are predominantly used in electricity production (co-firing with coal) rather than for heat (Department for Business, Energy and Industrial Strategy, 2017b).

One Danish argument in favour of electrification points to existing systems. Denmark's high levels of district heating are primarily based on CHP. As the growth of wind power generation accelerated from the mid 1990s, resultant volatility in power markets prompted an increase in CHP operators generating in response to power prices.[5] Not only did this improve power revenues to CHP, it also buffered the electricity market reducing curtailment and low prices for wind, thereby supporting deployment of turbines (Toke, 2007). As wind penetration has deepened wholesale power prices have fallen undermining the financial viability of many CHP units (Energinet.dk, 2015b), but proponents of electrification point to the experience of coupling district heating with power markets, and the support this affords to intermittent renewable generation. Instead of coupling via CHP, however, this proposition relies on electrification of heat generation, either through resistive electric boilers or (more efficiently, but at higher capital cost) large scale heat pumps (Danish Energy Agency, 2014b).

Calculative techniques also play a role in arguments in Danish debate. The financial cost of biomass heating is often considerably lower than electric heating. Taxes are significant to this difference, being high on electricity and effectively absent on biomass, making the latter financially attractive to users. Danish energy policy has a highly institutionalised process of socioeconomic cost/benefit analysis (Danish Ministry of Finance, 1999) which, in common with other state-defined socioeconomic analyses, excludes taxes when calculating costs 'to society' (taxes are considered a transfer payment). Unusually though, the Danish system registers the loss of tax revenue as a socioeconomic cost (arguing that lost taxes require compensating tax

[5] Live data from one such system in the town of Skagen can be viewed at http://www.emd.dk/plants/skagen/?english&history

increases elsewhere in the economy, reducing productive economic activities (Danish Ministry of Finance, 1999)). This feature means Danish socioeconomic calculations favour higher tax commodities, and contributes to the argument that electrification of heat is preferable to use of biomass (Energinet.dk, 2015a).

In Germany renewable heat is supported through regulation of new buildings and the Market Incentive Programme (MAP) for retrofit. These have contributed to the dominance of biomass across renewable heat and, amid debate about competing uses for bio-energy and the role of MAP in supply chain development, incentives have been recalibrated several times since 2006 in favour of heat pumps (interviews with industry association and policy delivery officers in Federal Government, 2015). In 2013 heat pumps accounted for 9% of new heating units and biomass 4% (DENA, 2015).

The role of heat electrification in German policy visions is framed as unproblematic. In target-hitting 2050 scenario models the required deployment of heat pumps is estimated to be achievable by continuing current installation rates (BMWi, 2015). Under these calculations the aggregate effect of heat pumps on peak power demand is calculated to be manageable, both because scenarios envisage compensating reductions in peak demand from other uses (including electric resistive heating) (BMWi, 2015), and because German network companies already manage heat pump peak demand: in exchange for reduced network fees, heat pump owners allow network operators to turn their heat pumps off for up to two hours per day (Delta Energy and Environment, 2013).

The role of heat pumps in the heat policy visions has been more turbulent in the UK. Following passage of the Climate Change Act in 2008, UK Government and its advisors (the Committee on Climate Change) drew on cost-optimisation models to present a future heavily dominated by heat pumps. Critics dubbed this vision ‘the all-electric future’ and argued it would lead to excessive peak power demand (Speirs et al., 2010). The point was illustrated forcefully in a graph that has come to be known as the 'Sansom graph' after its creator, a PhD candidate at Imperial College, London (Figure 5). The graph compares actual electricity with estimated heat demand to contrast peak flows. In its original context the graph was used to argue heat electrification would require heat networks with storage to avoid coordinated demand spikes, as occur with gas-fired boilers controlled by automatic timers (Sansom, 2014). The striking graph, which has been reproduced in many contexts (and used to advocate a variety of different solutions) has played a significant role in weakening the role of individual heat pumps as a 'silver bullet' solution to the UK problem of heat.

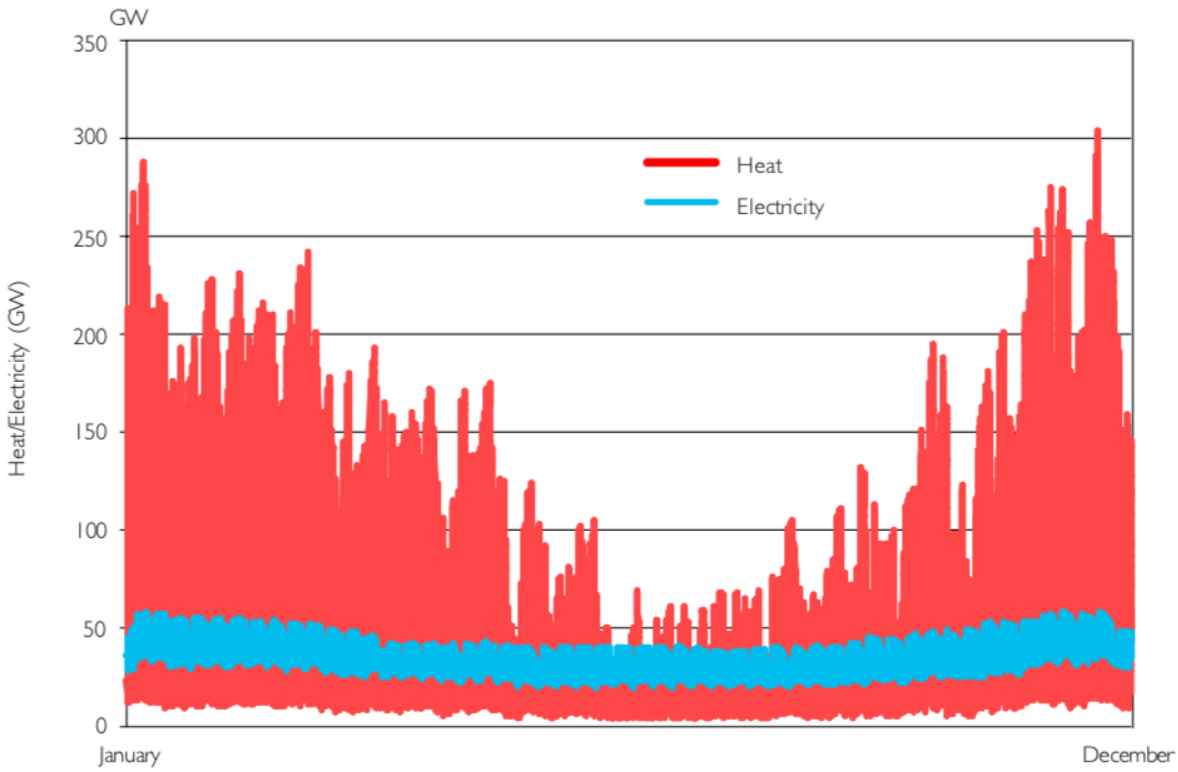

Figure 5. The 'Sansom' graph, comparing variation in (actual) electricity demand and (synthesised) heat demand across a year. Reproduced from (DECC, 2012b). Crown copyright 2012.

Debate in Germany and Denmark is able to draw on experience of coupling heat and electricity. By contrast, UK experience is relatively limited: electricity is used in electric storage heaters rather than heat pumps or heat networks, and these legacy heaters are commonly regarded as affording unsatisfactory heating (excessively expensive and inadequately controllable) (Webb et al., 2016). In consequence UK debate relies more on abstract calculation than local exemplars. Coupled with the relatively wide array of possibilities afforded by the UK's overarching primary energy framing (which has contributed to competing heat visions, see below), the role of heat electrification and hence the imperative for near term progress on heat pump deployment is weakly articulated. For example, in 2017 UK Government outlined three economy-wide 2050 scenarios, one of which saw electricity contributing 76% of domestic heating, another only 14%.

4.3.2 District heating

As well as limited experience coupling heat and electricity systems, the UK has little experience with heat networks, these supplying around 2% of heat demand (DECC, 2012b). Estimates of the scale of future district heating have been particularly labile. For example, a 'National Comprehensive Assessment' of the potential for district heating in the UK (required under the EU Energy Efficiency Directive) estimated the 'socially cost effective' potential for district heating in 2025 lay between 3% and 39% of heat demand (Ricardo Energy and Environment, 2015). The Committee on Climate Change (2016) estimates the potential for low carbon heat networks is limited to around 20% of heat demand in 2050, while Danish academics estimate UK potential is closer to 70% (Connolly et al., 2015). Lack of UK experience contributes to considerable variability in assumptions around issues such as coordinating users with heat network expansion, analysis of spatial relationships, infrastructure finance and writing down the value of existing network assets. These challenges compound the list of difficulties projecting scenarios into the future (technology improvement, energy resource availability and cost, user behaviour, etc.). As with electrification, a shared vision of the future role of heat networks has proven elusive in the UK, meaning the case for near term action is not compelling.

Danish district heating is (in urban areas) the dominant incumbent system. In consequence Danish analysts have abundant local exemplars on which to base their calculations. In 2014 the Danish Government analysed of the optimal extent of district heating projected slight growth in penetration from 50% in 2013 to around 60% (Danish Energy Agency, 2014b). While the scenarios explored some uncertainties and interdependencies (for example, heat losses from district heating pipes mean the option becomes relatively less efficient as assumed levels of building fabric efficiency increase), the optimal level of district heating was analysed independently of primary energy scenarios. This reflects both the relative narrowness of primary energy options under Danish policy framing as compared with the UK and a settled understanding that district heating contributes stability to the electricity system. The main conclusion of the study was relatively conservative, with the optimal level of district heating in future being roughly the same as its level today, with increases coming from connecting users already in DH supply areas but currently using other sources.

An equivalent analysis of district heating in Germany (Prognos AG et al., 2014a) considered varying connection rates (that is, the proportion of heat demand in a district connected to the heat network). It calculated the number of city districts in which the infrastructure would be socioeconomically viable at a connection rate of 90% was roughly double the number at a connection rate of 45% – that is, by doubling the connection rate the volume of heat demand cost effectively served by district heating quadrupled. Similarly, the CHP and district heating industry association (AGFW) argues that extending district heating in the 70 largest German cities from its current penetration of under 20% to 70% by 2050, would be a cost effective way of achieving 'climate neutral' heating (AGFW, 2015). However, achieving a high connection rate is regarded as requiring regulatory intervention to constrain building owner/occupant choice of heat supply (Prognos AG et al., 2014a). Currently this appears incompatible with the German government's declaration that measures supporting 'climate neutral' buildings be undertaken voluntarily (BMUB, 2014) and the political value of competition:

> *[On this street (pointing out the window)] you can still find one house with gas, one house with district heating and one house even based on oil, fuel oil.[…] On one hand you could say it's a well functioned competition, it's good for consumers because you have the opportunity to choose, but on the other hand, […] it would be much simpler if you would just declare one quarter for district heating, one quarter for gas piping and the other quarter for mineral oil or… But that does happen. I think also that it's not realistic. […] The German market, it's liberalised and maybe too much liberalised, but it's not possible to step back from competition. […] I would not even be sure if I, me as a customer, would be willing to choose district heating if the government obliges me to have district heating. Even though I know that it's good, that it may be reasonable. But I still like the idea of competition between the different fuels. (Interview, German energy consultant, 2015)*

Consequently scenarios for achieving the 80% primary energy reduction target envisage little change in district heating use from its current level of around 11% of heated floor area (Figure 6) (BMWi, 2015).

Voluntarism in the German government's approach to heat retrofit reflects a general trend across countries' energy politics, away from state planning and towards liberalised markets and consumer choice. This trend is apparent in Denmark where district heating companies expanding into new areas are reluctant to use powers to compel connection (a legacy of the heat planning regime of the 1980s), instead seeking to attract customers on the strength of their commercial offer (interview, Danish municipal energy company CEO, 2016). Interestingly, however, voluntarism leads to quite different assumptions about connection rates in national analyses: while 90% was considered an upper limit and politically challenging in Germany

(Prognos AG et al., 2014a), Danish analyses set 90% as the baseline (Danish Energy Agency, 2014b). This reflects differences in the existing configuration of infrastructure in the two countries, with German district heating systems commonly running alongside gas networks but Danish gas and heat networks serving distinct districts.

4.3.3 Gas networks

German target-hitting policy visions see little change in the number of buildings using district heating and heat electrification being accommodated (in terms of peak demand) by existing capacity. The volume of fossil gas supplied in these scenarios falls considerably (by 70-80% against 2008 levels, BMWi 2015) and is partially substituted with biogas. Much of the reduction in gas use in the scenarios occurs through efficiency improvements. Together these mean the overarching policy goal (reduction in primary fossil energy demand) can be achieved with modest reduction in the number of buildings connected to the gas network. As illustrated in Figure 6, while government-commissioned scenarios envisage fossil gas in heating falling over 70% (by primary energy content), the role of gas *networks* would fall by around a third (from 50% of heated floor area to 33%). Furthermore these scenarios concentrate this decline in the period after 2030 (reflecting near-term progress that can be made in other areas, for example through conversion from oil). As such German heat policy targets do not constitute a significant threat to sunk investment in gas networks, particularly in the near term.

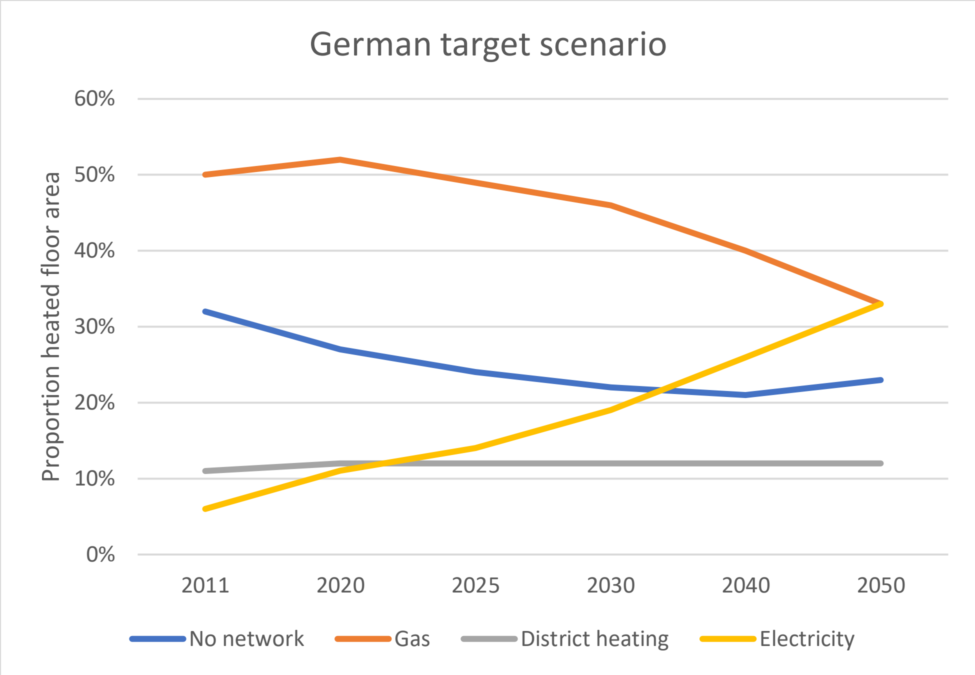

Figure 6 Proportion of heated floor area in Germany according to distribution network supplying heat for space heating (so, for example, buildings using electric heat pumps are represented as using electricity supply). Scenario constructed to meet 2050 targets. "No network" comprises oil, coal, biomass, solar thermal and no heating. From calculations presented in (Prognos AG et al., 2014c).

By contrast, the dominance of gas in the UK means the future of gas networks is an acute problem for heat policy. In 2012 the UK Government presented a 'strategic vision' for heat which envisaged the gas network being progressively 'squeezed out' by district heating and electrification (DECC, 2012b). In response the incumbent gas network owners commissioned an alternative scenario analysis which included technologies the Government's scenario had excluded (gas absorption heat pumps and gas boilers as backup to electric heat pumps) that would preserve connections to the gas network beyond 2050 (Delta Energy and Environment, 2012). The criticism was accepted by the Government who updated its strategy by including a role for these technologies (DECC, 2013).

Subsequently the gas network industry commissioned further research to explore whether their assets could be repurposed to deliver hydrogen (Northern Gas Networks et al., 2016). The study concluded mass conversion to hydrogen would be feasible, with large volumes of hydrogen being generated by steam methane reformation with CCS (the competing method of hydrogen production, electrolysis, having either relatively high cost or relatively low volume depending on assumptions). Again, this argument by the incumbent industry has been effective, leading to an expansion of the range of scenarios considered plausible for meeting 2050 targets (Committee on Climate Change, 2016; UK Government, 2017). A number of UK-specific factors are appealed to by advocates of hydrogen visions:

- In 2002 gas distribution network operators began a thirty year Iron Mains Replacement Programme (IMRP) to replace existing pipes with polyethylene (Health and Safety Executive and Ofgem, 2011). The programme responded to health and safety issues following gas leaks into buildings, but as a side-effect prepares the network for hydrogen (which at high concentrations would corrode the old iron pipes (Health and Safety Executive, 2015)).
- UK gas networks have switched gases in the past, from town gas to natural gas in the 1960s-70s (Arapostathis et al., 2013), providing local exemplar through which the plausibility of a switch to hydrogen can be more easily imagined.
- Hydrogen derived from natural gas with CCS is compatible with the UK's overarching energy problem framing as reduction of GHG emissions. By contrast it would not be compatible with the German government's emphasis on reducing primary energy demand or with the Danish government's commitment to elimination of fossil fuels.

Repurposing the gas system holds the attraction to policy makers of a seemingly minimally disruptive transition. Network upgrades are already underway through the IMRP, and continued use of the gas network appears a simple solution to the problem of peak energy demand for heating (represented by the 'Sansom graph', Figure 5). The attractiveness of continuity is not, however, matched by certainty in feasibility or costs. This has compounded difficulties in resolving questions about other technologies, particularly the extent of district heating that would be viable and the degree of electrification of heat that would be required (Committee on Climate Change, 2016; Scottish Government, 2017b; UK Government, 2017). Uncertainties around hydrogen have led to scaling back of ambitions on heat pumps: before gas network operators began advocating hydrogen the Committee on Climate Change (2015) argued the UK would need 2.5m heat pumps by 2030 to keep open the option of a high level of deployment for 2050. Following the inclusion of hydrogen scenarios in Government analysis it is currently working toward a level of around 0.5m (BEIS, 2018)

Of the three countries, Denmark's gas network supplies the smallest share of buildings' heat (Figure 1). Nonetheless the Government's overarching policy of fossil fuel elimination represents a threat to the gas networks which are the principal vector for fossil energy in heating (gas used in buildings representing 18% of primary energy for heating and gas used in district heating 11%). In addition, gas consumption in Denmark has fallen by almost half since 2000 as the use of gas CHP in district heating has declined, in part due to the expansion of wind generation depressing wholesale power prices (Energinet.dk, 2015b). As in the UK gas network owners have responded by advocating a role for gas networks consistent with energy policy objectives, though replacement of metal pipes with material suitable for hydrogen is not considered feasible. The owner of the gas transmission system (Energinet.dk, a publicly owned company) estimated the socioeconomic value of its asset in 2035 to be 3.3bn DKK. Gas distribution operators have begun exploring hybrid heat pump models. While these debates show some parallel with the UK, they are also distinctive, reflecting differences in locally resonant arguments and examples. In the UK is focused on infrastructure continuity and managing peak heat demand. In Denmark the distributed character of indigenous bioenergy resources (as sources of 'green gas') is emphasised, the transmission network opening opportunities for more productive uses than if the gas were to be used locally. A role of gas in heat is advocated alongside electric heat pumps, but rather than peak demand Danish debate reflects experience in heat/power coupling, extending both the system and consumer-convenience properties to non-district heating areas. Describing the possibility that hybrid heat pumps could be switched from electricity to gas as a 'virtual power plant' participating in energy markets, a gas distribution network officer explained "the customer […] will just be billed the agreed heat price so they don't have to consider [technology or power markets]. It's another way of getting district heating out to the areas where we don't have district heating today," (Interview 2017).

5 Discussion and conclusions

The problem of heat is not determined by climate science, by indigenous resources or by sociotechnical legacies, though these all play roles in the complex processes by which shared policy visions of the future of heat are developed. As a component of broader energy policy, heat is subject to more general ideas about problems and solutions in energy, and in particular is both shaped by and shaping of national visions for the future of primary energy. Differences across governments' visions for primary energy reflect a heterogeneous array of electoral politics, incumbent industries, geology, sociotechnical systems of provision in each country, brought together and crystallised as strategies to mitigate GHG emissions. The UK adopts a source agnostic approach, focused on the emissions themselves. Germany aims at elimination of nuclear and the reduction of fossil fuels, while Denmark adopted 100% renewable targets.

The specificity of primary energy visions shapes policy understandings of the need to make buildings more efficient. Constraints on renewable energy mean calculation of future scenarios tend to place a relatively high value on demand reduction, and this is reflected both within UK scenarios and across the three countries. Given the role of visions in mobilising policies and resources, the relative ambivalence of UK scenarios helps explain that country's limited near-term policy effort in improving building fabric performance.

National primary energy visions combine with infrastructure configurations to establish the extent to which the problem of heat implies radical reconfiguration. The role of existing infrastructure configurations is twofold is to shape perceived affordances for change, both in terms of the physical feasibility of different options and in the ways those options are understood and evaluated. German policy visions see the most limited change in spite of socioeconomic arguments in favour of radical expansion of district heating. Within political constraints of voluntarism, analysts have been able to present as plausible scenarios under which the impact of electrification on peak power demand is mitigated, dramatic reduction in the use of fossil gas is accompanied by more modest reduction in the role of gas networks, and district heating networks see very little change. Policy pressure for infrastructure change is further mitigated by extensive near-term opportunities to progress long-term goals by converting oil-based heating, an affordance that is more limited in Denmark and the UK.

Danish primary energy scenarios are supported by analyses of the role of district heating, seeing modest expansion and continuity in the coupling of heat and power, albeit via a shift from CHP to electrification. Primary energy visions threaten the gas networks, which have in turn responded with proposals in which their assets add value to future scenarios. Shared understandings of business/consumer models (purchase of heat rather than equipment and fuel) and heat/electricity coupling derived from district heating are used to render hybrid heat pumps familiar to policy makers.

In the three countries the impact of electrification of heat is framed differently. Denmark, which already has extensive intermittent renewable power, constructs visions in which heat electrification adds value to integrated energy systems (as well as mitigating bioenergy problems).

In Germany the discourse of electrification presents peak demand as a containable problem, in part drawing on existing exemplars of demand management. In UK debates electrification has the character of an unmanageable threat, encapsulated vividly by the Sansom graph (Figure 5). Critique of the UK's 'all electric future' established a pattern whereby problems identified in heat policy visions are acknowledged and solved by proliferating options (initially district heating, then hybrid gas solutions and most recently hydrogen). This reflects, and is enabled by, the UK's breadth of primary energy vision, and while maintaining flexibility it compounds uncertainties which in practice have further limited pressure for near-term progress (reflected, for example, in the lowering of anticipated numbers of heat pumps deployed by 2030).

It is tempting to view the relative breadth of futures compatible with UK visions and the reluctance of UK Government to constrain these through the lens of different Varieties of Capitalism (Hall and Soskice, 2001), the UK's liberal traditions being more at odds with planning than the coordinated market economies of Denmark and Germany. However, this literature has been criticised as overemphasising differences between countries at the expense of common trends toward liberalisation (Streeck, 2016). While further comparison of political economy under this tradition may shed some light, the approach taken here is already illuminating. In Denmark and Germany established calculative practices, local sociomaterial exemplars and narrow framings of desirable primary energy futures leave relatively little room for multiplicity in heat visions as compared with the UK. While UK political traditions may favour keeping options open, it is the dynamics of shared visions that open up the wide array of options which policy makers have to manage.

6 Funding

Funding: This work was supported by the UK Engineering and Physical Sciences Research Council [grant number EP/M008215/1]. The funder played no role in study design, data collection/analysis/interpretation, the writing of this paper or the decision to submit it for publication.

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