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Working Paper 3: Decarbonisation of heat: How smart local energy systems can contribute

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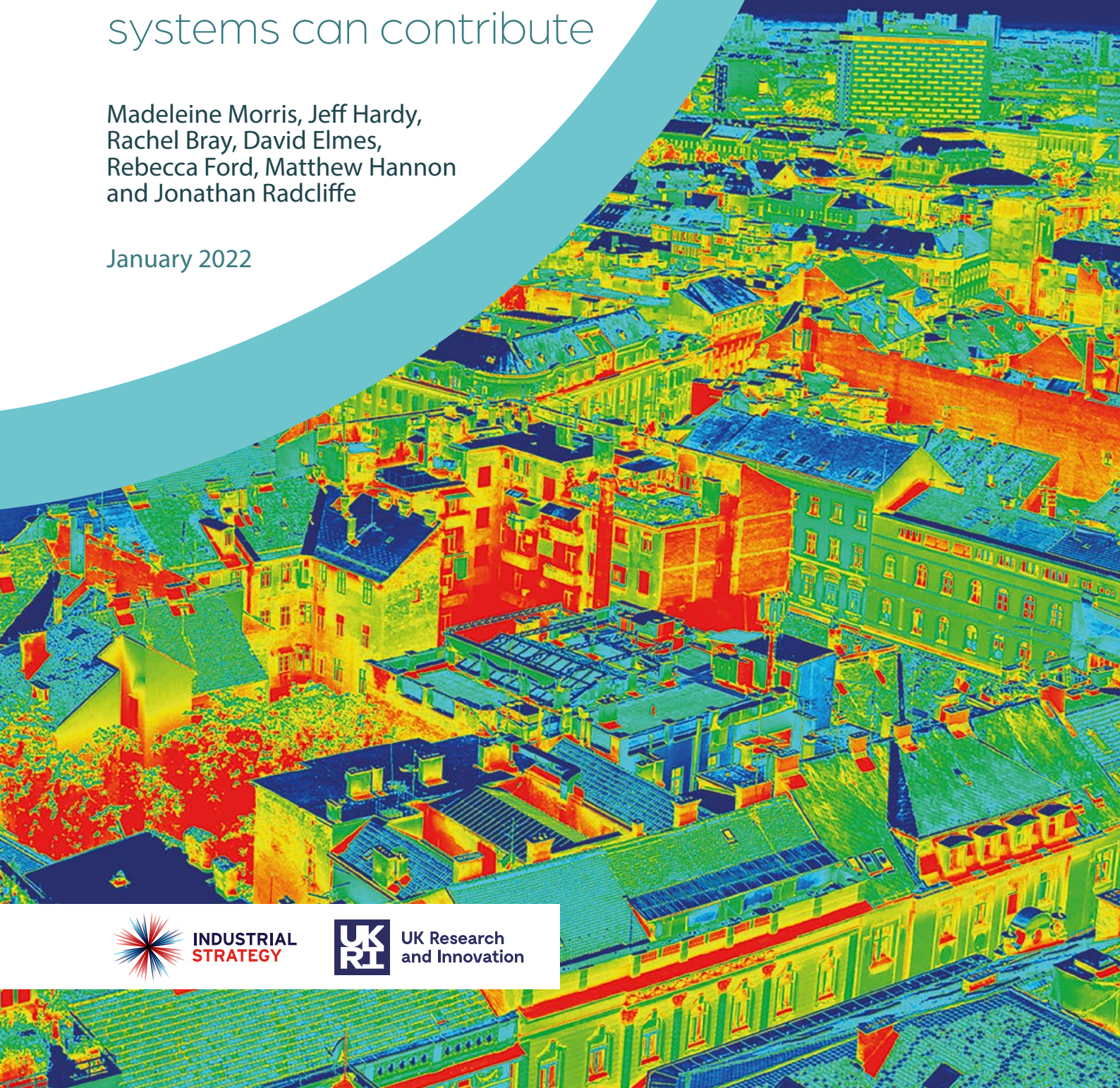

INDUSTRIAL STRATEGY

UK Research and Innovation

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Acronyms

BEIS	UK Department for Business, Energy & Industrial Strategy
CCC	Climate Change Committee
CSE	Centre for Sustainability
DSR	Demand-side response
ECO	Energy Company Obligation
EPC	Energy performance certificate
ESC	Energy Systems Catapult
GB	Great Britain
HNDU	Heat Network Delivery Unit (BEIS)
LAD	Local authority delivery
LAEP	Local area energy planning
LHEES	Local heat and energy efficiency strategies
LPG	Liquefied petroleum gas
PRS	Private rental sector
PV	Photovoltaic
RHI	Renewable Heat Incentive
RIIO	Ofgem's price control framework
SLES	Smart local energy systems

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Executive summary

Decarbonisation of heat is an immense challenge. Despite accounting for over a third of the UK's carbon emissions, little progress has been made in decarbonising heat. This is particularly in the case of space and hot water heating for buildings, which account for 75% of those emissions. Stop-start policies and delays to key decisions have resulted in a thermally inefficient building stock and just 8% of heat coming from renewable sources. There remain deep uncertainties about the technology mix that will make up the heat system in 2050.

A smart local energy systems (SLES) approach could facilitate a transition to a zero-carbon heat sector that is faster, fairer, and more cost effective than current trajectories. However, the current policy and regulatory landscape means that SLES struggle to deliver their potential environmental, societal, and energy system benefits.

The societal impacts and interactions of heat make decarbonisation much more than a technical challenge. Transformation of the sector must be done in a fair and just way – changes made could have major implications for fuel poverty and public health. Under current policy, regulatory and market structures, exacerbation of societal inequalities is likely. However, the transition also provides the opportunity to build a fairer system, bringing tangible societal and economic benefits across the country.

Our review identifies five cross-cutting barriers that will need to be addressed regardless of the zero-carbon heat technology mix that is ultimately adopted. Thus far, successive governments have taken a predominantly centralised and top-down approach to tackling these challenges. However, the supply, demand, and storage of heat has inherently local aspects. Changing the way we heat our buildings is likely to impact our daily lives, demanding new behaviours from consumers. It will also require millions of decision-makers to choose based on their own, often unique, circumstances. There are technical challenges on both the demand side - including coping with seasonal variation and changing consumer needs - and the supply side - including increasing integration of intermittent renewables. This means that we need to move to smarter, more flexible systems faster than achieved so far with decentralised electricity and smart meters.

The key findings of the report are summarised below. We show how each of the cross-cutting barriers identified through the review can be addressed by a SLES approach. We take this further by analysing the UK Government's Heat and Buildings Strategy and Scottish Government's Heat in Buildings Strategy, both published in October 2021. We identify missed opportunities, outline what SLES needs to succeed and make specific policy recommendations.

Table 1:	Summary table of the report

Information, engagement and behaviours	
Challenges We are a decade behind the power system in our understanding of how to effectively engage with consumers in decarbonising heat. Low awareness of the need to move away from fossil gas boilers coupled with low trust in the sector and embedded social practices around energy use means that inducing effective behaviour changes will be slow. Alternative methods of inducing rapid change are needed.	**How SLES could help** • A SLES approach can draw on the knowledge of trusted local actors like businesses, local authorities and community groups. This will facilitate two-way engagement between consumers and national actors in order to develop deeper understanding of consumer needs, priorities and drivers. • Smart business models could avoid the need for some behavioural changes or create new social practices, by transferring responsibility and risk away from consumers to third parties like energy businesses. • Approaches that put local societal co-benefits – health, alleviation of fuel poverty, job creation – at the heart of plans will be stronger and more acceptable for consumers. **UK Government approach & relevant issues** • Assumption that behavioural change will play a significant role in reducing emissions. Expecting to improve awareness and individual action through continuation of existing public engagement channels, including public consultation. • £4.8 billion of new grant funding announced for councils in England, but unclear the extent to which councils will have agency over how this is spent. **What SLES needs to succeed** • To undertake effective engagement work, local government needs to be resourced at a level commensurate with their ambition. Capacity, skills, and funding need to be improved so that they can work effectively with other local stakeholders and consumers. • Enough space and enough certainty for (local) energy business to innovate in order to deliver local SLES priorities and engage customers, including through smart business models. **Policy recommendations** • Local authorities should be mandated to engage citizens and businesses on net-zero. • Central Government should ensure that local authorities have the commensurate resources, capacity, and capabilities to deliver on local net-zero energy systems. • Ofgem should expand the regulatory sandbox approach[1] to to enable regional/local net-zero energy systems business model innovation.

1 A regulatory sandbox enables innovators to trial new products, services and business models without some of the usual rules applying (Ofgem, 2020c).

Strategy, policy and regulation

Challenges

Successive governments have failed to put in place robust, long-term strategies to decarbonise heat that integrate with the rest of the energy system. Fragmented, stop-start policy has left the UK with one of the least efficient building stocks in Europe and amongst the highest reliance on gas for heating. We continue to construct buildings that will need to be retrofitted to make them net-zero compatible.

Regulation of heat is inconsistent and inadequate. This puts consumers at risk, and fails to ensure efficiency and decarbonisation are built in.

How SLES could help

- A SLES approach could facilitate the development of co-ordinated plans which align heat decarbonisation strategies with local infrastructure requirements, socioeconomic characteristics.
- Smart and place-based approaches are projected to be cheaper than national plans that don't account for local context.

UK Government approach & relevant issues

- Strategy and policy are predominantly centralised and market-led, with focus on private spending. There is a lack of strategy to link national and local ambition and action.
- There is an absence of a strategy for improving energy efficiency of owner-occupier homes. There is a missed opportunity to signal support that could mobilise the private sector.
- There is also a deferral on the decision whether or not to ban gas connections for new builds.
- Intention to take primary powers to regulate heat network market.

What SLES needs to succeed

- Strong energy efficiency policy is required to upgrade the building stock so that it can be part of a smarter and more flexible heat system.
- Local actors need a robust framework that facilitates local action whilst supporting national objectives.
- Local government needs to be better resourced so that they can more effectively work towards their ambitions.

Policy recommendations

- Central government should devolve more powers to local authorities.
- Local authorities should be responsible for ensuring energy efficiency of buildings in existing and new builds is commensurate with net-zero targets.
- Heat networks should be regulated by Ofgem[2] to improve transparency in the sector and protect consumers.

2 Since this report was written, the UK Government published its proposals for introducing legislation to regulate the sector. This includes appointing Ofgem as the heat networks regulator, and Citizens Advice as the consumer advocacy body. See UK government announces major expansion of heat networks in latest step to power homes with green energy and Heat networks: building a market framework.

Infrastructure

Challenges

Crucial questions are yet to be answered about major infrastructure.

- What do we do with existing infrastructure, like the gas network and heat networks?
- How can we use existing infrastructure more effectively, to minimise need for expensive new infrastructure?
- How much new infrastructure will we need, and where must it be located?

Under current market conditions, a lack of long-term stable strategy and the absence of a decision-making framework makes it difficult to answer these questions. Heat is largely treated as separate from the rest of the energy sector, but as the transition progresses, it will become essential to integrate heat with the rest of the system.

How SLES could help

- A SLES approach can help to develop area plans which take into account local resources, challenges and capabilities across heat, transport, power and energy storage.
- This could inform and support national decisions on how to repurpose and better utilise existing infrastructure and decide how much and where new infrastructure should be built.

UK Government approach & relevant issues

- There is a missed opportunity to consider heat decarbonisation in the context of wider energy sector changes.
- Commitment to working with local authorities and other stakeholders to better understand local constraints and opportunities for different low-carbon heating technologies.

What SLES needs to succeed

- Decisions on whether or not to switch a given area to low carbon gas will be essential for the planning of infrastructure, as well as for local public engagement strategies.
- These decisions must consider the resources, needs, and capabilities of regions and communities.
- Long-term planning and advance notice of these decisions could be crucial for building trust between government, businesses and consumers.

Policy recommendations

- Mandate local authorities and network/system operators to work together on local strategic infrastructure investment plans and link to local economic development plans.
- BEIS should take key decisions that will impact national infrastructure, such as the gas networks, as soon as possible.

Supply chain

Challenges

The UK does not currently have the capacity to deliver zero-carbon heating at scale. History has taught us that scaling up too quickly without this can have negative impacts on quality and consumer experience.

A lack of clear direction from central government has instilled deep uncertainties across the sector, leaving businesses unable to invest in vital training, skills, capabilities, and partnerships.

How SLES could help

- A SLES approach aligns with the 'levelling up' agenda, which recognises that different areas of the UK have different assets, opportunities, and needs, and that local leaders are best placed to align the work of central government departments according to these characteristics. This can build robust supply chains that create quality, long-term jobs that deliver net-zero and economic benefits.
- Local authorities can leverage purchasing power to guarantee initial anchor loads than can help to provide certainty and accelerate supply chain development.

UK Government approach & relevant issues

- The government are supporting the scale-up of heat networks through continuation of the Heat Networks Delivery Unit and Heat Network Investment Project.
- While the ambition has been set to have the capacity to deploy 600,000 heat pumps per year by 2028, there is little detail on how this will be achieved whilst maintaining high standards of products, services and consumer protection. The government expects this to be largely market-led. There is no discussion of how these heat pumps will be distributed across the country.

What SLES needs to succeed

- Developing regionally specific training or upskilling could be an important factor that helps SMEs to develop knowledge in local materials and building vernacular.
- Extra resources are needed from central government to ensure that relevant local authority officers have expertise on low carbon heat and energy technologies. This will enable them to co-ordinate the development of a supply chain that helps local areas to prosper.

Policy recommendations

- Local authorities should coordinate skills and training for local energy system decarbonisation.
- Government should provide a long-term and whole systems vision for the decarbonisation of heat to provide near-term certainty to supply chains.

Distribution of costs and benefits

Challenges

Current policy, regulation and market structures are exacerbating societal inequities in health, housing and income.

The negative health and economic impacts of poorly insulated homes disproportionately affect those who are already in, or at risk of, fuel poverty. Yet, these impacts are not fully appreciated in evaluations of different pathways.

Distribution of environmental levies means that the relative price of electricity is inflated, while gas prices do not reflect the negative social and environmental impacts associated with burning of fossil fuels.

Without redistribution of costs, decarbonisation of heat will be slow, and increasing electrification will aggravate fuel poverty.

How SLES could help

- SLES could deliver £1.2–2.8 bn in cost savings by 2030, and £2.9-8.7 bn by 2040, compared to a future in which there is no integration of SLES.
- A SLES approach could also help to unlock the societal co-benefits (e.g. health improvements and alleviating fuel poverty) of zero-carbon heating. Local actors are ideally placed to both identify which benefits are most urgently needed (for whom) and develop plans to ensure fair distribution.
- A SLES approach could also help to capture multiple benefits through smarter planning – e.g. combining energy efficiency upgrades with clean heat technology installation to minimise disruption and ongoing costs, helping to decarbonise and improve health of occupants.

UK Government approach & relevant issues

- The Government are minded to rebalance policy costs over next decade, and will launch a call for evidence on options to do this.
- Grant scheme to help with costs of installing clean heat technology. Not targeted to those on low incomes/in fuel poverty. Not co-ordinated with financial support for energy efficiency measures.
- Innovation and supply chain growth to drive down costs – anticipate heat pump cost parity with gas boilers by 2035.

What SLES needs to succeed

- A fairer distribution of policy costs between electricity and gas is essential for SLES.
- Societal impacts of different approaches need to be embedded into cost-benefit analyses and impact assessments for different pathways.

Policy recommendations

- Government should review how societal and environmental impacts are reflected in policy costs, as well as how these costs are distributed.
- Central government should devolve the responsibility for dispersing coordinating grant funding, such as for heating and energy efficiency, to local government.

About this report

Context and methodology

This review on how SLES can contribute to the decarbonisation of heat is the third in a series of reviews of key areas in the UK's policy and regulatory landscape from the perspective of SLES. The first focused on electricity storage and electric vehicles, and the second on the emerging field of digital energy platforms (Morris & Hardy, 2019; Morris et al, 2020).

The purpose of the review series is to analyse current policy, regulation and market structures in the UK, and use the evidence to identify gaps and barriers to the emergence and success of SLES.

Evidence was gathered through a systematic search of 'grey literature'[3], and augmented with relevant documents obtained by crowdsourcing from a wide network of expert stakeholders. A systematic review approach was then used to analyse the evidence, identifying common themes. This report is informed by these themes. In the discussion, we use the concept of the 'SLES prism', first introduced in the EnergyREV report 'Post-pandemic recovery: How smart local energy systems can contribute,' to identify how key aspects of a SLES approach could help to identify synergies and maximise benefits during the transition to a decarbonised heat sector (Fell et al, 2020). Full details of the methodology can be found in the Appendix.

Scope and structure

In this report, we review relevant literature on the decarbonisation of heating through the perspective of SLES. In decarbonising the UK's energy overall, there has been significant progress through supply substitution – replacing electricity from burning fossil fuels with renewables, for example (CCC, 2021b). While we continue such substitution of electricity, we now recognise the need for a smarter, more integrated approach for further decarbonisation of electricity. This has been described recently in the updated Smart System & Flexibility plan and involves a "whole system" approach, where reducing or shifting demand, energy efficiency, storage, smarter controls, flexibility, trading, and a variety of other approaches are all considered in an integrated way (BEIS, 2021i).

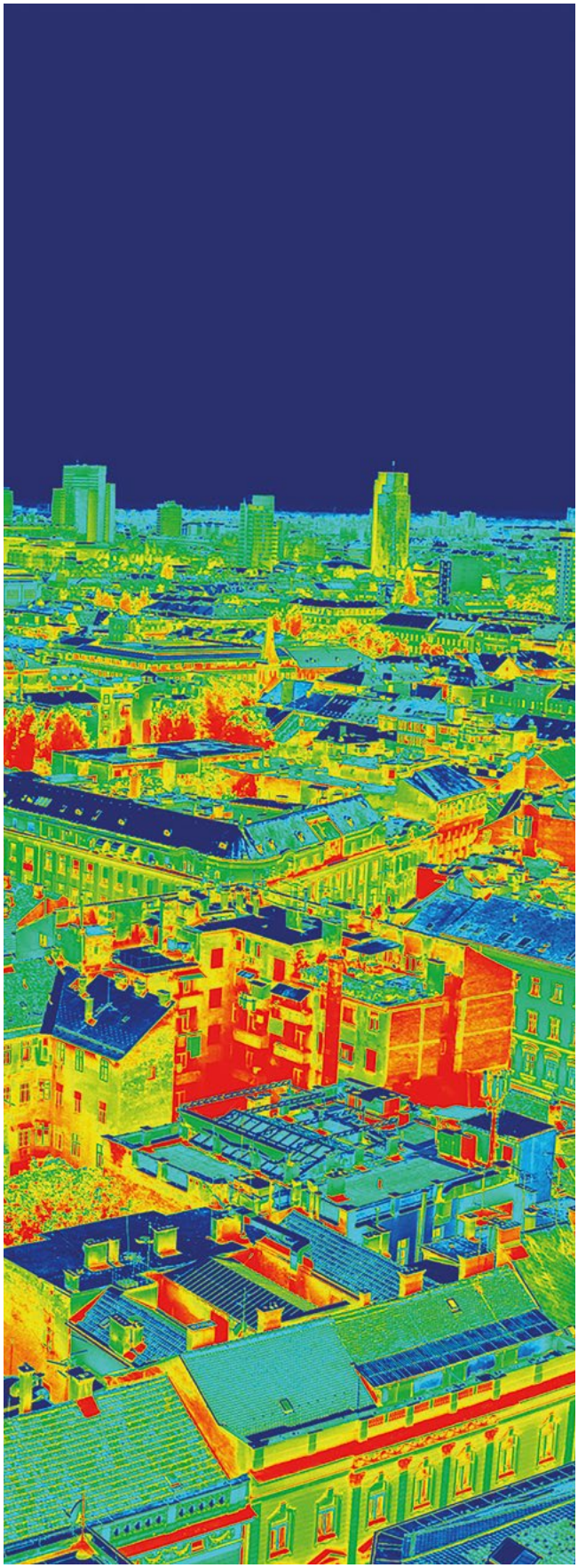
There is the opportunity for supply substitution in heating too – replacing gas boilers with heat pumps, as proposed by the Climate Change Committee (CCC) and in Government plans (CCC, 2020c; BEIS, 2021c). In this review we explore whether decarbonisation of heating needs to move from supply substitution to a whole system approach sooner than we experienced with electricity, and where a SLES approach could facilitate this. We therefore do not conduct an evaluation of different low carbon heat technologies, but rather focus on the cross-cutting themes that apply to the challenge of heat decarbonisation regardless of the pathway that is ultimately chosen.

3 Used here, 'grey literature' encompasses materials produced outside of academic publishing, such as reports, white papers, and government documents.

We focus in this review on space heating and hot water in buildings, though we fully realise that there are further demands for heating, for example for industrial processes, and also for cooling.

The structure of this report is as follows:

We start in Section 1 by looking at the scale and complexities of the challenge to decarbonising heat, and briefly summarise progress to date. We present the five areas that emerged from our evidence review as key cross-cutting barriers in Section 2. In Section 3 and Section 4 we explore why a SLES approach is valuable, and how it could help to address each of the five cross-cutting barriers. We analyse the UK Government's Heat and Buildings Strategy and Scottish Government's Heat in Buildings Strategy, both published in October 2021, and compare them to a SLES approach in Section 5, before concluding with specific policy recommendations in Section 6.



1 Introduction

1.1 Why do we need to decarbonise heat?

Decarbonisation of the heat sector is considered one of the greatest challenges in reaching the UK's target of net-zero greenhouse gas emissions by 2050 (National Grid, 2020; BEIS, 2017; BEIS, 2018). Emissions from heat are the biggest contributor to the country's carbon footprint, accounting for over a third (37%) of emissions.[4] With the UK committed to achieving net-zero greenhouse gas emissions by 2050, and an interim target of 68% by 2030, action to decarbonise the heat and buildings sector is urgently needed (BEIS, 2021j). However, while the UK has made good progress in reducing carbon emissions from the power sector, this has not been reflected in emissions from heat, as seen in Figure 1 (CCC, 2021).

Emissions from the heat sector are high because it remains dominated by fossil fuels; in 2020, 76% of the UK's space heating and hot water demand in buildings was met by natural gas and 10% by oil (BEIS, 2021a). Eight percent of demand was met by electricity, and just 3% by bioenergy and waste sources.

As seen in Figure 1 emissions from buildings have barely decreased in recent decades (BEIS, 2021a). One reason is the slow progress on improving energy efficiency in buildings. Although a high proportion[5] of newly-built homes achieve the highest rated EPC band A or B, this represents less than 5% of the total housing stock.

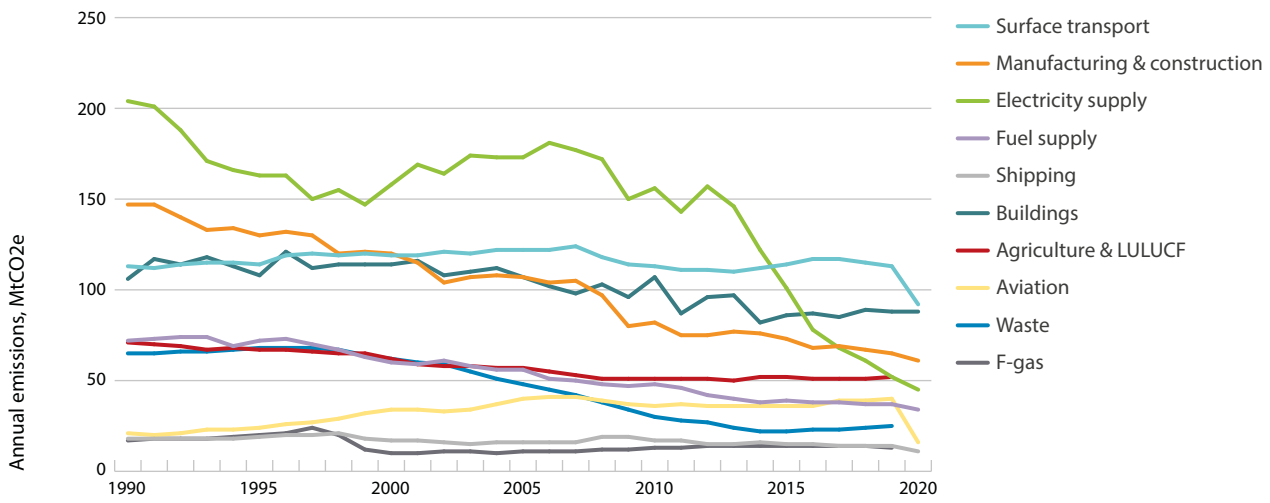


Figure 1: Change in UK emissions by sector 1990-2020. Data from Climate Change Committee.

4 Including space heating and cooling, hot water, cooking, and heat for industrial processes (BEIS, 2018).

5 84% in England and 87% in Wales during Q1 of 2021.

Around 60% of existing households are rated below EPC band C (BEIS, 2021c; Scottish Government, 2021; Welsh Government, 2019b; Scottish Government, 2019c). Retrofitting these buildings to improve thermal energy efficiency is considered a 'no regrets' option which will benefit the occupants with higher comfort levels and lower heating bills, as well as potentially make the transition to a decarbonised heating system cheaper and faster (BEIS, 2021c; National Grid, 2019; National Energy Agency, 2017; National Infrastructure Commission, 2018).

1.2 Why do we need to do this in a fair way?

While the urgency that underpins the challenge of decarbonising the heat sector is rooted in carbon reduction targets, there is also an opportunity to address some of the wider societal issues that are present in current systems.

The road to a net-zero energy sector is expected to incur significant costs. One study estimates that the infrastructure costs for the heat sector alone will require between £100 billion and £450 billion in cumulative additional costs to 2050 versus the status quo (National Infrastructure Commission, 2018). The distributional impact of the costs are a key challenge for the entire sector, but this is particularly the case for heat because of its impact on fuel poverty and public health.

An estimated four million households across the UK live in fuel poverty (Scottish Government, 2019c; BEIS, 2020a; Northern Ireland Housing Executive, 2017; Welsh Government, 2019a; BEIS, 2021h).[6] On average, domestic consumption of gas is four times that of electricity which is mostly used for heating (BEIS, 2021e).

There are very real risks that making heat more expensive will put additional economic strain on those already living in fuel poverty, and place significantly more households at risk of fuel poverty and the negative health implications associated with it.

Being unable to adequately heat homes has major implications on health. Living in poorly insulated homes can both increase the risk of developing respiratory and circulatory problems, and exacerbate existing health problems (Public Health England, 2014; Ofgem, 2019). Studies suggest that almost 17,000 excess winter deaths[7] in 2017/18 can be directly linked to cold homes, and around 5,500 to the associated difficulties of living in fuel poverty (Office for National Statistics, 2020). Moving away from fossil-powered heating systems can also improve both indoor and outdoor air quality, and reduce levels of damp in homes (Rosenow & Lowes, 2020; IEA, 2019; Gupta et al, 2015). Better heating systems and controls could also help people to understand and manage their energy use, reducing the likelihood of them self-rationing at the expense of physical and mental well-being (Ofgem, 2019; Anaam et al, 2020).

The benefits of better insulated homes and zero-carbon heating systems could lead directly to significant healthcare cost savings; the annual cost to the NHS of poor-quality housing has been estimated at £1.4 billion–£2 billion in England alone (CCC, 2019; Nicol et al, 2015). The links between fuel poverty and ill-health mean that focussing efforts on these households could provide the greatest healthcare related benefits; it is estimated that for every £1 spent on retrofitting fuel-poor homes, an estimated £0.42 is saved in NHS spending (UKGBC, 2017; Brown et al, 2018).

6 The definition of 'fuel poverty' is a devolved matter and varies across the UK nations. In 2021, the UK Government updated the metric used to measure fuel poverty in England – approximately 1 million households are 'newly' measured as fuel poor (relative to before the change), and around 400,000 are no longer considered fuel poor (BEIS, 2021h).

7 Excess winter deaths (EWDs) are a way to measure the health burdens associated with cold during the winter and is estimated by comparing the average number of deaths during the winter (December to March) with that of the four-month periods before and after (i.e. August to November and April to July) (Office for National Statistics, 2020).

Crucially, the societal benefits that could be achieved in this transition are not guaranteed. For example, without improving building energy efficiency, health issues that are caused or exacerbated by cold, damp homes are unlikely to be alleviated through heating technology switches. Without a holistic approach which is based on a deep appreciation of the impact of heat on the welfare of people, these issues could in fact be worsened.

Fairness, therefore, must be at the heart of this transition, and considered throughout the design, delivery, and ongoing maintenance and operation of sector changes.

1.3 What are the local and smart aspects of heat?

The place-based nature of the majority of heat demand – i.e. in homes and businesses – means that there are inherently local aspects to the challenge of decarbonisation. Changes will need to be made to buildings on an individual basis, requiring millions of decision makers to make choices based on their own unique circumstances. This makes decarbonisation of heat a fundamentally different challenge from power, which, as the sector with the most significant carbon emission reductions, can provide some useful comparisons in terms of progress.

The regional and national governments and the CCC indicate that the bulk of heat decarbonisation will be achieved from switching from fossil fuels to zero-carbon electricity. In essence, this means replacing fossil fuel heating systems, like gas boilers, with electricity-driven heating technologies, such as heat pumps. Uptake of these alternatives has been slow, partly because they currently cost more than the existing heating technologies and because public awareness of alternative heat technologies – and the need for them – is low. Greater awareness is crucial to ensure successful transformation of the sector.

Heating supply substitution alone is not enough, as is evident in the power sector. The UK Government's Smart Systems and Flexibility Plan was first launched in 2017, to address the fact that we have reached the point where wider system changes need to be ramped up to facilitate deeper penetration of renewables and, in turn, full decarbonisation of the sector (BEIS & Ofgem, 2017; BEIS & Ofgem, 2017a). Updated most recently in 2021, this strategy highlights the increasingly important roles that consumers, flexibility (including demand-side response (DSR) and storage), markets and digitalisation will play going forward (BEIS, 2021i). The plan involves a "whole systems" approach which addresses these key components in a smarter and more integrated manner than efforts to date.

Similar smart and flexible system-wide changes will be needed for heat decarbonisation, and because we are at the beginning of the heat transition there is an opportunity to make early progress. But, any changes must be placed in the context of the wider energy sector transition. For example, significant electrification of both the heat and transport sectors as recommended by the CCC will place additional demands on local and national electricity networks and introduce further complexities in system operation (CCC, 2020d; Strbac et al, 2018; BEIS and Ofgem, 2021). This necessitates an integrated approach to supply substitution, demand reduction, infrastructure impacts, flexibility, markets, business models, and users.

The personal nature of heat means that it relies, more often than not, on consumer choice; for example switching from a gas boiler to an electric heat pump (BEIS & Ofgem, 2017a). Decarbonisation is likely to alter our daily experience and require behaviour change and/or significant investment costs. A 'one-size-fits-all' approach is therefore unlikely to be appropriate for a challenge which involves so many individuals. The transition will also inevitably change the landscape of industry 'winners' and 'losers' (Ofgem, 2019; Citizens Advice, 2021). Understanding who will be affected and how will need a high level of granularity, without which we run the risk of increasing the inequality gap and creating more losers.

1.4 What has been done so far?

The UK has seen very limited progress in reducing emissions from the heat and buildings sector (CCC, 2021b). The approach to heat and buildings policy has been largely centralised and lacking in strategy over the past 40 years, being described as 'fragmented' and 'stop-start' (House of Commons Energy and Climate Change Committee, 2016; Eyre & Killip, 2019).

This includes weakening or withdrawal of policies such as the Code for Sustainable Homes and the Zero Carbon Homes (ZCH) standard, which was scrapped in 2015 (CCC, 2019a). Although a replacement to ZCH – the Future Homes Standard – was announced in 2019, the full details of this policy, including key decisions on new gas connections, are yet to be finalised (BEIS, 2021c; MCLG, 2021). Retrofit policy has been similarly lacking in strength, continuity and strategy. The introduction of the Green Deal in 2013, for example, was widely considered a costly failure due to its poor design, limited financial appeal, and inadequate engagement with consumers (Eyre & Killip, 2019; Fawcett et al, 2019; Webb, 2016; Policy Connect, 2019; Rosenow & Eyre, 2016; Broad et al, 2020). It is viewed as being responsible for the "collapse" of the domestic energy efficiency market, with installation rates of insulation falling dramatically compared to before its implementation (Eyre & Killip, 2019; CCC, 2018). It closed to new applications in 2015, and a replacement financial incentive scheme, the Green Homes Grant, wasn't implemented until 2020, as a short-term response to the COVID-19 economic recession. Having faced issues with delivery from the outset, it was scrapped after just six months, leaving the vast majority of the £1.5 billion pot unspent (BEIS, 2021b; Laville, 2021). The recent Heat and Buildings Strategy notably does not feature any new announcements on financial support for improving thermal efficiency of buildings (BEIS, 2021c).

A stable central policy environment can provide the certainty and confidence businesses need to deliver change. The UK's offshore wind market, bolstered by clear and consistent central government policies and incentives including the Contracts for Difference (BEIS, 2021), is the world's largest and has seen dramatic cost reductions in the technologies. A clear commitment to electrification of transport along with government support and incentives has energised the UK's EV market (Stark et al, 2019; Energy Taskforce, 2020; Hirst et al, 2020). To date, a centralised approach has also been UK Government's preferred approach for heat. National, top-down policies such as the flagship Renewable Heat Incentive (RHI, first launched in 2014), and the Energy Company Obligation (ECO, first launched in 2013), are both financial incentive schemes set and overseen by BEIS and Ofgem.

While there are examples of local approaches to heat decarbonisation across the UK, these are not fully supported by UK Government strategy, policy or regulation. For example, the Scottish Government supports local authorities to produce Local Heat and Energy Efficiency Strategies, and expects all local authorities in Scotland to have produced delivery plans by 2023 (Scottish Government, 2020c). However, in their Heat in Buildings Strategy published in 2021, the Scottish Government argued that they "do not have all the powers necessary to deliver the transformational change required" (Scottish Government, 2021). In England, Local Enterprise Partnerships (LEPs), which are collaborations between local authorities and local businesses, were supported by central government in 2018 to develop local energy strategies and they are now being supported to deliver on these strategies through Regional Energy Hubs. However, some have criticised that local players like local authorities do not have the capacity or resource availability to effectively deliver such activities, calling on the UK Government to ramp up support (Policy Connect, 2019; Citizens Advice, 2021a; CCC, 2021a).

While central government's heat network policy generally includes more local elements (e.g. the Heat Network Delivery Unit (BEIS, 2020e) and implementation of zoning[8] (BEIS, 2021d) the Heat and Buildings Strategy has been criticised for lack of detail on the involvement of local government in the planning and delivery of schemes (BEIS, 2021c; Lowes, 2021).

1.5 Why has progress not been better?

Decarbonisation of heat and buildings is an inherently complex problem. It will require policies that reach into people's homes, ask them to invest in building renovations, adopt new technologies, and likely require them to significantly change their behaviours. It will also change the landscape of 'winners' and 'losers' across industry and society. This makes committing to a long-term and coherent decarbonisation strategy politically sensitive, and successive UK governments have delayed action, focussing instead on the power sector (McDowall & Britchfield, 2021; Lowes & Woodman, 2020). For example, the last strategy on heating was published in 2013. It has been described as a 'wicked problem':

> "Because different stakeholders have different versions of what the problem is, it has many interdependencies and is often multi-causal and not stable, is socially complex, it does not sit conveniently within the responsibility of any one organisation, it involves changing behaviours, attempts to address it often lead to unforeseen consequences and it may have no clear solution." (Welsh Government, 2019)

Within the Government alone, roles and responsibilities relevant to the challenge, sit in different and often siloed departments[9], and devolution of powers means that there can be differences in approaches and commitments across the different scales of government such as local and regional authorities, devolved administrations, and national government (CCC, 2020b).

Tackling emissions is also more difficult for heat than for electricity generation because there are fundamental differences in how we use the different forms of energy (Eyre & Killip, 2019). We require electricity as a means to an end; we use it for illumination, cooking, warmth, entertainment, work and mobility. The increase in integration of renewables sources of electricity has so far changed very little, if anything, about how we conduct these activities, and has gone largely unnoticed by the public (BEIS & Ofgem, 2017a). On the other hand, changing the way heat is generated and transported to and through our homes and workplaces – for example switching from a gas boiler to an electric heat pump – is likely to alter our daily experience and require behaviour change and/or significant investment costs. The personal nature of heat therefore, more often than not, relies on consumer choice (BEIS & Ofgem, 2017a).

There remain many barriers to progress, which span technical, financial, governance and social issues, and are complex and often interdependent. In the next chapter, we explore some of these barriers in detail.

8 A heat network 'zone' is a designated area within which heat networks are identified as the best option of decarbonising heating for that area. The UK Government proposes that, once a zone has been designated, certain types of building must connect to their local heat network in a given timeframe (BEIS, 2021d).

9 For example, the Department for Business, Energy & Industrial Strategy (BEIS) is responsible for energy supply, climate change and business. Responsibility for air pollution in England sits within the Department for Environment, Food & Rural Affairs (Defra), and accountability for new housing in England lies with the Department for Levelling Up, Housing and Communities (previously Ministry of Housing, Communities and Local Government, until September 2021).

2 Barriers to decarbonising heat

Our review has uncovered a range of barriers to zero-carbon heating and cooling. Many of these are specific to technologies or approaches and are well documented. Others cut across different approaches, and are related to the fact that, although there are many potential benefits to the transition, there are also some potentially negative impacts which need to be mitigated against. We focus on these cross-cutting barriers in this section because overcoming them could enable multiple pathways to net-zero heating. When we analysed the barriers, we found they clustered into five themes:

- Information, engagement and behaviour
- Strategy
- Infrastructure challenges
- Supply chain
- Distribution of costs and benefits

We have structured this section around these cross-cutting themes of barriers. There are also instances of where these barriers intersect.

2.1 Information, engagement and behaviour

In their Sixth Carbon Budget, the CCC advised that:

> "It will not be possible to get close to meeting a net-zero target without engaging with people or by pursuing an approach that focuses only on supply-side changes." (CCC, 2020d)

They estimated that around 16% of the measures required to reach net-zero would require 'largely societal or behaviour changes,' with a further 43% involving a combination of societal/behaviour and technology changes (CCC, 2020d).

Heating and cooling, or comfort, is inherently personal and must be part of technology, policy, regulation, and market design. Decarbonisation of heat and buildings will, in many instances, require people to make changes within homes and businesses, including installing new heating systems and energy efficiency upgrades and also getting used to new heating controls and, indeed, tariffs (Carmichael, 2019; Carmichael et al, 2020).

2.1.1 Awareness about the need to decarbonise heating

There is low public awareness about the contribution of heating to climate change and the associated actions required to decarbonise heating. The Energy Systems Catapult surveyed 2000 consumers in 2020 on their attitudes to low-carbon heating technologies. They found that half of the respondents linked their gas boilers to climate change, less than 20% said they would consider switching to low carbon heating, and just 2% had already made the switch (Energy Systems Catapult, 2020c). Knowledge of specific heating (potentially low-carbon) technologies is also low. For example, only two out of ten UK households have ever heard of heat networks, according to a Government Public Attitude Tracking Survey published in 2016 (ADE, 2018).

Information alone isn't sufficient to increase awareness about low-carbon heating and affect behaviour change. For example, the Energy Performance Certificate rating scheme, designed to summarise buildings' energy performance and provide tips to occupants on improving energy performance, has been in place since 2007.

A 2019 BEIS Public Attitudes Tracker survey found that only 2% of respondents had made changes due to their EPC assessment (BEIS and MHCLG, 2020). This is in keeping with the debunking of the Information-Deficit Model (IDM). The IDM assumes that householders presented with the 'correct information', will make rational, economic decisions about energy consumption based on their attitudes and beliefs. Many energy devices, such as Home Energy Management Systems, have traditionally been designed around the IDM. A promising alternative approach to is to co-design and test systems with users, for example recent work has shown user-centred design's potential to create new designs of, and sustain greater engagement with, home energy management systems (Peacock et al, 2017).

2.1.2 Engagement

Most households and businesses will need to take action on energy efficiency, heating (and, for some, cooling) for the UK to meet its carbon targets (BEIS, 2018). In addition to the low public awareness of the importance of heating and cooling in carbon targets, there are other cross-cutting barriers to engagement and action.

Public acceptability

To a large extent, consumers will need to choose to make changes to homes and businesses to decarbonise them. Public acceptability of alternative heat and energy efficiency solutions will therefore be required to enable the deployment of measures to realise deep emissions reductions in buildings. Even amongst those who are aware of the need to decarbonise heating, there is the perception that alternative technologies (e.g. heat pumps and hydrogen heating) would not provide additional benefits (Williams et al, 2018).

Framing

In the past, low-carbon heating and energy efficiency measures have been separately treated, for example, through the Renewable Heat Incentive (Ofgem, 2018a; Ofgem, 2018) and ECO schemes (BEIS, 2018). However, evidence shows that households and businesses generally think about warmth and comfort rather than heating technologies and energy efficiency (CCC, 2016; Energy Systems Catapult, 2019). Combining energy efficiency and heating interventions into whole-house comfort approaches could reduce household disruption and improve the operational performance of technologies such as heat pumps.

Hassle factor

Some heating and cooling approaches require alterations to buildings. These could include fitting insulation or modifying heating systems with new radiators and fitting a hot water tank for heat pumps, or altering appliances to run on hydrogen (pure or as a mix). This disruption can be a barrier for consumers, particularly when coupled with unfamiliarity with technology and installers (Carmichael et al, 2020; Navigant and ENA, 2019; BEIS, 2020).

In addition to the hassle factor of fitting new heating systems, the new systems themselves can be more complex to operate, particularly where best value is coupled with smart tariffs, like time of use tariffs. Getting used to new heating controls and modes of operation is an issue for many, and particularly for elderly and people in vulnerable situations (Carmichael et al, 2020; Energy Systems Catapult, 2019b).

Trust

Given the scale and pace of the transformation required to deliver zero-carbon heating and cooling public trust in any programme is crucial. There are trust issues in several aspects of this transformation: trust that retrofits and new heating solutions will deliver the financial and carbon benefits promised (Green et al, 2020); trust in the information and advice about heating and cooling (Brown et al, 2018); trust in energy companies and government (BEIS, 2017); and trust in the supply chain to deliver measures (Demski et al, 2019).

Upfront and running costs

While renewable heating and cooling technologies and energy efficiency measures can provide benefits such as low running costs, they often have higher upfront costs than fossil fuel alternatives (IRENA, IEA, and REN21, 2020). These upfront costs can count for more than possible savings from such systems in household decision-making due to a cognitive bias towards near-term costs and gains known as 'temporal discounting' (Carmichael et al, 2020).

Running costs are also affected by the relative cost of fuels; for example electricity is more expensive than gas in the UK, partly because of fundamental efficiency differences and partly because most policy costs are assigned to electricity (Ofgem, 2019; IRENA, IEA, and REN21, 2020).

This is, in part, because carbon taxes and several levies are assigned to electricity bills but not gas (Rosenow & Lowes, 2020). Research by Barnes et al has shown that taxes and levies on electricity bills weaken the economic case for heat pumps. However, they also conclude that addressing the high capital costs and seasonal performance factors could improve the economics of heat pumps compared with gas boilers (Barnes & Bhagavathy, 2020).

2.1.3 Behaviours

Zero-carbon heating is likely to alter our daily experience and require behaviour change. This is borne out in the recent Government Heat and Buildings Strategy, which references behaviour 20 times, and states that:

> "Households will not be forced to remove their existing boilers, instead we will be taking an approach that goes with the grain of markets and consumer behaviour to minimise costs and disruption."

In part this assumes that consumer behaviours, or habits, are inflexible and thus such behaviours are an obstacle to change. Or to put it another way, heat decarbonisation must not perturb existing behaviours. Professor Elizabeth Shove, in her paper on Habits and Their Creatures (Shove, 2012), notes that:

> "Much of the consumption that matters for environmental sustainability is habitual, recurrent and ordinary."

As an example relating to heating a generation ago a weekly bath was normal in contrast to today's more resource-intensive pattern of showering once (or more) times a day (Shove & Walker, 2010). Professor Shove asks the important question, considering behaviour from the "habits point of view":

> "Can policy makers do anything to help sustainable habits capture large swathes of the population and edge other more damaging habits out of the way?"

The point, and challenge, here is that current policy and regulatory approaches are somewhat stuck in a transition to net-zero carbon without modification of current patterns of consumption. However, current patterns of demand, including heating, are not commensurate with a predominately renewable energy supply.

2.2 Strategy, policy and regulation

Until October 2021, the UK lacked a long-term strategy for how energy efficiency and heating will contribute to the UK's net-zero target. The UK track record in this space is stop-start (House of Commons Energy and Climate Change Committee, 2016; Eyre & Killip, 2019). In energy efficiency this stop-start policy has been in evidence over the past 40-years for domestic properties and almost absent for non-domestic buildings (Eyre & Killip, 2019).

A similar story is true for new buildings. It is most cost effective to make new buildings zero carbon at the build stage. However, policies to support this have been weakened or withdrawn in recent years (CCC, 2019a). Consequently, few new homes are being built to the highest standards; for example in 2018 only 1% of homes met EPC Band A standard (Carmichael et al, 2020). According to the CCC, compliance with existing building standards is weak due to their complexity and some confusion over roles and responsibilities (CCC, 2019a). On the latter point, the current Planning and Energy Act allows local planning authorities to set local energy efficiency standards for new homes that exceed national standards, leading to different standards of new-build across the country (HM Government, 2008). There are also non-compliance and enforcement issues with energy efficiency schemes, like the EPC, and buildings (Eyre & Killip, 2019; BEIS and MHCLG, 2020).

A key challenge for heating strategy is the diurnal and seasonable nature of heating demand. Over the course of a day, heating demand is characterised by a short morning, and longer evening peak. This correlates with current electricity demand, so fuel switching from gas to electricity without demand-side flexibility would exacerbate existing electricity demand peaks. Seasonal demand is challenging as currently winter peak day gas demand is around 5 TWh, which is five times more energy than the electricity grid can currently carry (Carmichael et al, 2020). Managing these swings in demand will be a major challenge for the decarbonisation of heat.

Smart meters are a vital part of the infrastructure required to enable domestic and business consumers to participate in more flexible electricity consumption (Carmichael et al, 2020). The GB smart meter rollout is currently five-years delayed and expected to complete in 2025. To date 46% of homes and relevant non-domestic buildings have been fitted with a smart or advanced meter (BEIS, 2021g). This delay has impacts on wider programmes of work, such as the introduction of a mandatory market-wide half-hourly settlement regime by Ofgem.

Half-hourly settlement is intended to help provide the right 'incentive framework' to suppliers for "bringing forward new products, services and business models, supporting more dynamic competition, and helping consumers to manage and shift their consumption to cheaper periods" (Carmichael et al, 2020).

2.3 Infrastructure challenges

There are several cross-cutting infrastructure challenges for delivering zero-carbon heat. These broadly fall into three categories: Repurposing existing, building more of the same, and issues with existing.

Repurposing existing infrastructure

Moving to lower carbon gases, such as to hydrogen from methane, would require some repurposing of the national and local gas networks (Carmichael et al, 2020). The gas grid is currently unable to transport hydrogen without leaks and will require new high pressure pipes. The existing Iron Mains Replacement Programme is expected to convert 90% of the gas distribution network to hydrogen compliant polyethylene pipes by 2032 (Carbon Connect, 2017). Hydrogen could also require some new or modified equipment in homes, including hydrogen meters and sensors. Also existing appliances like cookers and boilers will need to be upgraded or replaced (Dodds & Demoullin, 2013). Work is ongoing to better understand the technical, safety and economic case for deploying hydrogen in different sectors (HM Government, 2020).

Building more of the same infrastructure

Fuel switching from natural gas to electricity for heating – for example from gas or oil boilers to heat pumps for heating and hot water – requires additional zero-carbon generation to meet new electricity demand and potentially significant reinforcement of electricity grids. This additional requirement would be exacerbated in the absence of energy system efficiency and flexibility.

The Energy Technologies Institute has shown that replacing a gas boiler with a heat pump can increase household electricity demand to 8 MWh per annum from around 3 MWh per annum. In context, running an electric vehicle would add an addition 3 MWh per annum of electricity demand (Energy Systems Catapult, 2018a). This can in part be offset by a 'flexibility first' approach to building retrofits and electrification of heating (Rosenow & Lowes, 2020; Carmichael et al, 2020).

Issues with existing infrastructure

The presence of existing infrastructure such as electricity, gas and telecoms networks can make it difficult to accommodate new infrastructure, like heat networks. This is exacerbated by the fact that heat networks are not regulated in the same way as electricity and gas networks and so do not have the same powers, for example to dig up roads to lay new infrastructure. This means the cost of building new heat networks is higher than in regulated networks (Carmichael et al, 2020; Maclean et al, 2016).

Existing buildings themselves may not be suitable for certain types of heating or efficiency, for example if they are space constrained or protected (e.g. heritage) (CCC, 2019). For example, buildings that have solid walls will require internal or external solid wall insulation which is significantly more expensive than those newer buildings with cavity walls. Also, the appropriate measures might vary even when the buildings are identical due to occupant behaviour: heat requirements are driven by age, health and lifestyle (Policy Connect, 2019).

Answering these questions without a clear, long-term strategy could result in 'lock-in' to infrastructure which is more expensive and less efficient than alternatives. For example, the UK Government have deferred a decision on the future of hydrogen heating until 2026, with research and development efforts continuing to assess feasibility in the meantime (BEIS, 2021c). It is therefore unclear the extent to which the Iron Mains Replacement Programme will ultimately be required, and in which regions of the country. This is an example of where one barrier (lack of strategy) intersects with and exacerbates another (infrastructure).

2.4 Supply chain

Capacity to deliver

In their sixth carbon budget report, the CCC outlined the challenge to the supply to deliver millions of energy efficiency and heating installations over the next three decades. According to the Construction Industry Training Board, over 200,000 additional jobs will be created to deliver low-carbon heat installations. While some of these jobs replace those currently installing fossil fuel technologies, such as gas boilers, additional labour will be required for more complex installations, such as heat pumps (CCC, 2020d). The earlier challenge around strategy for zero-carbon heating affects supply chains since they will need certainty in order to invest in the training, skills, capabilities and partnerships to deliver on these challenging heat decarbonisation scenarios (Simpson et al, 2018). Scaling up too quickly without putting in place the appropriate skills to deliver can have negative impacts on quality (CCC, 2021b).

Business model innovation

There is growing evidence that the current model for energy supply, predicated on the increasing throughput of energy commodities, is a barrier to low-carbon heating (Brown et al, 2019). In the future, a wide range of heating technologies, smart tariffs, whole house packages and supplier offerings could present customers with a 'choice overload'. Business models such as heat-as-a-service could take away some of this complexity. They could also mitigate some of the financial, technical, performance and price risks (Delta-EE, 2019), although consumers would still need to be able to choose between different offers (Carmichael et al, 2020). Such models could better understand and align with their customers' needs and preferences (Ofgem, 2020). Ofgem has recognised that there are barriers to innovative energy service business models under current licensing arrangements. It is exploring how to adapt regulatory requirements to enable experimentation and foster innovation (Ofgem, 2020).

2.5 Distribution of costs and benefits

The transition to decarbonised energy system will incur costs, and there remains a high level of uncertainty around how these costs should be distributed. The costs include the upfront costs (including to government, industry and consumers), and the ongoing costs of a decarbonised system.

The upfront costs to replacing or repurposing infrastructure and technologies and upgrading building energy efficiency are significant and one of the main barriers to action, particularly for individual households (Carmichael et al, 2020; IRENA, IEA, and REN21, 2020; .[However, it is expected that homeowners will be required to fund measures where they are able to do so (Scottish Government, 2019). Over the last decade, attempts by the UK Government to encourage homeowners to improve the energy efficiency of buildings have had limited success. The Green Deal, for example, arguably did more harm than good for the energy efficiency sector (Eyre & Killip, 2019; CCC, 2018), whilst the recent Green Homes Grant, which reached just 10% of the target 600,000 homes, closed to new applicants six months after launching (CCC, 2021b; Harvey, 2021).

Relative costs of gas and electricity are currently skewed because social and environmental policy costs are levied disproportionately onto electricity bills (~23% of a typical electricity bill, vs just 2% of a typical gas bill) (Policy Connect, 2019; Ofgem, 2021). Without a redistribution of social and environmental policy costs, the transition is likely to impact the cost effectiveness of different sustainable heating solutions and negatively affect electric heating customers, especially those who are in, or are at risk of, fuel poverty (CCC, 2019a). There are therefore calls to level the playing field by redressing the imbalance of tax and regulatory costs across fuels, which could help to accelerate uptake in market segments that are emerging (CCC, 2019a; IRENA, IEA, and REN21, 2020; IEA, 2021). In the Heat and Buildings Strategy, the UK Government committed to reviewing and redistributing costs over the next decade (BEIS, 2021c).

2.6 The intersection between barriers

While we have separated the barriers into distinct sections in this report, they are often intertwined and can exacerbate each other. For example, without clear and long-term strategies from central government, decisions on infrastructure risk locking us into the wrong pathway, or making action impossible. The complexities of this challenge can also make committing to a strategy politically difficult, particularly in the absence of an existing supply chain which can deliver the strategy. However, businesses will be reluctant to make the investments required to build a strong supply chain – such as reskilling their workforce, and realigning their business models and plans – until they can be certain of long-term stability, for which government strategy is (usually) required (Kemp et al, 2009). The longer key decisions are deferred, the more quickly the solutions must ultimately be implemented, and the more expensive the transition becomes (CCC, 2020d).

3 The local and smart aspects of heat

The cross-cutting barriers outlined in the previous section will need to be addressed regardless of which technology mixes are ultimately pursued. It is therefore crucial that decarbonisation strategies consider how to lower the barriers and/or mitigate negative outcomes.

In this section, we begin to explore how a SLES approach could facilitate a transition to a zero-carbon heat sector that is faster, fairer and more cost effective than current trajectories. The meanings of 'smart' and 'local' in this context are outlined in Box 1.

Box 1 Smart & local

What is smart?

The concept of 'smart' in the context of energy systems is well-discussed yet remains broad. It is often used to describe improving the efficiency and/or effectiveness of the energy system. This can be through technical means, for example incorporation of information and communication technologies and implementation of automation and self-regulation. It can also be through more effective decision making aided by enhanced data and insights. Smart energy systems are generally understood to work across multiple sectors and vectors. Importantly, 'smart' is usually a relative term, and therefore its meaning is constantly evolving (Ford et al, 2021; Ford et al, 2019; Local Energy Scotland, 2021).

What is local?

'Local' in the context of energy is similarly broadly used. Local can be defined geographically, for example along local authority boundaries or according to distribution network lines. It can also be defined spatially, for example by proximity to generation assets. While local energy is not necessarily defined by the active participation of local actors, it is generally understood to deliver value to people within a defined area (Ford et al, 2021; Ford et al, 2019; Local Energy Scotland, 2021).

What is SLES?

We understand 'smart local energy systems' to include principles of both smart and local in an integrated way, to enable increasingly localised forms of system balancing and network management, supported by flexibility across energy vectors like heat and electricity. SLES also include more local forms of system management, operation, governance, ownership, and user engagement and participation. Geographical boundaries can be drawn around the system, defined loosely around generation assets, network infrastructure, or social identity (Fell et al, 2020).

We found throughout this review that there are clear examples of the 'local' nature of heat, as well as a recognition of the need for heat to be 'smart,' and examples of smart technology integration. However, we found little in the way of evidence of smart and local approaches to heat decarbonisation. In this section, we outline the evidence that points to the inherent 'localness' of heat demand and supply today, as well as examples of local approaches to heat decarbonisation. We then consider how a SLES approach – i.e. one that combines both smart and local elements in a more holistic way – could facilitate a transition to a zero-carbon heating sector that is faster, fairer and more cost effective than current trajectories.

3.1 Heat is local

Throughout this review, it was clear that the local elements of current heat demand and supply are strong. Unlike electricity generation – 70% of which is connected to the GB transmission network (National Grid ESO, 2021a) – heat is mostly generated where it is used (Carmichael et al, 2020). For the 85% of residential buildings connected to the gas network, for example, gas arrives via pipes, which is burned on site to generate heat. This means that associated emissions are generated on premises (National Grid, 2019). It also means that changing the energy vector that is used to deliver heat will be an impact felt on an individual level. Rather than simply making changes 'upstream', it will require millions of decision makers to choose to change the technology they have in their home, and potentially change their behaviour in the long term.

The personal nature of heat combined with the diversity of the UK's building stock, which is one of the oldest in and least efficient in Europe, means that making the 'right' decision on heating is difficult (Fylan et al, 2016).

It depends on both building characteristics – like type, age, locality, building fabric and design features – and on the personal circumstances – income, needs and preferences, tenure[10] – of those who use the building, particularly in the residential sector. The most appropriate solution for a given building will also depend on the wider circumstances that might impact the business case for a particular technology in that locality. Hydrogen, for example, is emerging in 'clusters' from industrial centres in the UK and growing from local demonstrations.[11] Heat networks, including district heating, need strategic planning and infrastructure deployment at local levels. Electrification of heating has significant implications for electricity networks particularly at distribution (i.e. local) levels. Energy efficiency measures will need to be tailored to accommodate this variability, in both the retrofitting and new home markets (Climate Xchange, 2019).

A 'one-size-fits-all' approach to heat decarbonisation is unlikely to be able to address the inherent intricacies.

Ofgem, the energy regulator, has set out its proposals to "rewire Britain at a local level to deliver a greener and fairer energy system for British consumers" (Ofgem, 2020a). It also commissioned a methodology report from the ESC and the Centre for Sustainable Energy which details Local Area Energy Planning (LAEP), "a whole-systems approach to achieving local commitments on net-zero carbon emissions" (Energy Systems Catapult, 2020). We discuss the concept of LAEP later in this chapter.

10 Housing tenure describes the legal status under which people have the right to occupy their accommodation (Shelter, 2009). The most common types of tenure in the UK are owner-occupied (including owned outright and buying with mortgage), and rented (including social rented housing and private rented housing) (Shelter, 2009; Office for National Statistics, 2021).

11 In its Ten Point Plan for a Green Industrial Revolution, the UK Government outlined support for development of a 'Hydrogen Neighbourhood' beginning in 2023, with the ambition of scaling up to a pilot hydrogen town before the end of the decade (BEIS, 2020g).

3.1.1 Local approaches

There are examples of locally designed and delivered heat decarbonisation activities which demonstrate the potential value of this approach. For example, while the Green Homes Grant Voucher scheme was largely considered a failure, reaching just 10% of the target 600,000 homes (CCC, 2021b; Harvey, 2021), the Local Authority Delivery (LAD) arm of the scheme has been deemed a relative success by the CCC (CCC, 2021b). Through the LAD scheme, which is now in its third phase, funding is allocated to local authorities in England to improve the energy efficiency of low income and low energy performance homes (BEIS, 2020d). The involvement of local authorities facilitates the identification of those who would most benefit from home efficiency upgrades, tackling not just carbon emissions but also fuel poverty.

The Scottish Government have also been pursuing a more local approach to heat decarbonisation. As part of their Energy Efficient Scotland programme, they are working with local authorities to develop methodologies for delivering Local Heat and Energy Efficiency Strategies (LHEES). Following a pilot programme, which ran between September 2017 and April 2021, the Government have proposed to introduce legislation that makes LHEES strategies and delivery plans a statutory duty by the end of 2023 (Scottish Government, 2021; Scottish Government, 2019a; Scottish Government, 2020; Scottish Government, 2021b). They are now working with local authorities and wider stakeholders in Scotland to finalise a methodology and set of guidelines to facilitate the development of these plans (Scottish Government, 2021). 'Area based schemes' have also been delivered by councils and local delivery partners since 2013. Government funding is used to leverage ECO finance and private investment to deliver home energy efficiency improvements, with the aim of reducing both emissions and fuel poverty (Scottish Government, 2021; Scottish Government, 2016).

3.2 Heat must be smart

The need for future heating systems and the wider sector to be smarter than they are today was also a strong theme throughout the literature.

The seasonal variation of (domestic) heat demand is significantly more pronounced than either the daily or seasonal variation in power demand (see Figure 2) (Carmichael et al, 2020). Heating demand is linked to climate – which varies across the UK – and weather, which is difficult to predict on long timescales and impossible to control. The current gas network is generally well-equipped to meet winter peak demand. Flexibility and whole systems thinking will be a crucial consideration as electricity plays an increasingly important role in both the heat and transport sectors, and increasing integration of intermittent renewables poses challenges in managing seasonal variations in an ever-growing demand (BEIS, 2021i; BEIS & Ofgem, 2017; Delta-EE, 2018; BEIS, 2020b). While just 8% of UK households use electricity as their main heating source today, the CCC's Balanced Pathway Scenario puts this at over 53%[12], with electricity demand potentially doubling by 2050 (CCC, 2020c; BEIS, 2021a). In other words, in both relative and absolute terms, the share of power that is used for heat will grow considerably. Ensuring that flexibility is built into the transition is absolutely crucial.

Currently, flexibility is predominantly provided on the supply side through generation and production (BEIS, 2021i). Dispatchable power[13] generators are asked to either turn up or down their output as demand fluctuates. The switch to renewable energy sources like solar and wind introduces a level of variability that is higher than the current system is designed to manage, and supply-side flexibility becomes insufficient on its own.

12 Assumption that by 2050 all heat demand is met by low-carbon sources of which 52% is heat pumps, 42% is district heat, 5% is hydrogen boilers and around 1% is new direct electric heating.

13 Dispatchable power sources of electricity that can be dispatched on demand.

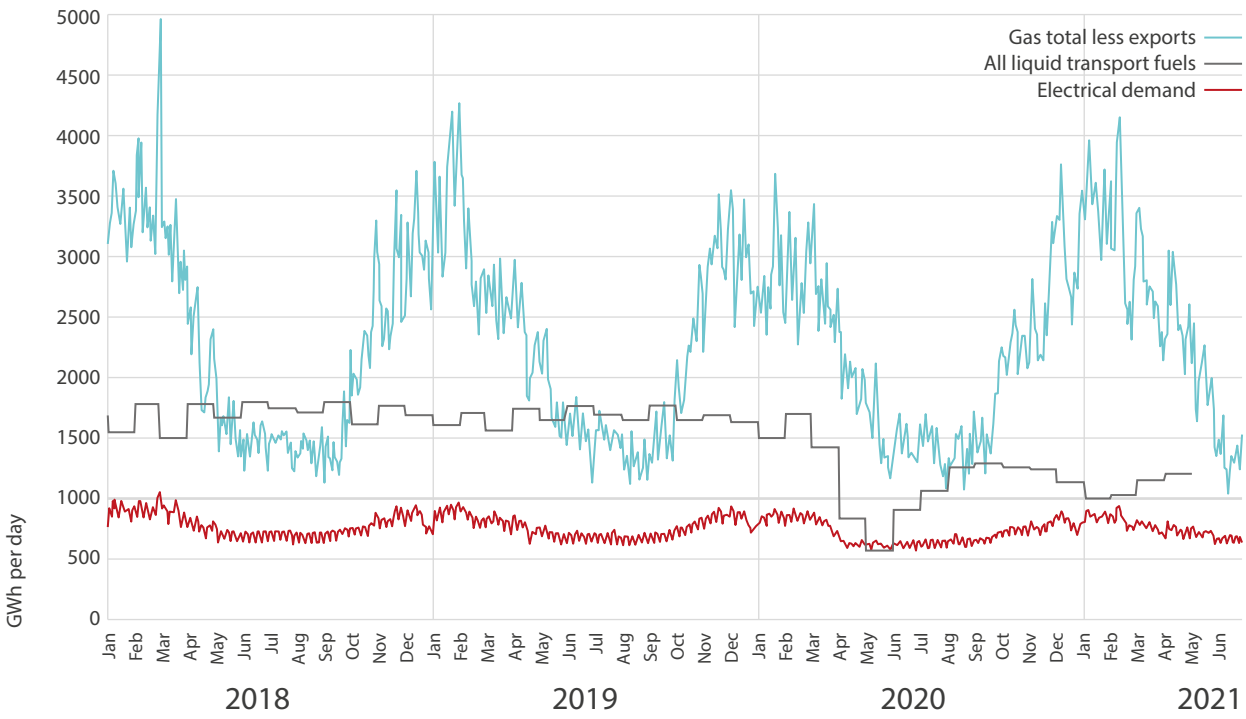


Figure 2: Multi-vector energy diagram for Great Britain between January 2018 and July 2021. Redrawn from graph by Dr Grant Wilson, University of Birmingham. Underlying data from National Grid, Elexon and BEIS.

Supplementing – or replacing – this with other forms of flexibility, including demand-side response (DSR), energy storage, and cross-vector flexibility, is crucial to maintaining a safe and secure system, and is projected to be worth up to £10bn per year in 2050, with a cumulative value from reduced system costs of between £30 billion—£70 billion between now and then (BEIS, 2021i). As natural gas is phased out, the future of the heat sector has major implications for how this flexibility can be achieved.

3.2.1 Smart approaches

Throughout this review, we found examples of smart approaches to managing the increasing complexities of current and future heat systems. These are generally pursued for the purpose of improving system efficiency and flexibility. Increased flexibility can be enabled through increased thermal efficiency of buildings, smart controls and appliances, and cost-reflective pricing.

More thermally efficient buildings can minimise the expected increase in required peak capacity of the energy system by both reducing overall demand and improving the potential for load-shifting[14] (Carmichael et al, 2020). For example, buildings could be 'pre-heated' to avoid peak periods, providing flexibility to the energy system. Scenarios which explore what the energy system might look like in 2050, such as those from National Grid ESO and the CCC, assume improvements in energy efficiency of buildings regardless of the pathway and technology mix chosen, which would contribute to lower overall costs (CCC, 2020d; National Grid ESO, 2020; National Grid ESO, 2020).

14 Load-shifting, or load management, is moving energy consumption from one time to another. This can help to lower peak energy demand.

Electricity-based heating systems (including heat pumps and direct electric heating) in particular can be combined with smart controls and price signals to automate actions like pre-heating homes during periods when renewable energy is abundant, and turning off or down during peak times without causing discomfort to residents (Energy Systems Catapult, 2019b; Delta-EE, 2018). Time-of-use tariffs provide a financial incentive for customers to do so, and automation allows customers to easily and efficiently respond with minimal behaviour change. This approach has shown some successes, for example in Octopus's Agile and the Danish eFlex project. A recent report by the Imperial College London Energy Futures Lab explores the value of, and pathways for, smart electrification in more detail (Carmichael et al, 2020).

Smart and innovative business models are also expected to play a role in improving flexibility. Innovative business models that treat energy as a service, rather than as a commodity, could incentivise businesses to invest more in improving energy efficiencies, which could defer or even negate the need for reinforcements of grid infrastructure. Trials of heat-as-a-service (HaaS) or, more broadly, energy-as-a-service (EaaS), have been shown to reduce energy demand and increase flexibility by incentivising providers to use as little energy as possible during peak times, whilst improving the consumer experiences and accelerating the uptake of low carbon heating systems (Energy Systems Catapult, 2019b).

Heat networks, too, have the ability to store thermal energy, whether in the carrier fluid, storage device (thermal or electrical) or the building fabric itself, acting as a flexible asset that can follow resource availability (Rosenow & Lowes). Heat networks can make use of multiple sources and vectors of energy, including waste heat from industry, renewable electricity and hydrogen.

This is particularly true for newer heat networks – dubbed fourth and fifth generation (4G and 5G) – which can work at relatively low (down to ambient) temperatures, reducing losses and expanding the possibilities for viable heat sources to solar and geothermal energy, for example (Revesz et al, 2020). This can provide multi-vector flexibility, as well as increased integration of energy end use and supply sectors that opens up additional avenues for grid balancing. Denmark has shown strong progress in this type of sector coupling between its extensive district heating networks and high shares of wind power (Kvarnström, 2019).

Hydrogen has the potential to provide system flexibility at both the production and consumption ends. Excess renewable electricity can be utilised for green hydrogen[15] production, potentially avoiding curtailments (IRENA, 2019). Hydrogen could also be used to 'top up' heat demand at peak times when combined with electric heat pumps in hybrid systems, providing flexibility coupling of the gas and power sectors (Element Energy, 2017).

Smart zero-carbon heating systems and services could also open up routes to stronger consumer engagement in the wider smart energy transition; it is suggested that those with first-hand experience of smart technology and services have an increased interest in other smart products via a 'familiarity effect' (Carmichael et al, 2020; Scottish Government, 2011).

3.3 The need for a SLES approach

Whilst there are plenty of examples of approaches that employ smart or local principles of heat decarbonisation, there are few which integrate both in a way that would be considered a SLES approach. There are, however, early suggestions that point to the potential value of such a trajectory.

15 Hydrogen which is produced by splitting water using electricity (electrolysis) is known as 'green hydrogen'. If the electricity is generated from renewable sources, this is a 'zero-carbon' process. 'Blue hydrogen' is produced through steam reforming of methane (natural gas) – this process produces carbon emissions and must be paired with carbon capture and storage technology to be considered in a net-zero world. Hydrogen production from methane where the carbon is not captured is known as 'grey hydrogen'.

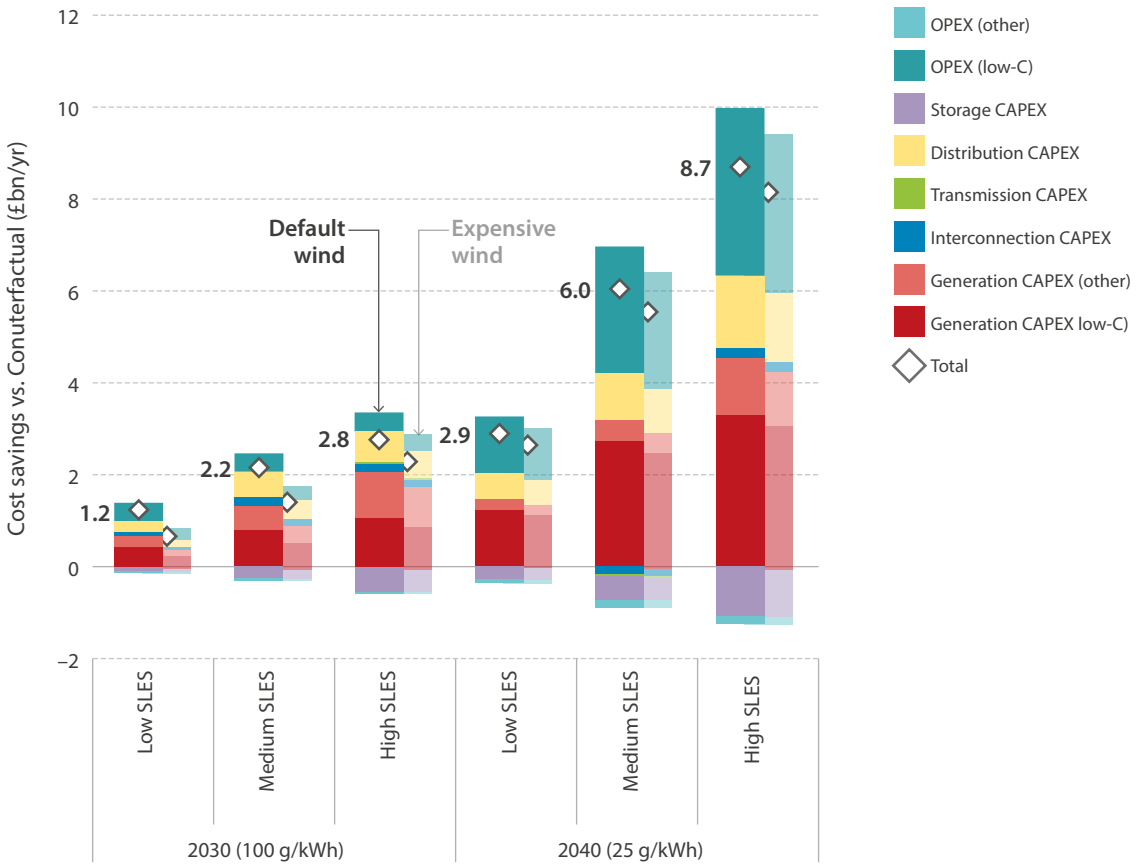
The UK's ESC has warned that an approach to decarbonising heat that substitutes gas with either electricity or hydrogen is projected to cost two to three times more than a "whole-systems approach" implemented at regional levels (Energy Systems Catapult, 2020a). The ESC defines a whole systems approach as considering the entire energy system across three areas:

- vectors – heat, electricity, transport
- supply chains – from energy generation to how it reaches people's homes
- systems – physical, digital, market and policy systems (Energy Systems Catapult, 2020a; Energy Systems Catapult, 2020a).

It also commissioned a methodology report from the ESC and the Centre for Sustainable Energy which details Local Area Energy Planning (LAEP), "a whole-systems approach to achieving local commitments on net-zero carbon emissions" (Energy Systems Catapult, 2020).

Early insights from EnergyREV suggest that SLES could deliver significant energy and cost savings, even with low penetration (see Figure 3) (Aunedi & Green 2020). By applying smart principles and a local approach to planning, SLES could provide total system cost savings of £2.2 billion per year by 2030 with medium penetration. It could also lower the levels of peak electricity demand, reduce costs associated with low-carbon generation, and avoid the need for reinforcement of local distribution networks.

Figure 3: Modelled net system cost benefits of SLES, from Aunedi and Green (2020) (Aunedi & Green 2020). Cost savings are relative to a counterfactual in which there is no SLES uptake.



4 How SLES can overcome the barriers

In a previous EnergyREV report, we investigated how adopting a smart and local approach to implementing energy-related post-pandemic recovery measures could enhance outcomes by taking advantage of six key elements. These six elements are outlined in the 'SLES prism' in Figure 4.

We now apply a similar approach to the challenge of heat decarbonisation, exploring how smart and local elements could help to overcome cross-cutting barriers and facilitate a transition which is faster, fairer and more cost effective than centralised, top-down approaches. We also identify areas where a SLES approach could induce tensions, for example between local and national priorities.

4.1 The SLES prism

The six elements included in this SLES prism were developed through an inductive approach.

Economic strategy: This facet refers to the extent green and resilient post-pandemic economic recovery enables alignment with local economic strategies. These can cover local business initiatives, development of workforce skills and other identified training needs, local and national supply chain development, and innovation strategy. Such approaches could unlock multiple benefits both locally and nationally (Fell et al, 2020).

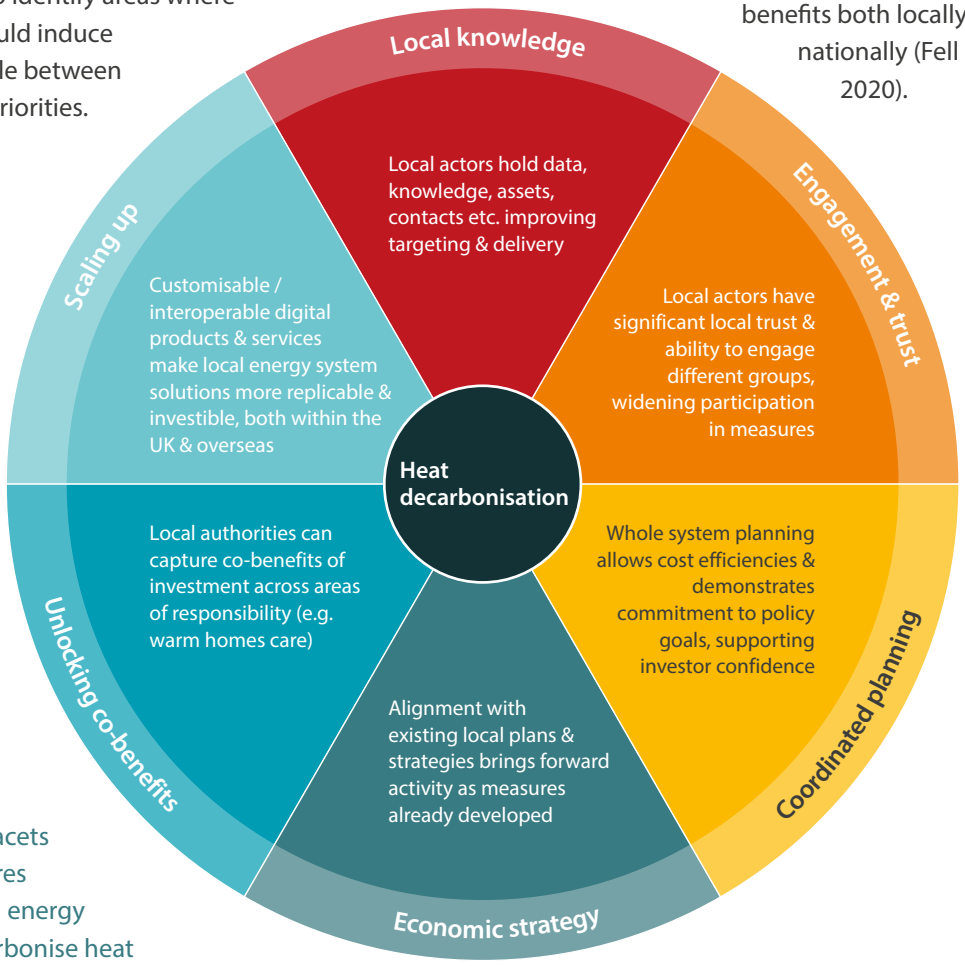


Figure 4: The SLES prism and how its facets can support measures to improve building energy efficiency and decarbonise heat

Local knowledge: This facet recognises that local authorities and local actors such as community groups and distribution network operators hold data, knowledge and assets that can inform green and resilient recovery strategies. They work in a local and national context and deliver on multiple local objectives. (Fell et al, 2020).

Engagement & trust: Related to Local Knowledge, this facet takes into consideration that councils and community groups are an important "trusted brand" for many. This trust makes it more likely that people will choose to participate in recovery-related schemes with these groups than if some unknown or less trusted entity were involved. This in turn can help drive growth through uptake of related products and services. It can be easier for all parties to interact and collaborate when they are operating in the same spatial scale (Fell et al, 2020).

Unlocking co-benefits: While the impacts of individual local energy projects could appear almost negligible when compared to the national-scale, local actors are well placed to capture any resultant benefits much more directly. For example, providing warmer homes for people in more vulnerable circumstances could feed through directly to a reduction in care-related costs, which are often borne by local authorities (Fell et al, 2020).

Scaling up: This facet recognises that developing smart, customisable, and interoperable digital products and services can make local energy system solutions more replicable and investible, both within the UK and as an export opportunity (Fell et al, 2020).

Co-ordinated planning: This recognises that considering a green and resilient recovery from a local perspective permits adoption of a whole, local, system planning approach that combines energy generation, mobility, heat, wider environmental and other objectives such as economic goals. For example, taking measures to decarbonise heat and buildings according to existing local plans and strategies is one area that could contribute to both post-pandemic recovery and environmental targets, as well as bringing forward activity to enable SLES (Fell et al, 2020).

The elements of a SLES approach could help to lower the cross-cutting barriers and mitigate the negative outcomes identified in Section 2. We now take each of these in turn and explore how a SLES approach could help to lower or remove the barrier.

4.1.1 Information, engagement and behaviour

- Local knowledge
- Engagement & trust
- Unlocking co-benefits

As outlined in Section 2.1, a major barrier to progress is the limited awareness amongst the public of the link between home heating and carbon emissions. There is a need to ramp up efforts to engage people and businesses to ensure a successful transition. Local actors including local authorities, businesses, and community groups hold a high level of **local knowledge**. There is an opportunity to capitalise on this knowledge and use the **engagement** channels and **trust** that have already been established by local actors to provide solutions.

Local or regional authorities have an important role in delivering energy efficiency and low carbon heat. Local authorities have the most granular knowledge of the existing housing stock, and should be the most effective in engaging and involving local people in the transition. In a recent report from the House of Commons Housing, Communities and Local Government Committee, it was recognised that 'no layer of government is closer to people or better able to tailor climate action to meet the needs of local communities' (UK Parliament Housing Communities and Local Government Committee, 2021). In addition, through public procurement, local authorities have the ability to drive the market through their ownership of social housing and public buildings (Policy Connect, 2019).

Public acceptability of alternative heat technologies and energy efficiency improvement measures will be required to enable the deployment of measures to realise deep emissions reductions in buildings (Williams et al, 2018).

However, as outlined in Section 2.1 public awareness – which can provide a crucial step towards acceptability – of the changes needed is currently very low and barriers exist which can prevent uptake even where there is occupant appetite (Policy Connect, 2019). One of the main barriers is lack of trust.

To address issues of awareness and trust, local authorities, community organisations, and community groups could play a greater role in providing energy advice at the local level (BEIS, 2019). Some have called for dedicated intermediaries in every community to facilitate energy advice 'one-stop-shops' through which households can access impartial advice on technological and financing options, as well as tradespeople, contractors and installers (Brown et al, 2018). In addition, one study highlighted the option of home visits to impartially assess the potential for low carbon heating and energy efficiency as being of particular importance in helping households evaluate their options (Policy Connect, 2019).

The Warm Homes and Welsh Housing Quality Standard (WHQS) programmes have also demonstrated that people are much more inclined to agree to a housing decarbonisation programme if they and those in their neighbourhood have been involved in its development and can see clear benefits for their families, friends, neighbours and local businesses (Welsh Government, 2019). Another project studying the impact of low carbon community groups, found that person-to-person feedback through advice was 'crucial' in informing residents about how to reduce energy consumption in their homes (Gupta et al, 2015). Another method of feedback is through social learning, which can involve local communities and networks sharing occupant experiences of energy retrofits through home visits and open days for the wider community (Gupta et al, 2015).

Importantly, the engagement that is required for robust policymaking is not simply one way, i.e. from government to consumers or 'outward' engagement. In the UK Government's Heat and Buildings Strategy, the importance of 'inward' engagement – i.e. channels that facilitate the views of consumers to be fed into policymaking – was recognised (BEIS, 2021c). Local and regional actors are well-placed to facilitate two-way engagement between consumers and national actors. This could allow the benefits of heat decarbonisation to be communicated effectively in the context of a given locality or community, as well as provide useful insight into what the priorities and drivers are for that area. Local-level public participation in policymaking is well established in the UK (Stilgoe & Cohen, 2021).

Understanding how co-benefits can be unlocked through a smart and local approach could also provide insights into how to design robust strategies to decarbonise heat and buildings that are acceptable to the public. A lack of perceived tangible consumer benefit from clean heat technologies has been cited as a barrier to progress (Williams et al, 2018). It has been suggested that people-focused outcomes – like comfort, air quality, health and elimination of fuel poverty – rather than carbon-based ones may be better drivers for energy efficiency policies (Gupta et al, 2015). Engaging the public through the appeal of zero-carbon heating because of its potential to help solve widespread problems like damp, draughts and overheating could be more compelling than simply discussing the potential carbon and financial benefits. Local authorities are well-placed to capture the co-benefits of heat decarbonisation. For example, providing warmer homes for people in more vulnerable circumstances could feed through directly to a reduction in care-related costs, which are often borne by local authorities (Fell et al, 2020).

The benefits of SLES are linked to the engagement and behaviours of its users. Homes and businesses will need to install new equipment like heats pumps and be willing to be flexible and change energy use habits by, for example, responding to price signals in time-of-use tariffs.

Consumers will need to be actively engaged in the net-zero target, and play an active role in heat decarbonisation, for instance through adopting new technologies, services and retail offerings (Ofgem, 2020). Many consumers are already becoming informed and engaged, and due to the rise in domestic renewable generation, many have become 'prosumers' (Brown et al, 2019; Energy Systems Catapult, 2018). At the same time, digitalisation and a shift in focus from offering products to offering smart services, such as the 'connected home,' is seeing new business models emerge based on 'flexibility' which require consumers to change their electricity use and behaviour (Energy Systems Catapult, 2018).

From a consumer perspective, SLES could involve an overwhelming landscape of complexity and choice (Carmichael et al, 2020). But, evidence suggests that consumer first-hand experience with smart technology and flexibility services leads to increased interest in other smart products via a 'familiarity effect'; leading to consumers becoming more aware of the financial savings and other benefits possible (Energy Systems Catapult, 2018). Innovative business models could also be a way for businesses to take away some of the complexity and risk from customers. Heat-as-a-service (HaaS), for example, is a model by which customers can choose to pay a set amount on the experience they want (e.g. a given number of 'warm hours' per month, or feeling warm when and where they are in their home), rather than per unit of energy (Energy Systems Catapult, 2019).

A HaaS proposition could include installing heating technology at no upfront cost and operating it in a flexible way to minimise price risk. In essence, the HaaS provider is taking on installation, financial, behavioural and energy supply risks on behalf of its customers. In return for this service, customers will need to accept a longer contract term to pay back the capital costs, a third party operating devices within their homes and agree to share energy and potentially personal data with the supplier (Delta-EE, 2019). In this model, trust between the service provider and customer is essential and needs to be greater than is currently exhibited by the public in energy suppliers (Policy Connect, 2019).

Box 2: How Brighton and Hove is creating a new energy-as-a-service business model

Brighton and Hove Energy Services (BHESCo) is a community-owned company that is using an innovative business model to make buildings more energy efficient by installing energy efficiency measures, solar PV and heat pumps and electricity and heat storage (Cairns et al, 2020).

BHESCo employs a Pay-As-You-Save approach, whereby the customer pays nothing upfront, but covers the cost of the measures through the savings they generate, normally over a 10-year period. The majority of its income comes from these Pay-As-You-Save contracts, although many of these are facilitated by government grants. It is very much in the interest of BHESCo to work with its customers to ensure that predicted savings materialise.

BHESCo is delivering carbon and wider benefits such as reduced fuel bills and greater comfort at potentially no upfront cost. While this business model is somewhat complex, it does appear scalable or replicable in other places.

4.1.2 Strategy, policy and regulation

- Co-ordinated planning
- Unlocking co-benefits

A coherent strategy that works for consumers and the energy system is needed for heat decarbonisation. With an estimated three quarters of local authorities across the UK having declared climate emergencies, many local government plans are driven by an ambition to reach net-zero (CCC, 2020a; Citizens Advice, 2021a). Following the COVID-19 pandemic, some are having to reassess their approach to net-zero, with the costs of doing so being overridden by the devastating economic impact of the pandemic (Citizens Advice, 2021a).

There is an opportunity – and desire – to ensure that economic recovery strategies align with environmental priorities (Citizens Advice, 2021a). **Coordinated planning** could be key to achieving this.

Developing smart and local plans could help local authorities to develop robust strategies for decarbonisation that also align with local infrastructure requirements and socioeconomic priorities (Energy Systems Catapult, 2019b). Local area energy planning, is one example of this (Energy Systems Catapult, 2020).

Local authorities have also shown ambition to align net-zero ambitions with existing goals and statutory duties, including the health and well-being of local communities. They are therefore well-placed to understand how to design and develop area-based strategies that demonstrate tangible benefits, which could prove to be more robust than purely climate-oriented ones.

Local knowledge is critical to creating an environment and strategy for businesses to deliver zero-carbon heating and cooling. The literature indicates two important aspects.

First, local government and local stakeholders, such as gas and electricity network operators, have an essential role in providing a vision and plan for local energy system development (Energy Systems Catapult, 2019b). Local area energy plans can create certainty for local and national businesses to deliver future smart local energy systems. A plan can also clarify important roles and responsibilities from all local actors, ranging from citizens and local businesses, for example, whether citizens and businesses are expected to participate in DSR, through to businesses delivering SLES, including those businesses with more customer-facing propositions, such as selling energy-as-a-service) (CCC, 2019; BEIS, 2019 (Welsh Government, 2018). It can also highlight where there are current market failures, such as a lack of long-term programmes for local energy efficiency upgrades, or where innovation/experimentation is required.

This might be, for example, where a regulatory sandbox[16] is required to trial new innovative business models (Energy Systems Catapult, 2019b).

Second, there is an opportunity for local government to create the conditions for, or to become directly involved in, the businesses that deliver zero-carbon heating and cooling. This links strongly with the previous point about the importance of a local vision and plan. In some cases, this could be through the direct formation of a business or organisation to deliver SLES – such as a local government-owned energy company or a community energy organisation (Brown et al, 2019). Alternatively, it could be that local actors create the certainty and vision required for commercial businesses to innovate and invest in delivering local heating and cooling propositions. However local businesses are configured, it is vital they are trusted by their customers. This trust is essential for businesses to install assets such as heat pumps or insulation in homes or take on some responsibility for operating assets, for example, providing automated DSR services (Ofgem, 2020).

4.1.3 Infrastructure challenges

While many of the infrastructure challenges of heat decarbonisation – and the wider energy system – are national in nature, there will be significant impacts at local levels. The impacts will in large part be technology-dependent; in the CCC's Balanced Pathway scenario, for example, 5.5 million homes will have low-carbon district heat networks, 21 million homes will have heat pumps (including hybrid heat pumps), and 2 million homes will have direct electric heating. The most appropriate technology for a given building may depend not only on the building characteristics, but on wider system changes. **Co-ordinated planning** along with the **local knowledge** could help to determine which pathway is most suited for a given area, and the **engagement** and **trust** channels of local actors could help to communicate decisions and measures effectively.

16 A regulatory sandbox enables innovators to trial new products, services and business models without some of the usual rules applying (Ofgem, 2020c).

(How) Is existing infrastructure repurposed?

The extent to which the UK Government and Devolved Administrations commit to supporting the use of lower carbon gases, including hydrogen, as an alternative to fossil gas will have implications for the future of the gas grid, which in turn will impact SLES. Although a full 'hydrogen economy' is unlikely, hydrogen is likely to play a significant role in a net-zero energy system, with both the UK and Scottish Governments signalling their commitment to rapidly increasing low-carbon hydrogen production capacity by 2030 (BEIS, 2020g; Scottish Government, 2020b).

Due to its nature, the planning and management of a low-carbon gas strategy is likely to remain a matter of central decision-making (Keay, 2020). Implementation and deployment, however, are expected to be 'cluster-based,' growing from hubs where 'renewable energy, CCUS and hydrogen congregate' (BEIS, 2020g; Keay, 2020). A SLES approach could therefore help to strengthen the strategy, for example by using **coordinated planning** and capitalising on **local knowledge**, **engagement** and **trust** to facilitate an efficient transition that is embraced by local residents and businesses.

How much new infrastructure is needed, and where?

Electrification of heating, alongside significant electrification of transport, will require additional zero-carbon generation, as well as potentially substantial reinforcement of existing infrastructure at both transmission and distribution levels (Broad et al, 2020).

Electricity and gas network planning and operation in GB is undertaken by monopoly network businesses. All these wires and pipes businesses have their customer outputs and allowed revenues set through Ofgem's RIIO price controls. The RIIO framework recognises that zero-carbon transition entails a number of changes to how the networks are used.

This could mean alterations in the fuel mix potentially to less gas and more electricity, changes in patterns of demand, for example to more electric vehicles, and in supply, for example to more national and local renewables such as offshore wind and solar PV farms respectively. Ofgem also recognises that there is benefit in whole systems thinking, whereby actions on one network could carry benefits to another network or sector. Ofgem's stated strategy is to maximise the value of existing infrastructure by accommodating new demand and generation using a smart and flexible approach. In essence, this means building as little new infrastructure as possible to achieve net-zero energy (Ofgem, 2019a).

If further build of local renewables – such as solar PV and smaller-scale wind – is supported, then there is a strong case for local balancing of supply and demand. The costs benefits that could result are demonstrated in Figure 3. In this case, there would be an increasing role for network operators, and a shift from distribution network operators to distribution system operators (Revesz et al, 2020; BEIS & Ofgem, 2017). A SLES approach which incorporates local knowledge and coordinated planning could ensure that high levels of distribution-connected renewables contribute to an efficient, flexible energy system (Aunedi & Green 2020).

On the other hand, an electricity system that is dominated by offshore wind and nuclear power plants connected at transmission level could call for an ongoing significant role for the system operator. The role of SLES in this scenario may be less significant.

4.1.4 Supply chain

Utilising key SLES elements of **local knowledge**, **economic strategy**, and **scaling up** could contribute to building the robust supply chain needed to decarbonise heating.

There are domestic economic opportunities that could be won through heat decarbonisation, particularly those that support the 'levelling up' agenda (Local Government Association, 2021).

This recognises that different areas of the UK have different assets, opportunities, and needs, and that local leaders are best placed to align the work of central government departments according to these characteristics (Local Government Association, 2021). Local authorities are also well-placed to guarantee initial 'anchor loads' to the network, for example through planning requirements for public sector buildings (BEIS, 2020g).

An appropriately skilled workforce is critical to enabling effective deployment of sustainable construction and building performance and clean heat technology (Stark et al, 2019). There are estimates that to achieve EPC band A or B in all properties across the nation by 2030, an additional 220,000 tradespeople will be needed (Energy & Climate Intelligence Unit, 2020). This figure comprises a variety of housing and renovation professionals, such as joiners and plumbers, and also renewable heat specialists and those with expertise in energy efficiency (Energy & Climate Intelligence Unit, 2020). In the Heat and Buildings strategy, the UK Government announced its intention to support the growth of UK manufactured heat pumps to 300,000 a year by 2028, creating an estimated 10,000 jobs.

Importantly, these jobs would be spread across the country encouraging economic growth and employment opportunities in all regions. A key theme is the importance of SMEs in the supply chain as SMEs are often a householder's first port of call for energy efficiency advice (Scottish Government, 2019b).

Heat and building sectors across the world will face similar challenges to the UK in the need to decarbonise. Developing smart solutions in the UK could provide new investment and export opportunities. One study has estimated that the local energy systems market could be worth almost £8 billion in the UK, and £350 billion globally (Morris et al, 2019). These estimates are based on technologies which were identified as having been already successfully demonstrated in Scottish SLES projects, falling into the categories of smart grid solutions, renewable power to heat and renewable power to hydrogen (Morris et al, 2019).

4.1.5 Distribution of costs and benefits

- Unlocking co-benefits
- Economic strategy

Distributing the costs and co-benefits including better air quality, improved public health, and alleviation of fuel poverty, in a fair and appropriate way will be crucial to the transition.

Importantly, many of these 'co-benefits' are not guaranteed in the transition, and might only be unlocked through a holistic, whole-systems approach to delivery. For example, without changes to current markets, regulations and business models, significant electrification of heating could exacerbate levels of fuel poverty and inequity, which in turn could preclude associate health improvements in vulnerable segments of society. On the other hand, approaching this challenge from a smart and local perspective could pave the way for developing a strategy that not only aligns with net-zero targets, but also tackles wider societal issues like health and fuel poverty.

There are already examples of where more joined-up approaches are being explored in the energy sector. For example, a 'boilers on prescription' scheme was found to both reduce the number of GP appointments required by patients with poor living conditions and reduce their energy bills (Gentoo, 2016).

There are also suggestions that smart home energy management devices could be beneficial in informing diagnosis of health conditions, for example by indicating unhealthy living conditions or periods of unexpected inactivity amongst those in vulnerable circumstances (Fell et al, 2017).

The NHS Health Scotland is a member of the Scottish Fuel Poverty Advisory Panel, and is working to develop national referral pathways between NHS services and local advice services, including energy advice (Scottish Government, 2018).

The aim is to "maximise the income of patients" as well as capture wider benefits which could ultimately lead to reduced sickness absence, and improved educational attainment and productivity (Scottish Government, 2018).

Smart approaches could also help to unlock co-benefits of zero-carbon heating by empowering customers to take control of their heating. Smart controls and digitalisation, for example, can be a good way to engage people with home energy use, and have been shown to lead to raised awareness of usage, as well as revealing details about user preferences and requirements (Policy Connect, 2019; Energy Systems Catapult, 2019b). In isolation, smart controls do not lead to people installing zero-carbon heat technology or energy efficiency retrofits, but can lead to them being more open to doing so (Energy Systems Catapult, 2019b). Customers could also benefit from innovative business models, as it is possible that businesses could automate home energy demand on behalf of their customers.

But there is a fairness issue in smart approaches. Currently, technologies that enable smart demand control are relatively expensive, including home energy management systems (like smart thermostats) and solar PV coupled with home batteries. Thus the benefits of smart devices accrue to those that can afford them. In some instances, for example using a home battery to avoid paying network costs can cause those costs to fall on all other customers (Sandys, 2021). In part, removing this distortion by making all end users pay for the fixed costs of electricity networks was a motivation behind Ofgem's Targeted Charging Review (Ofgem, 2019b). Adopting a local energy approach could raise the transparency of such costs and benefits and facilitate a fair way to allocate them.

5 Gaps and opportunities for SLES in government strategies

During this systematic review, both the Scottish and UK Governments released strategies for decarbonisation of heat in buildings (BEIS, 2021c; Scottish Government, 2021).

The UK Government has also published its Net Zero Strategy (BEIS, 2021f). Table 2 summarises the announcements and actions from each, mapped against the cross-cutting barriers we outlined in Section 2.

Table 2: Summary of the UK Government's Heat and Buildings Strategy and Scottish Government's Heat in Buildings Strategy mapped against the cross-cutting barriers identified in this review (BEIS, 2021c; Scottish Government, 2021).

Barrier(s)	Topic	UK Government	Scottish Government Domestic Heat in Buildings
Information, engagement & behaviours	**Public engagement/ information**	No major announcements. Continuation of use of public consultations, and Simple Energy Advice online platform[17].	National Public Energy Agency to be launched over the next year, initially as virtual agency. Dedicated body established by Sept 2025. Development of a public engagement strategy for heat in buildings
Strategy, policy & regulation	**Local governance**	Recognition of key role that local authorities can take, but no additional support or responsibility is detailed. Continuation of Local Net Zero Programme (Net Zero Strategy). Carbon Literacy training for local authority staff. Ongoing work by BEIS/Ofgem on opportunities and challenges of local area energy mapping & planning.	Statutory duty for all local authorities to develop Local Heat and Energy Efficiency Strategies and Plans by 2023.

17 Simple Energy Advice website

Barrier(s)	Topic	UK Government	Scottish Government Domestic Heat in Buildings
Strategy, policy & regulation **Infrastructure**	**Building energy efficiency – new homes**	Future Homes Standard from 2025 (previously announced in 2019). Plan to introduce interim uplift to building regulations from June 2022	Developing regulation (New Build Heat Standard) to require new builds to use zero emissions heating and cooling from 2024.
Strategy, policy & regulation **Infrastructure**	**Building energy efficiency – retrofitting**	Energy efficiency upgrades and low-carbon heating to low income households in off-gas-grid homes through Home Upgrade Grant 2022-25 (after Local Authority Delivery of Green Homes Grant ends). Require energy efficiency upgrades through regulations that use 'natural trigger points' (such as house sales).	All PRS to be minimum EPC C with new tenancies by 2028. Owner occupied required to meet EPC C at trigger points (e.g. purchase/sale, re-mortgaging or significant renovations).
Strategy, policy & regulation **Infrastructure**	**Fossil fuel heating phase out**	Oil and LPG – no new installations from 2026 (domestic) and 2024 (non-domestic). Signalling an intention to phase out installation from 2035. Gas grid connections for new homes – consultation on whether banning this would be 'appropriate' from 2025 (to link with decision on hydrogen).	Developing regulation (New Build Heat Standard) to require new builds to use zero emissions heating (and cooling) from 2024.
Infrastructure	**Heat networks**	Continuation of existing research, delivery support and demonstration projects	Heat Network Investment Prospectus published during next financial year. Launch of Heat Network Pre-Capital Support Unit in 2021
Infrastructure	**Gas network**	Decision in 2026 on hydrogen for heating. By 2025, plans for 'possible' hydrogen heated town.	Reserved. Scottish Government ambitions for 100% hydrogen for heat. Urging UK Government to expedite regulatory changes to allow greater levels of gas blending.

Barrier(s)	Topic	UK Government	Scottish Government Domestic Heat in Buildings
Supply chain	**Skills/jobs**	Action plan for England published Spring 2022, following findings from Green Jobs Taskforce. Development of Heat Network Skills Programme	With Scottish Renewables, will undertake a Heat in Buildings Workforce Assessment Project, with output Spring 2022. Heat in Buildings Supply Chain Delivery Plan developed with sector, output Summer 2022. Involvement in development of GB-wide common technical standards for development and operation of heat networks.
Distribution of costs **Strategy, policy & regulation**	**Costs**	Innovation and supply chain growth to drive down costs Anticipate heat pump cost parity with gas boilers	Continuation of interest-free loans for heat and energy efficiency technologies, plus cashback scheme, until at least 2023.
Distribution of costs and benefits **Supply chain**	**Subsidies for clean heat tech**	£5000 grants to replace gas boilers, up to equivalent of 30k heat pumps per year for 3 years. Not means-tested.	Interest free loans with cashback scheme via Home Energy Scotland until at least 2023 (launched in 2020)
Distribution of costs & benefits	**Policy levies**	Decision in 2022 on shifting from electricity to gas over the next 10 years.	Reserved to Westminster Looking at these and other government strategies from the perspective of SLES, we can identify gaps and missed opportunities. We make a number of recommendations for actions that could support a smart and local approach.

5.1 Information, engagement and behaviour

Government approach

Both the UK and Scottish Governments have highlighted the importance of increasing public awareness and engagement in accelerating the transition to zero-carbon heat.

The Scottish Government have committed to developing a bespoke Public Engagement Strategy for heat in buildings, and the establishment of a National Public Energy Agency which aims to inform and advise the public as well as provide coordination and leadership for delivery programmes (BEIS, 2021c; Scottish Government, 2021).

No new public engagement channels were announced by the UK Government, who will continue to use existing channels (including Citizens Advice, the Simple Energy Advice online platform, and public consultations).

The strategies also assume that consumer behaviour change – i.e. the choice to replace gas boilers with a sustainable alternative – will play a significant role in driving change. For example, there is an assumption that significant price reduction in heat pumps will prompt consumers to purchase these over gas boilers. There are also proposals to use 'natural trigger points,' such as house sales, to incentivise or mandate energy efficiency upgrades.

Missed opportunity/gaps

While behaviour is discussed throughout both published heat strategies, neither adopts a social practice-based approach or recognises the importance of habits. There appears to be an assumption that behaviours are set and that heat decarbonisation should not perturb these. However, as discussed in Section 2.1 zero-carbon transformation is a paradigm shift and policy should be exploring whether habits and behaviours, many of which are based in fossil fuel practices, are commensurate or even desirable in a zero-carbon energy system. In Section 4.2.1 we explored the possibility of innovative, customer-centred business models to help their customers adopt new zero-carbon behaviours.

There is also limited discussion of the wider implication of net-zero on lifestyle and behaviour in the strategies – for example linking decarbonising power and transport to heating and buildings. This is a missed opportunity to describe the whole system benefits of integrating these different elements together, particularly in SLES. We discussed the value of this in Section 3.3.

The UK Heat and Buildings Strategy makes little mention of how local authorities will be encouraged and supported to increase engagement with people and communities on heat and buildings decarbonisation.

What SLES needs

Recommendation: Local authorities should be mandated to engage citizens and businesses on net-zero.

While many local areas are already working to engage local communities and businesses in the transition, there is a risk that some regions and communities will be left behind. Local authorities are already under-resourced because of budget cuts. Without a statutory duty to plan and deliver emissions reductions, they may feel required to delay climate mitigation projects in order to deliver their core statutory duties (CCC, 2020). SLES may struggle to emerge as solutions in these areas; EnergyREV research has found that local energy systems are more likely to be found in local areas with existing energy and climate action plans (Arvanitopoulos & Wilson, 2021). Requiring local authorities to engage with businesses and consumers on net-zero could stimulate action that would support smart and local approaches to heat decarbonisation that is tailored to a local area's characteristics.

Recommendation: Central government should ensure that local authorities have the commensurate resources, capacity and capabilities to deliver on local net-zero energy systems.

Crucially, any increase in responsibility or expected action from local authorities must be matched by a commensurate increase in resources. Research has shown that local authorities and other bodies involved in developing and delivering local energy plans have struggled to meaningfully engage with local people (Citizens Advice, 2021a). Time and cost were seen as the two main resourcing issues to more widespread engagement. The pandemic has also had an effect on local authority engagement, although switching from face-to-face engagement to online engagement has enabled some local authorities to reach a more diverse local audience (Citizens Advice, 2021a). Yet, public engagement is considered vital for securing a local mandate for infrastructure development (such as heat networks) and public acceptance can help avoid costs and delay.

To deliver on net-zero plans and ambition, central government needs to support local authorities to improve their capacity and capabilities. Increased funding and skills are essential. In the 2021 Budget and Spending Review, the UK Government announced that councils in England will be provided with £4.8 billion of new grant funding, the 'largest annual increases in local government core funding in over a decade' (HM Treasury, 2021). It remains unclear the extent to which councils will have agency over how this money is spent. In response to the announcement UK100, a network of local government leaders, have called for further devolution of powers and funding (HM Treasury, 2021). The Housing, Communities and Local Government Select Committee have urged the Government to ensure that councils are given the 'confidence and ability to plan for the long term' through a clear plan for funding climate action (UK Parliament Housing Communities and Local Government Committee, 2021).

Recommendation: Ofgem should expand the regulatory sandbox approach to enable regional/local net-zero energy systems business model innovation.

Evidence shows that net-zero heating could entail an overwhelming landscape of complexity and choice for consumers (Carmichael et al, 2020). It will also require citizens, customers and consumers to adopt new habits and behaviours. To help people navigate this complex net-zero landscape, new energy business models, such as heat-as-a-service, are required. Such business models struggle with the current energy retail regulatory regime, especially in the domestic market. Given that much of the innovation with be regional in focus, it may be necessary for differentiated business model innovation to be enabled locally or regionally.

5.2 Strategy, policy and regulation

Government approach

The Heat and Building Strategy confirmed that the UK Government's approach to heat decarbonisation remains largely centralised and market led.

For example, one of the primary mechanisms for accelerating the installation of clean heat technologies is the Boiler Upgrade Scheme (previously the Clean Heat Grant). This is a centrally-run grant scheme which offers an upfront grant to households and small businesses (BEIS, 2021c). The budget covers the equivalent of 90,000 heat pumps or equivalent low-carbon heat technology over three years. For comparison, there were almost 35,000 heat pumps sold in the UK in 2019. The primary intention of this scheme is not to make clean heat technologies available to those who cannot afford them; it does not target those in or at risk of fuel poverty. Rather, the Government anticipates that this will help to kickstart the heat pump market, aiming to achieve cost parity between heat pumps and gas boilers by 2030 (BEIS, 2021c). However, a centralised and market-led approach has been hitherto unsuccessful in reducing emissions in the sector at the scale and pace needed, and without robust policies which protect poorer households, there is a risk that these measures will increase inequality.

The UK and Scottish Government strategies differ in their approach to strengthening local governance. While the Scottish Government have proposed to introduce legislation that makes Local Heat and Energy Efficiency Strategies and delivery plans a statutory duty by the end of 2023, (Scottish Government, 2021; Scottish Government, 2019a; Scottish Government, 2020; Scottish Government, 2021b) the UK Government have ruled out such a move, instead regarding this as an opportunity for businesses (BEIS, 2021f). They have stated that while local authorities 'should' build climate change considerations into their work, net-zero statutory requirements for action and reporting are 'not needed' (BEIS, 2021f).

While the UK Government committed in the Net Zero Strategy that they would clarify the relationship between central and local government (in England) in the delivery of net-zero, details on what action will be taken to do this are currently lacking (BEIS, 2021f; CCC, 2021).

Missed opportunities

As discussed throughout this review, local actors have shown both the ambition and potential to deliver net-zero while also unlocking co-benefits like alleviating fuel poverty. An estimated three quarters of local authorities have declared climate emergencies (CCC, 2020a; Citizens Advice, 2021a). However, a robust strategy that facilitates local ambition while supporting national objectives is currently lacking in the Government's approach.

Just a third of local authorities who have declared climate emergencies have developed strategies or action plans to deliver on net-zero targets (CCC, 2020a). Local authorities do not always have clear roles in the reduction of emissions, and delivery of plans is fragmented (CCC, 2020). The CCC have identified the lack of clear statutory duties as an issue, particularly in the wake of COVID-19; local authorities, who have faced significant funding cuts to budgets, may feel required to delay climate mitigation projects in order to deliver their core statutory duties (CCC, 2020).

There is also a missed opportunity to strengthen the role of local authorities in influencing building energy efficiency standards. In 2019, the UK Government proposed removing the existing rights for local planning authorities to set energy efficiency standards for new homes that exceed the requirements of the Building Regulations (MHCLG, 2019). However, the majority of respondents to the survey were opposed to this proposition, instead being in favour of retaining local planning authorities' flexibility to apply higher standards (DLUHC and MCLG, 2021). As outlined in this review, local authorities are well-placed to act on building energy efficiency improvements.

However, both the importance and current pitfalls of local government leadership have been identified by the CCC. In their latest progress report, they made a recommendation that Number 10, the Cabinet Office and Department for Levelling Up, Housing and Communities should support local government to play a full role in the net-zero transition, specifically mentioning local area energy plans as a way to do this (CCC, 2021a). Increased funding for staffing and resources was highlighted as a support measure likely to be required.

This could be considered a missed opportunity given the influence that local authorities have on the planning system (Nesta, 2021). BEIS and Ofgem are continuing work to explore local area energy planning (LAEP). However, without additional resources or responsibilities, implementation of this risks causing harm. Citizens Advice warn that, without a national framework to help and support local stakeholders develop and implement plans, this approach could result in fragmented strategies that deliver an unequal distribution of benefits (and drawbacks) (Citizens Advice, 2021a). For LAEP to be effective, it requires a level of resources that are commensurate with the role of local authorities, and meaningful and consistent methods of monitoring and assessment alongside a clear framework that ensures fair access for all. This is likely to also apply to SLES.

In contrast, the Scottish Government have proposed to introduce legislation that makes development of Local Heat and Energy Efficiency Strategies (LHEES) and Delivery Plans a statutory duty by the end of 2023 (Scottish Government, 2021). Although the Scottish Government have committed to 'resourcing their development accordingly,' no details about what this entails were included in the Heat in Buildings Strategy.

What SLES needs

Recommendation: Central government should devolve powers and responsibilities commensurate with delivering local net-zero energy systems to local authorities.

Clarity is needed on the expectations of local authorities. A robust framework that facilitates local action whilst supporting national objectives could help to accelerate progress.

Recommendation: Local authorities should be responsible for ensuring energy efficiency of buildings in existing and new builds is commensurate with net-zero targets.

Strong energy efficiency policy is required to upgrade the building stock so that it can be part of a smarter and more flexible heat system. Local actors are well placed to work with the buildings sector to co-ordinate efforts to improve thermal efficiency and can align action with local economic plans, statutory duties and wider net-zero ambitions.

Recommendation: Heat networks should be regulated by Ofgem[18] to improve transparency in the sector and protect consumers.

Given that different forms of heating may be appropriate in different local energy systems, it is important that regulation and consumer protection is consistent.

5.3 Infrastructure

Government approach

Announcements regarding the future of the gas grid were highly anticipated by the sector. While the UK Government has not imposed an outright ban on fossil fuel boilers, it stated an 'ambition' to phase out fossil fuel boilers by 2035. This has been described by some as a strong signal to the market (Nesta, 2021).

No decision on whether or not to ban new-build homes from connecting to the gas grid was announced, although the UK Government will consult on whether doing so from 2025 in England would be 'appropriate.'

Promisingly, the UK Government has committed to working with local authorities and other stakeholders to better understand local constraints and opportunities for different low-carbon heating technologies. Taking a SLES approach here could provide an efficient solution to deciding how existing infrastructure can be better utilised, for example through smarter local balancing, as well as what new infrastructure is needed in different regions across the country.

Energy efficiency receives relatively little attention in the strategy. No new money has been announced to help households and businesses make improvements. The approach appears to favour delivering emission reductions through regulation, for example by nationwide uplifts to building standards. A further example is the proposal to require mortgage lenders to reach an average EPC band C across their portfolio by 2030.

There also remain discrepancies between how different forms of heat are regulated, in particular regulation of heat networks compared to heat supplied by electricity of gas.

18 Since this report was written, the UK Government published its proposals for introducing legislation to regulate the sector. This includes appointing Ofgem as the heat networks regulator, and Citizens Advice as the consumer advocacy body. See UK government announces major expansion of heat networks in latest step to power homes with green energy and Heat networks: building a market framework.

The Competition and Markets Authority investigated this in its 2018 heat markets study and recommended that heat networks should be regulated by a public sector body to improve transparency in the sector and protect consumers (Competition and Markets Authority, 2018).

Missed opportunities

A centrally made decision on whether or not to switch a given area to low carbon gas will impact the business case for electrification of heating in that area, potentially making it unfeasible and removing the possibility for consumer choice (Keay, 2020).

Long-term planning and advance notice of these decisions will be essential for planning local infrastructure, as well as for public engagement strategies to communicate the decisions and likely impacts. While further demonstration of the feasibility of hydrogen for heating is needed (and is being pursued by government and industry), delaying this decision until 2026 could prevent progress in replacing high-carbon heating systems with low carbon ones.

There continues to be risk of a gap in Government policy and funding for building energy efficiency improvements (Lowes, 2021). The UK's building stock, if significant improvements are made, could be a valuable source of flexibility for the future energy system. However, no new money has been announced to work towards this, and critics have highlighted that new regulations – such as those proposed for mortgage lenders – will result in costs being passed onto homeowners, and potentially harm particular segments of society such as first-time buyers (Gabbatiss, 2021; Forrest, 2021).

What SLES needs

Recommendation: BEIS should take key decisions that will impact national infrastructure, such as the gas networks, as soon as possible.

Decisions on whether or not to switch a given area to low carbon gas will be essential for planning of infrastructure, as well as for developing local public engagement strategies to communicate the decisions and impacts on households and businesses. Long-term planning and advance notice of these decisions could be crucial for building trust between government, businesses and consumers.

Recommendation: Mandate local authorities to work with energy system and network operators on local strategic infrastructure investment plans and link them to economic development plans.

For SLES to be able to effectively contribute to heat decarbonisation, the decisions must consider the resources, needs, and capabilities of regions and communities. Many of the key decisions are influenced or made by system and network operators, including Distribution Network Operators and Gas Distribution Networks. This includes currently non-regulated network operators, such as heat networks. To ensure that local interests are represented, local authorities and system/network operators should work closely together to develop plans that bring economic and other benefits to the region.

5.4 Supply chain

Government approach

The UK Government announced an ambition to reach the capacity to manufacture and supply over 300,000 heat pump units in the UK per year by 2028. It was recognised in the Heat and Buildings Strategy that there are currently gaps in both the supply chain and workforce skills that need to be filled; currently just 10,000 heat pump units are manufactured in the UK per year, representing only 30% of heat pumps sold in the UK. It was also highlighted that upskilling of the existing workforce is required, as well as the creation of new jobs. The Government committed to continue working with the Department of Education and further education sector to ensure training opportunities are available. However details on what this looks like are lacking.

The Government also emphasised that the industry already has the capacity to do this, suggesting that an industry-led approach is expected to provide most training resources.

It alluded to a local approach to building a UK supply chain. The Net Zero Strategy announced the continuation of the BEIS-funded Local Net Zero Programme (BEIS, 2021f).

First established in 2017, this supports local authorities, local partners and communities with their capability and capacity to deliver net-zero activities, including heat decarbonisation (BEIS, 2021c). By identifying and supporting low carbon projects, this could help to build supply chains.

Missed opportunities

To reach the Government's ambitious targets, significant efforts will be required to strengthen the supply chain and improve its efficiency. There is a missed opportunity to recognise the role that local authorities could have in co-ordinating training and skills for heat decarbonisation. Local actors, including local authorities, installers and assessors/surveyors, are often key 'touch points' where professionals are interacting with households to not only provide the products and services, but promoting behaviour change.

Upskilling of the existing workforce is urgent, and while industry is well-equipped to scale up training, a lack of long-term vision on future heat systems could prevent progress at the pace and scale needed. The role of local authorities was not clarified in the Heat and Buildings Strategy however, and there remain wide-ranging uncertainties, around technology, roles and responsibilities, business models, public acceptance and behaviours, and finance.

These areas need more understanding and innovation before services can be scaled up to the required levels. Many businesses are cautious about the scale of opportunities that will be available to them in future and can be reluctant to invest in the capacity and skills required (Scottish Government, 2019b).

In the absence of key decisions being taken, there is a risk that the businesses will delay making necessary changes until they receive more certainty from government. Local energy pilot and demonstration projects can provide an environment that supports learning, upskilling and development of supply chains.

It is also essential that appropriate standards are applied when developing new products and training opportunities. Poor quality workmanship undermines adoption of new technologies (Chitchyan & Bird, 2021; Chitchyan & Bird, 2021a). There are clear issues around skills resources which require a coordinated response as it is not just a matter of training the additional tradespeople, but also the upskilling of the existing workforce to meet the standards required (Navigant and ENA, 2019). There is a lack of long-term training in the building sector (Ramboll, 2019) and criticism that National Vocational Qualifications (NVQs) are inconsistently assessed (Green et al, 2020). At present, there are notable skills gaps and regional variations in both the type and quality of skills across the workforce, leading to calls for a nationwide training programme to upskill the existing workforce, with appropriate accreditation schemes to be implemented to ensure a coordinated response.

A comprehensive and integrated approach is essential for delivering sustainable heating. While installation targets can provide a useful signal to the sector, efforts must be made to build a market for new technologies and services, alongside developing a supply chain and ensuring an appropriately skilled workforce. Whilst many of these elements are present in the Heat and Buildings Strategy, details on how each part will work together are missing.

What SLES needs

Recommendation: Government should provide a long-term and whole systems vision for the decarbonisation of heat to provide near-term certainty to supply chains.

The UK does not currently have the capacity to deliver zero-carbon heating. History has taught us that scaling up too quickly without this capacity can have negative impacts on quality and consumer experience. However, a lack of clear direction from central government has instilled deep uncertainties across the sector, leaving businesses unable to invest in vital training, skills, capabilities, and partnerships. For SLES to be allowed to emerge, Government needs to help to build confidence within the sector.

Financial support from national government to actors can also help to catalyse scale up of low- and zero-carbon heat solutions. For example, the Heat Networks Delivery Unit (HNDU), set up by BEIS in 2013, supports both local authorities and private projects in England and Wales through the early stages of heat network project development BEIS, 2020g). Over 200 projects were funded in the first 7 funding rounds of the HDNU (now in its tenth round), across 140 local authorities (BEIS, 2018). Alongside this is the Heat Network Investment Project, through which the UK Government has pledged up to £320 million to accelerate market growth (BEIS, 2020f). Five local authority-led projects have received funding totalling £30 million.

Recommendation: Local authorities should coordinate skills and training for for local energy system decarbonisation decarbonisation.

Developing regionally specific training or upskilling could be an important factor for SMEs, assisting them to develop knowledge in local materials and building vernacular (Green et al, 2020). This local identification of training needs could be developed through the assistance of Local Enterprise Partnerships (LEPs) who are in the position to build up an evidence base for skills gaps and where training is required. Currently, a large proportion of clean heat components are delivered from abroad (for example, 70% of heat pump units are imported) (BEIS, 2021c). SMEs may need support to develop the necessary skills and training in order to build strong supply chains.

Some upskilling and extra resource is also required in the short term to ensure that relevant local authority officers have expertise on low carbon heat and energy technologies. While some local authorities or local enterprise partnerships have skills advisory boards that assess skills gaps, this is not a requirement, and risks some areas being left behind if they lack the initial capacity and capability. Some of this upskilling could be provided by local LEPs as part of year-long CPD programmes, but extra resources from central government are needed to allow prioritisation of energy planning (Policy Connect, 2019).

5.5 Distribution of costs and benefits

Government approach

The UK Government highlight the issue of costs and cost distribution in the Heat and Building Strategy and mention the need for fairness in sharing costs. The Government is minded to rebalance policy costs over next decade, and will launch a call for evidence on options to do this. A new grant scheme – the Boiler Upgrade Scheme – has been launched to help with costs of installing clean heat technology. However, this is not targeted to those on low incomes or in fuel poverty and is not co-ordinated with financial support for energy efficiency measures.

The approach to implementation remains centralised and is largely reliant on market-led cost reductions of clean heat technologies. Whilst this could make these more affordable in the medium-to-long term, it does not address the immediate upfront cost barrier for those who are most in need of financial help.

Missed opportunities

There is also a missed opportunity for the UK Government to capture and fairly distribute the societal co-benefits that could be achieved through a more holistic approach to heat decarbonisation. Energy efficiency is a weak point of the strategy. While the Government set out, in 2017, an aspiration to upgrade 'as many homes as possible' to EPC band C by 2035, there remains a lack of detail on a long-term strategy for achieving this (BEIS, 2017).

This is particularly the case for owner-occupier homes. Without upgrades, poorly insulated homes will remain difficult to heat, and the costs of doing so adequately may increase, at least in the short-to-medium term, with increasing electrification. This means that many households could miss out on the health, comfort and economic benefits that are associated with energy efficient homes. A market-led approach could also exacerbate existing inequalities, with those who are able to afford decarbonisation measures benefiting from them, whilst those most at risk of adverse health and economic effects being priced out in the short-to-medium term.

The Scottish Government launched a nation-wide cashback incentive scheme for both SMEs and homeowners in November 2020 that provides discounts on both renewable heating systems and energy efficiency measures.[19] (Scottish Government, 2020a). While this provides some financial incentive for owner-occupiers, it still requires them to hold the cash up front, making it difficult for households without significant savings to access the same level of financial support.

Moving some policy costs from gas to electricity bills is essential, but ultimately the distribution of costs through energy bills rather than general taxation is regressive, and risks perpetuating, or even exacerbating, existing inequities.

What SLES needs

Recommendation: National government should review how societal and environmental impacts are reflected in policy costs, as well as how these costs are distributed.

For SLES to deliver zero-carbon heating that also brings wider societal benefits, a fairer distribution of policy costs between electricity and gas is crucial. It is also essential that the societal impacts of different approaches to heat decarbonisation are fully appreciated and embedded into cost-benefit analyses and impact assessments for different pathways.

Recommendation: Central Government should devolve the responsibility for dispersing coordinating grant funding, such as for heating and energy efficiency, to local government.

For SLES to offer opportunities for individual and local community preferences and requirements to be accounted for, so that no one is 'left behind,' support for households and businesses to switch to zero-carbon heating will often need to be targeted.

19 Homeowners will be able to apply for 75% cashback up to the value of £7,500 towards the cost of a renewable heating system and a further 40% cashback up to £6,000 for energy efficiency measures.

6 Conclusions and recommendations

In this review, we have outlined how a SLES approach could deliver a transition to a decarbonised heating sector that is faster, fairer, and cheaper than a top-down, one-size-fits-all approach. There are cross-cutting barriers that will need to be overcome regardless of which technology mix is eventually adopted. Approaching these challenges through the 'SLES prism,' we identify the aspects of a smart and local approach that could lower the barriers to progress, and which often intersect with each other.

However, under current governance structures, SLES will struggle to emerge and achieve the potential environmental and societal benefits that are at stake. Solutions to decarbonisation of this sector must consider the inherently local nature of heat, and how it impacts on people's lives. This is both complicated and exacerbated by the whole systems nature of the net-zero transformation, as decarbonisation of heating is happening alongside that occurring in power and transport. Despite evidence showing that tailoring measures to suit a particular region or community will provide cost savings and deliver benefits, the UK Government's strategy continues to take a centralised, top-down approach.

Our systematic review indicates that existing actors will be required to take on new roles and responsibilities if we are to realise the benefits of a SLES approach to decarbonising heating. We outline these below.

Roles and responsibilities: Local actors

Local actors are key enablers of SLES, particularly local authorities. The key role of local authorities in heat decarbonisation is highlighted in the UK Government's Heat and Buildings Strategy.

However, while there are examples of ambitious and innovative action at a local level, there is no statutory duty on local authorities to act to reduce emissions. A smart and local approach to heat decarbonisation could align well with existing statutory duties, for example alleviation of fuel poverty.

With more responsibility and commensurate resources, local authorities could help to overcome some of the main cross-cutting barriers facing the heat transition and deliver societal benefits to the local area. A number of our recommendations are therefore centred around devolving more powers and responsibilities to local authorities.

Recommendation: Central government should devolve more powers and responsibilities to local authorities.

These include:

- **Recommendation**: Local authorities should be responsible for ensuring energy efficiency of buildings in existing and new builds is commensurate with net-zero targets.
- **Recommendation**: Require local authorities to engage businesses and consumers on net-zero.
- **Recommendation**: Mandate local authorities to work with network and system operators on local strategic infrastructure investment plans and link them to local economic development plans.
- **Recommendation**: Central Government should devolve the responsibility for dispersing coordinating grant funding, such as for heating and energy efficiency, to local government.
- **Recommendation**: Local authorities should coordinate skills and training for heat decarbonisation.

Devolving powers to local authorities could help to address multiple cross-cutting barriers and deliver zero-carbon heating at lower cost, faster and more fairly. A SLES approach can utilise the knowledge of trusted local actors to engage with households and businesses, helping them to understand the need to decarbonise heat, the measures required to do so, and the tangible societal benefits that action can bring. Through two-way engagement between citizens and central government, local authorities can help to gain valuable insight into the behaviours and approaches compatible with decarbonising heating. This in turn could create local decarbonisation visions and inform the roles of other actors, such as the heating supply chain, customer-centred energy businesses, community energy groups and training providers. It could also inform where there is a local need for innovation space, such as regional regulatory sandboxes.

Local authorities are key to developing robust strategies and policies, shaping regulation that can align local infrastructure requirements and socioeconomic properties, and supporting wider energy system flexibility.

Roles and responsibilities: Central government

Recommendation: Central government should ensure that local authorities have the commensurate resources and capabilities to deliver on local net-zero energy systems.

Crucially, devolving additional responsibilities on local authorities must be matched by increasing resources to ensure they have the capacity and capability to deliver. Local authorities have already faced budget cuts and, while well-placed to enable the transition, they are not currently resourced to do so. They need additional resources in the form of funding, skills, and time. We therefore stress that no new additional expectations should be placed on local authorities without additional support from central government.

Recommendation: Governments should provide a long-term and whole systems vision for the decarbonisation of heat to provide near-term certainty to supply chains.

Recommendations: BEIS should take key decisions that will impact national infrastructure, such as the gas networks, as soon as possible.

Central government also has a key role to play in setting the tone for the transition. The 2021 Heat and Buildings Strategy, which comes over eight years after the last sector strategy, is a welcome start to this.

However, some key decisions have not yet been taken, such as the future of the gas network. There are also policy gaps, most notably on a plan for retrofitting the UK's building stock. Long-term policy stability is likely to help local and national actors to design robust action plans, including how the current and future workforce will be provided with the skills and supply chain needed to roll-out energy efficiency and clean heat measures. The longer these decisions are delayed, the more expensive and difficult the transition becomes.

There are also missed opportunities to join up action in a way that integrates decarbonisation of heating with the creation of a smarter, more flexible energy system. A SLES approach to policy design is one that employs whole-systems thinking, and could help to shape decisions on infrastructure and support measures that will continue to work on timescales out to 2050. It is the responsibility of central government to ensure that rapid action towards emissions reductions can be taken with confidence.

Recommendation: Heat networks should be regulated by Ofgem to improve transparency in the sector and protect consumers.

It is important that there are consistent regulations and customer protections in place across different forms of heat. This is not currently the case, as heat networks are regulated differently to heating from electricity and gas. This is something that should be addressed rapidly, given that a significant role for heat networks is foreseen in the heating strategies.

Recommendation: National government should review how societal and environmental impacts are reflected in policy costs, as well as how these costs are distributed.

The transition to a decarbonised heating system is an opportunity to address current structural inequalities. A SLES approach has been projected to be more cost effective in both the short and long-term and could keep costs low compared to blanket-approaches to decarbonisation. However, current tax, billing, and market arrangements are negatively impacting the cost competitiveness of the innovative business models for sustainable heating options on which SLES could depend. We support the Government's decision to consult on rebalancing environmental and social policy costs between gas and electricity.

Any review of costs should be expanded to consider alternative cost-distribution arrangements, and to be more inclusive of wider societal and energy system benefits. The way buildings are heated and cooled can acutely impact the health and wellbeing of occupants and surrounding localities. These are not fully accounted for in decision-making processes. Unless this changes, the advantages of a SLES approach over top-down, one-size-fits-all solutions may not be fully appreciated.

Roles and responsibilities: Regulator

Recommendation: Ofgem should expand the regulatory sandbox approach to enable regional/local energy systems business model innovation.

Businesses could play a central role in delivering building energy efficiency improvements and zero-carbon heating, as well as new ways of engaging with consumers. If expanded, the regulatory sandbox could provide opportunities for businesses across the UK to innovate and experiment with locally and regionally bespoke business models.

7 References

ADE, 2018. Market report: Heat networks in the UK. London: Association for Decentralised Energy.

Anaam, A., Chard, R. and Fleck, R. 2020. Fuel poverty in a smart energy world: How vulnerable energy consumers could benefit from smarter heating controls. Birmingham: Energy Systems Catapult.

Arvanitopoulos, T. and Wilson, C. 2021. Local conditions associated with local energy system projects. EnergyREV, University of Strathclyde Publishing: Glasgow, UK. ISBN: 978-1-909522-87-9.

Aunedi, M. and Green, T. 2020. Early insights into system impacts of smart local energy systems. EnergyREV, University of Strathclyde Publishing: Glasgow, UK.

J. Barnes, J. and Bhagavathy, S.M. 2020. The economics of heat pumps and the (un)intended consequences of government policy. *Energy Policy*, **138**: 111198. doi: 10.1016/j.enpol.2019.111198

BEIS & Ofgem, 2017. Upgrading our energy system. London: Crown Copyright.

BEIS & Ofgem, 2017a. Upgrading our energy system – smart systems and flexibility plan: Progress. London: Crown Copyright.

BEIS and Ofgem, 2021. Energy future system operator consultation. London: Crown Copyright.

BEIS, 2017. Census of owner-occupier applicants to the domestic RHI. London: Crown Copyright.

BEIS, 2017. The clean growth strategy: Leading the way to a low carbon future. London: Crown Copyright.

BEIS, 2018. Clean Growth – transforming heating. London: Crown Copyright.

BEIS, 2018. Energy Company Obligation: ECO3, 2018–2022.London: Crown Copyright.

BEIS, 2018. Local Authorities supported by HDNU. London: Crown Copyright.

BEIS, 2019. Building a market for energy efficiency: Call for evidence summary of responses. London: Crown Copyright.

BEIS, 2020. Transforming heat-public attitudes research: A survey of the GB public on the transition to a low-carbon heating future. London: Crown Copyright.

BEIS, 2020a. Annual fuel poverty statistics in England, 2020 (2018 data). London: Crown Copyright.

BEIS, 2020b. Energy White Paper: Powering our Net Zero Future. ISBN 978-1-5286-2219-6. London: Crown Copyright.

BEIS, 2020c. Future support for low carbon heat: Consultation. London: Crown Copyright.

BEIS, 2020d. Green Homes grant local authority delivery scheme, Phase 1B: entering a bid. London: Crown Copyright.

BEIS, 2020e. Heat networks delivery unit. London: Crown Copyright.

BEIS, 2020f. Heat networks: building a market framework. London: Crown Copyright.

BEIS, 2020g. The ten point plan for a green industrial revolution. London: Crown Copyright.

BEIS, 2021. Contracts for difference. London: Crown Copyright.

BEIS, 2021a. Energy consumption in the UK. London: Crown Copyright.

BEIS, 2021a. Energy Consumption in the UK 2021, End uses data tables, Table U2. London: Crown Copyright.

BEIS, 2021b. Green Homes Grant: make energy improvements to your home. London: Crown Copyright.

BEIS, 2021c. Heat and buildings strategy. London: Crown Copyright.

BEIS, 2021d. Heat network zoning,. London: Crown Copyright.

BEIS, 2021e. National Energy Efficiency Data-Framework (NEED) report. London: Crown Copyright.

BEIS, 2021f. Net Zero Strategy: Build back greener. London: Crown Copyright.

BEIS, 2021g. Smart meter statistics in Great Britain: Quarterly report to end of June 2021. London: Crown Copyright.

BEIS, 2021h. Sustainable warmth protecting vulnerable households in England. London: Crown Copyright.

BEIS, 2021i. Transitioning to a net zero energy system: Smart systems and flexibility plan 2021. London: Crown Copyright.

BEIS, 2021j. UK enshrines new target in law to slash emissions by 78% by 2035. London: Crown Copyright.

BEIS and MHCLG, 2020. Energy performance certificates for buildings Action Plan. London: Crown Copyright.

Broad, O., Hawker, G. and Dodds, P.E. 2020. Decarbonising the UK residential sector: The dependence of national abatement on flexible and local views of the future. *Energy Policy*, **140**: 111321. doi: 10.1016/j.enpol.2020.111321

Brown, D., Kivimaa, P., Rosenow, R., Martiskainen, M. and Bird, J. 2018. Warm homes for all – a comprehensive policy approach for residential energy efficiency retrofit in the UK. Brighton: Centre on Innovation and Energy Demand.

Brown, D., Hall, S. and Davis, M.E. 2019. Prosumers in the post subsidy era: an exploration of new prosumer business models in the UK. *Energy Policy*, **135**: 110984. doi: 10.1016/j.enpol.2019.110984

Cairns, I., Hannon, M., Braunholtz- Speight, T., Hardy, J., McLachan, C., Mander, S., Manderson, E. and Sharmina, M. 2020. Financing community energy case studies: Brighton and Hove energy services. London: UKERC. doi: 10.17868/69790

Carbon Connect, 2017. Next steps for the gas grid. London: Policy Connect.

Carmichael, R., Rhodes, A., Hanna, R. and Gross, R. 2020. Smart and flexible electric heat. Energy Futures Lab Briefing Paper. London: Imperial College London. doi: 10.25561/82290

Carmichael, R. 2019. Behaviour change, public engagement and Net Zero. A report for the Committee on Climate Change. London: Imperial College London.

CCC, 2016. Next steps for UK heat policy. London: Climate Change Committee.

CCC, 2018. Reducing UK emissions: 2018 Progress Report to Parliament. London: Climate Change Committee.

CCC, 2019. Net Zero Technical Report. London: Climate Change Committee.

CCC, 2019a. UK housing: Fit for the future? London: Climate Change Committee.

CCC, 2020. Local Authorities and the Sixth Carbon Budget. London: Climate Change Committee.

CCC, 2020a. Policies for the Sixth Carbon Budget and Net Zero. London: Climate Change Committee.

CCC, 2020b. Reducing UK emissions – 2020 Progress Report to Parliament. London: Climate Change Committee.

CCC, 2020c. The Sixth Carbon Budget (Buildings). London: Climate Change Committee.

CCC, 2020d. The Sixth Carbon Budget: The UK's path to Net Zero. London: Climate Change Committee.

CCC, 2021. Independent assessment: The UK's Net Zero Strategy. London: Climate Change Committee.

CCC, 2021a. Joint recommendations: 2021 report to Parliament. London: Climate Change Committee.

CCC, 2021b. Progress in reducing emissions 2021 Report to Parliament. London: Climate Change Committee.

Chitchyan & Bird, 2021. Bristol's building and retrofit subsystem: Case study on skills and training needs for transitioning to smart local energy systems. EnergyREV, University of Strathclyde Publishing: Glasgow, UK. ISBN 978-1-909522-89-3

Chitchyan & Bird, 2021a. Bristol: a case study on the training and skills needed for a smart local energy 'system of systems.' EnergyREV, University of Strathclyde Publishing: Glasgow, UK. ISBN 978-1-909522-86-2

Citizens Advice, 2021. Rough trade? Balancing the winners and losers in energy policy. Birmingham: Citizens Advice.

Citizens Advice, 2021a. Look before you LAEP Ending the postcode lottery of local. Birmingham: Citizens Advice.

Climate Xchange, 2019. Research-policy workshop on heat decarbonisation. Edinburgh Centre for Carbon Innovation 14 & 15 October 2019. Edinburgh: Scottish Government.

Competition and Markets Authority, 2018. Heat networks market study. London: Crown Copyright.

Delta-EE, 2018. Heat pumps in smart grids UK. Report for BEIS. Edinburgh: Delta Energy & Environment.

Delta-EE, 2019. The transition to ' new heat ': How decarbonisation & market disruptions are shaping market opportunities. Edinburgh: Delta Energy & Environment.

Demski, C., Pidgeon, N., Evensen, D. and Becker, S. 2019. Paying for energy transitions: public perspectives and acceptability. UKERC Policy briefing. London: UKERC.

Dodds, P.E. and S. Demoullin, S. 2013. Conversion of the UK gas system to transport hydrogen. *International Journal of Hydrogen Energy*, **38**(18): 7189–7200. doi: 10.1016/j.ijhydene.2013.03.070

Element Energy, 2017. Hybrid heat pumps final report for BEIS. Cambridge: Element Energy.

Energy & Climate Intelligence Unit, 2020. Lockdown in leaky homes. London: Energy & Climate Intelligence Unit.

Energy Systems Catapult, 2018. Energy data review. Birmingham: Energy Systems Catapult.

Energy Systems Catapult, 2018a. ETI and ESC, Smart systems and heat project: WP1 integrated electrical heat Integrated Electric Heat-Upgrade Analysis Final Report. Birmingham: Energy Systems Catapult.

Energy Systems Catapult, 2019. Heat as a service: An introduction. Birmingham: Energy Systems Catapult.

Energy Systems Catapult, 2019b. Smart Systems and Heat programme: Phase 2 summary of key insights and emerging capabilities. Birmingham: Energy Systems Catapult.

Energy Systems Catapult, 2020. Local area energy planning: The method. Birmingham: Energy Systems Catapult.

Energy Systems Catapult, 2020a. Local Area Energy Planning key to minimising decarbonisation costs. Birmingham: Energy Systems Catapult.

Energy Systems Catapult, 2020c. Understanding Net Zero: A consumer perspective. Birmingham: Energy Systems Catapult.

Energy Taskforce, 2020. Energising our electric vehicle transition. Birmingham: Energy Systems Catapult.

Eyre, N and Killip, G. (eds). 2019. Shifting the focus: energy demand in a net-zero carbon UK. Centre for Research into Energy Demand Solutions. Oxford, UK. ISBN: 978-1-913299-04-0

Fawcett, T., Rosenow, J. and Bertoldi, P. 2019. Energy efficiency obligation schemes: their future in the EU. *Energy Efficiency*, **12**: 57–71. doi: 10.1007/s12053-018-9657-1

Fell, M.J., Kennard, H., Huebner, G., Nicolson, M.,Elam, S. and Shipworth, D. 2017. Energising Health: A review of the health and care applications of smart meter data. doi: 10.13140/RG.2.2.23987.63521

Fell, M.J., Bray, R., Ford, R., Hardy, J. and Morris, M. 2020. Post-pandemic recovery: How smart local energy systems can contribute. EnergyREV, University of Strathclyde Publishing: Glasgow, UK. ISBN 978-1-909522-70-1

Ford, R., Maidment, C., Vigurs, C., Fell, M.J. and Morris, M. 2019. Smart Local Energy Systems (SLES): A conceptual review and exploration. doi: 10.31235/OSF.IO/J4D57

Ford, R., Maidment, C., Vigurs, C., Fell, M.J. and Morris, M. 2021. Smart local energy systems (SLES): A framework for exploring transition, context, and impacts. *Technological Forecasting and Social Change*, **166**: 120612, 2021, doi: 10.1016/j.techfore.2021.120612

Forrest, 2021. Plan to link mortgages to green standards 'will hurt first-time buyers'. London: The Independent.

Fylan, F., Glew, D., Smith, M., Johnston, D. Brooke-Peat, M., Miles-Shenton, D., Fletcher, M., Aloise-Young, P. and Gorse, C. 2016. Reflections on retrofits: Overcoming barriers to energy efficiency among the fuel poor in the United Kingdom. *Energy Research & Social Science*, **21**: 190–198. doi: 10.1016/j.erss.2016.08.002.

Gabbatiss, 2021. In-depth Q&A: How will the UK's 'heat and buildings strategy' help achieve net-zero? London: Carbon Brief.

Gentoo, 2016. Boilers on prescription scheme reduces GP appointments by 60% – for customers. Sunderland, UK: Gentoo.

Green, E., Lannon, S., Patterson, J. and Iorwerth, H. 2020. Homes of today for tomorrow: Decarbonising Welsh Housing between 2020 and 2050. Cardiff: Welsh Government.

Gupta, R., Gregg, M., Passmore, S. and Stevens, G. 2015. Intent and outcomes from the Retrofit for the Future programme: Key lessons. *Building Research & Information*, **43**(4): 435–451. doi: 10.1080/09613218.2015.1024042

Harvey, 2021. UK government scraps green homes grant after six months. London: The Guardian.

Hirst, D. 2020. Electric vehicles and infrastructure. London: House of Commons Library.

HM Government, 2008. Planning and Energy Act 2008.

HM Government, 2020. The Government Response to the Committee on Climate Change's 2020 Progress Report to Parliament.

HM Treasury, 2021. Autumn budget and spending review 2021: A stronger economy for the British people.

House of Commons Energy and Climate Change Committee, 2016. Home energy efficiency and demand reduction Fourth Report of Session 2015–16. London: House of Commons.

IEA, 2019. The critical role of buildings: Perspectives for a clean energy transition. Paris: International Energy Agency.

IEA, 2021. Heat pumps – analysis. Paris: International Energy Agency.

IRENA, 2019. Renewable power-to-hydrogen: Innovation landscape brief. Abu Dhabi: International Renewable Energy Agency.

IRENA, IEA, and REN21, 2020. Renewable energy policies in a time of transition – Heating and cooling. Abu Dhabi: International Renewable Energy Agency. ISBN 978-92-9260-289-5

Keay, M. 2020. Energy systems thinking and the decarbonization of heat in the UK. Oxford: Oxford Institute for Energy Studies. ISBN 978-1-78467-156-3

Kemp, R., Loorbach, D. and Rotmans, J. 2007. Transition management as a model for managing processes of co-evolution towards sustainable development. *International Journal of Sustainable Development & World Ecology*, **14**(1): 78–91. doi: 10.1080/13504500709469709

Kvarnström, O. 2019. District Heating: heat-as-a-service and sector coupling. Amsterdam: Energy Post.

Laville, 2021. Hundreds of millions in green grants for English homes pulled despite delays. London: The Guardian.

Local Energy Scotland, 2021. What is Local Energy? – Edinburgh: Energy Saving Trust.

Local Government Association, 2021. The levelling up agenda, House of Commons, 15 June 2021. London | Local Government Association.

Lowes, R. and Woodman, B. 2020. Disruptive and uncertain: Policy makers' perceptions on UK heat decarbonisation. *Energy Policy*, **142**: 111494. doi: 10.1016/j.enpol.2020.111494

Lowes, R. 2021. "On heat networks (while BEIS are currently consulting on zoning) I feel there is a huge governance problem here. Local authorities will need to be involved from planning to delivery (probably finance too) and this has." Twitter.

Maclean, K., Sansom, R., Watson, T. and Gross, R. 2016. Managing heat system decarbonisation comparing the impacts and costs of transitions in heat infrastructure Final Report Acknowledgment. London: Imperial College London.

McDowall, W. and Britchfield, C. 2021. Decarbonising heating at home: Learning from past successes and failures to improve energy policy making. London: Institute for Government.

MHCLG, 2019. The Future Homes Standard 2019 Consultation on changes to Part L (conservation of fuel and power) and Part F (ventilation) of the Building Regulations for new dwellings. London: Crown Copyright.

MHCLG, 2021. Consultation on changes to Part L (conservation of fuel and power) and Part F (ventilation) of the Building Regulations for new dwellings Summary of responses received and Government response. London: Crown Copyright.

Millman, 2020. Hy to Hydrogen. Exeter: Regen.

Morris, M. and Hardy, J. 2019. Electricity storage & electric vehicles: Policy & Regulatory Landscape Review Series – Working Paper 1. Energy Revolution Research Centre, Strathclyde, UK. University of Strathclyde Publishing. ISBN: 978-1-908522-56-5

Morris, S., McCullough, A., Swan, A. and Wilkinson G. 2019. Smart local energy systems international research. Shoreham-by-Sea: Ricardo Energy & Environment.

Morris, M., Hardy, J., Gaura, E., Hannon, M. and Morstyn, T., 2020. Policy & Regulatory Landscape Review Series – Working Paper 2: Digital energy platforms. Energy Revolution Research Centre, Strathclyde, UK. University of Strathclyde Publishing. ISBN: 978-1-909522-64-0

National Energy Agency, 2017. Heat Decarbonisation Potential impacts on social equity and fuel poverty. Lomdon: National Energy Agency.

National Grid ESO, 2020. Future Energy Scenarios 2020. Warwick: National Grid ESO.

National Grid ESO, 2021. Future Energy Scenarios 2021. Warwick: National Grid ESO.

National Grid ESO, 2021a. What is transmission connected generation? Warwick: National Grid ESO.

National Grid ESO, 2019. Future energy scenarios. Warwick: National Grid ESO.

National Grid, 2020. Bridging the gap to net zero. Warwick: National Grid ESO.

National Infrastructure Commission, 2018. Cost analysis of future heat infrastructure options Report for National Infrastructure Commission. London: National Infrastructure Commission.

Navigant and ENA, 2019. Pathways to net-zero: Decarbonising the gas networks in Great Britain. Prepared for the Energy Networks Association. London: Navigant Europe.

Nesta, 2021. Government's plan for home heating: warm on the surface, a little cool beneath. London: Nesta.

Nicol, S., Roys, M. and Garrett, H. 2015. The cost of poor housing to the NHS. Watford: Building Research Establishment (BRE).

Northern Ireland Housing Executive, 2017. Estimates of fuel poverty in Northern Ireland in 2017 and 2018 revised. London: Crown Copyright.

Office for National Statistics, 2020. Excess winter mortality in England and Wales. London: Office for National Statistics.

Office for National Statistics, 2021. People in households by housing tenure and combined economic activity status of household members: Table I. London: Office for National Statistics.

Ofgem, 2018. Easy guide to the non-domestic RHI. London: Ofgem.

Ofgem, 2018a. Factsheet: An introduction to the Domestic RHI. London: Ofgem.

Ofgem, 2019. Our strategic narrative for 2019–23. London: Ofgem.

Ofgem, 2019a. RIIO-ED2 framework decision. London: Ofgem.

Ofgem, 2019. State of the energy market. London: Ofgem.

Ofgem, 2019b. Targeted charging review: minded to decision and draft impact assessment. London: Ofgem.

Ofgem, 2020c. Energy Regulation Sandbox: Guidance for Innovators. London: Ofgem.

Ofgem, 2020. Ofgem decarbonisation programme action plan. London: Ofgem.

Ofgem, 2020a. Ofgem proposals to 'turn your street green', transforming local electricity networks. London: Ofgem.

Ofgem, 2021. Costs in your energy bill. London: Ofgem.

Peacock, A.D., Chaney, J., Goldbach, K., Walker, G., Tuohy, P., Santonja, S., Todoli, D. and Owens, E.H. 2017. Co-designing the next generation of home energy management systems with lead-users. *Appl Ergon*, **60**: 194–206. doi: 10.1016/j.apergo.2016.11.016

Policy Connect, 2019. Why Britain urgently needs a low carbon heat strategy. London: Policy Connect.

Public Health England, 2014. Local action on heath inequalities: Fuel Poverty and cold home-related health problems. London: Crown Copyright.

Ramboll, 2019. Alternative heat solutions converting a town to low carbon heating. London: Ramboll.

Revesz, A., Jones, P., Dunham, C., Davies, G., Marques, C., Matabuena, R., Scott, J. and Maidment, G. 2020. Developing novel 5th generation district energy networks. *Energy*, **201**: 117389. doi: 10.1016/j.energy.2020.117389

Rosenow, J. and Eyre, N. 2016. A post mortem of the Green Deal: Austerity, energy efficiency, and failure in British energy policy. *Energy Research and Social Science*, **21**: 141–144. doi: 10.1016/j.erss.2016.07.005

Rosenow, J. and Lowes, R. 2020. Heating without the hot air: Principles for smart heat electrification. Brussels: Regulatory Assistance Project (RAP).

Rosenow, J. and Lowes, R. Smart heat: principles and policies for integrated heat decarbonisation.

Sandys, 2021. Emerging inequalities, emerging challenges & opportunities: Reshaping the essential energy service. LinkedIn.

Scottish Government, 2011. Energy Legislation, no. 11, p. 2050. Edinburgh: Scottish Government.

Scottish Government, 2016. Home energy efficiency programmes for Scotland: area-based schemes. Edinburgh: Scottish Government.

Scottish Government, 2018. Fuel poverty strategy for Scotland 2018. Edinburgh: Scottish Government.

Scottish Government, 2019. Energy Efficient Scotland Improving energy efficiency in owner occupied homes. Edinburgh: Scottish Government.

Scottish Government, 2019a. Local Heat and Energy Efficiency Strategies (LHEES): phase 1 pilots – technical evaluation. pp1–30. Edinburgh: Scottish Government.

Scottish Government, 2019b. Energy Efficient Scotland. Strategic outline case for proposed development of a national delivery mechanism. Edinburgh: Scottish Government.

Scottish Government, 2019c. Scottish house condition survey: 2019 key findings. Edinburgh: Scottish Government.

Scottish Government, 2020. Local Heat and Energy Efficiency Strategies (LHEES): phase 2 pilots evaluation. Edinburgh: Scottish Government.

Scottish Government, 2020a. Renewable heat scheme for homeowners. Edinburgh: Scottish Government.

Scottish Government, 2020b. Scottish Government hydrogen policy statement. Edinburgh: Scottish Government.

Scottish Government, 2020c. Update to the Climate Change Plan 2018–2032: Securing a green recovery on a path to net zero. Edinburgh: Scottish Government.

Scottish Government, 2021. Heat in buildings strategy – achieving net zero emissions: consultation. Edinburgh: Scottish Government.

Scottish Government, 2021b. Local heat and energy efficiency strategy pilots: phase 3 – evaluation. Edinburgh: Scottish Government.

Shelter, 2009. Housing Tenure Factsheet. London: Shelter.

Shove, E. and Walker, G. 2010. Governing transitions in the sustainability of everyday life. *Research Policy*, **39**(4): 471–476. doi: 10.1016/j.respol.2010.01.019

Shove, E. 2012. Habits and their creatures. Collegium.

Simpson, K.,Owen, A. and Chatterton, P. 2018. SRI Briefing Note Series No. 15. Equipping construction workers with sustainable building skills: A focus on Leeds.

Stark, C., Thomson, M.et al. 2019. Net Zero: The UK's contribution to stopping global warming. London: Climate Change Committee.

Stilgoe, J. and Cohen, T. 2021. Rejecting acceptance: learning from public dialogue on self-driving vehicles. *Science and Public Policy*, **48**(6): 849–859. doi: 10.1093/scipol/scab060

Strbac, G., Pudjianto, D., Sansom, R., Djapic, P., Ameli, H., Shah, N., Brandon, N., Hawkes, A. and Qadrdan, M. 2018. Analysis of alternative UK heat decarbonisation pathways. London: Imperial College London.

UK Parliament Housing Communities and Local Government Committee, 2021. Local government and the path to net zero. London: Crown Copyright.

UKGBC, 2017. Regeneration and retrofit. London: UK Green Building Council.

Webb, J. 2016. Heat and energy efficiency: making effective policy – Advisory group report. A report for the UK Committee on Climate Change. Edinburgh: University of Edinburgh.

Welsh Government, 2018. Welsh Government Smart Living Initiative. AD Research & Analysis, and Centre for Sustainable Energy.

Welsh Government, 2019. Better homes, better Wales, better world: Decarbonising existing homes in Wales. Report to Welsh Ministers from the Decarbonisation of Homes in Wales Advisory Group. Cardiff: Crown Copyright.

Welsh Government, 2019a. Fuel poverty estimates for Wales, 2018: revised Households living in fuel poverty by tenure. Cardiff: Crown Copyright.

Welsh Government, 2019b. Welsh housing conditions survey (energy efficiency of dwellings): April 2017 to March 2018. Cardiff: Crown Copyright.

Williams, H., Lohmann, T., Foster S. and Morrell, G. 2018. Public acceptability of hydrogen in the home (Madano and Element Energy). London: Climate Change Committee.

Appendix: Review methodology, results and analysis

A detailed account of the motivation for this review can be found in our first Working Paper of this review series (Morris & Hardy, 2019). Below is a brief description of the process, followed by the results of this review.

Literature search

Figure 1 depicts the process used to gather literature for this review, as well as a breakdown of the evidence characteristics for included documents. Four search methods – crowdsourcing, systematic online keyword searches, background knowledge (i.e. literature already known to the authors) and citation searches – were used. The total body of evidence collected through these methods was 314 distinct documents. These documents were screened for relevance (assessed on factors such depth of discussion on topic and date of publication), with 176 being included in this review. Evidence was characterised according to factors such as geographic area covered, publishing institution, date and type of publication. Note that, in some cases, more than one institution may be attributed to pieces of evidence. Additional literature was consulted in the post-analysis stage; this literature is included in the references section but was not analysed systematically and is therefore not included in the above figure.

Database searches

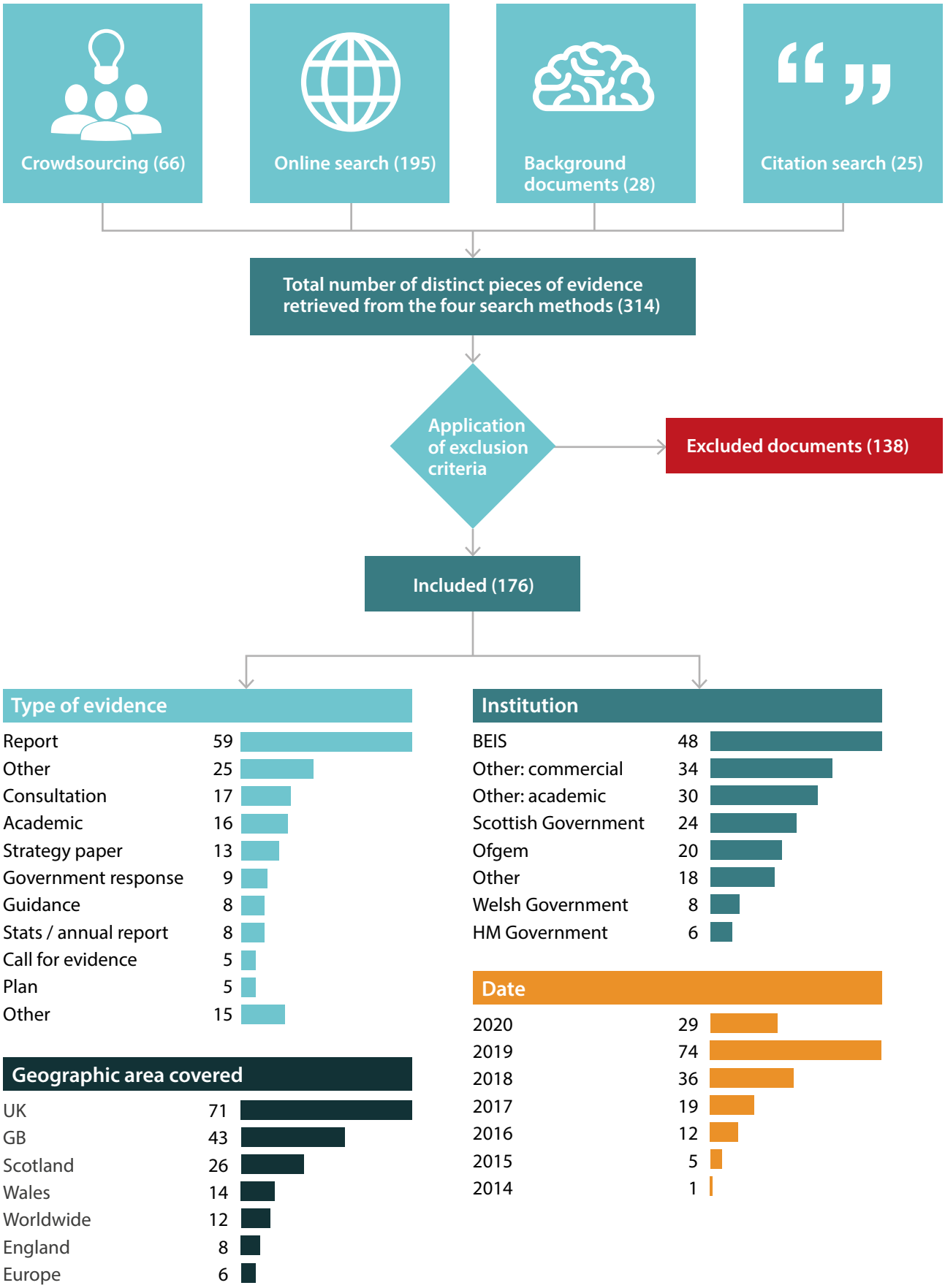
The focus of this review is of policies and regulations which are currently in place in the UK. The most immediately relevant sources were therefore bodies responsible for developing these.

We primarily gathered information published on the UK Government website, Ofgem's website and the Devolved Administration websites (Northern Ireland Executive, Scottish Government and Welsh Government). Searches were performed using the search engine of these institution and limited to exclude certain types of result (e.g. new and communications, transparency/freedom of information releases). Date restrictions were used when searches returned large numbers of results (updated after 15/07/2016).

An iterative search strategy was combined with the authors' background knowledge to gather relevant documents from known sources. Search terms used included:

- Biomass / biogas / bioenergy
- Cooling
- "Decarbonisation of gas"
- "Decarbonisation of heat" / decarbonisation AND heat
- "Electric heating"
- "Energy company obligation"
- "Energy demand"
- "Energy efficiency"
- "Future homes"
- Heat / heating
- Heat AND storage
- "Heat network" / "district heating"
- - "Heat pump"
- Hydrogen
- "Renewable heat incentive" / RHI / "domestic RHI" / "non-domestic RHI"

Documents deemed relevant (considering e.g. type and date of publication) were downloaded and imported into the EPPI-Centre systematic EPPI-Reviewer software.



Crowdsourcing

A call for evidence detailing both the scope of the entire review and the relevant topics for this sprint was circulated using a combination of professional, public and personal networks.[20] All received documents were imported first into a reference management software (Mendeley) for tracking purposes, and then into EPPI-Reviewer.

Inclusion and exclusion criteria were applied to determine the included documents (see Morris & Hardy, 2019 for details).

Below is a list of the primary networks we used to gather evidence. The list is not exhaustive, as it evolved throughout the process and the call for evidence was shared further by these networks.

Table 4: List of primary networks used to disseminate a call for evidence for literature relating to decarbonisation of heating and cooling.

Network	Description
General	
Association of Decentralised Energy	Trade association
Association of Public Service Excellence (APSE)	Not for profit unincorporated association
Centre for Environmental Policy (CEP)	Academic research institute, Imperial College London
Centre for Research into Energy Demand Solution (CREDS)	UK academic and industry research centre
Community Energy England	Not for profit organisation
Community Energy Scotland	Charity
Community Energy Wales	Not for profit membership organisation
Energy Futures Lab (EFL)	Academic research institute, Imperial College London
Energy Institute	Society for Energy Professionals
Energy Systems Catapult Energy Revolution Integration Service (ERIS)	Expert guidance and support for PFER projects
EnergyREV consortium	PFER Academic Consortium
Grantham Institute	Academic research institute, Imperial College London.
IGov	Established career fellowship, The University of Exeter
Local Enterprise Partnerships (LEPS)	Business-led partnerships between local authorities and local private sector businesses
Personal Networks	Channels include LinkedIn, Twitter, email
PFER SLES demonstrators and related projects	Including the four funded demonstrators and design projects
Powerswarm	Open network for power system transformation
RegenSW	Not for profit centre of energy expertise and market

20 The call for evidence can be found on LinkedIn.

Network	Description
UK Energy Research Centre (UKERC)	Academic research centre based at University College London
UK100	Local government leader network
BEAMA	UK trade association for manufacturers and providers of energy infrastructure technologies and systems.
BEAMA	UK trade association for manufacturers and providers of energy infrastructure technologies and systems.
Project ESO	Oxford-based PFER demonstrator
Project ESO	Oxford-based PFER demonstrator
Project LEO	Oxfordshire PFER demonstrator
Project LEO	Oxfordshire PFER demonstrator
Project LEO	Oxfordshire PFER demonstrator
Project LEO	Oxfordshire PFER demonstrator
ReFLEX Orkney	Orkney PFER demonstrator
ReFLEX Orkney	Orkney PFER demonstrator
West Sussex County Council	West Sussex demonstrator
British Electrotechnical and Allied Manufacturers' Association (BEAMA)	UK trade association for manufacturers and providers of energy infrastructure technologies and systems.
Energy UK	UK trade association for energy
Specific to Sprint 3: Heating and cooling	
Carbon Connect	Think tank
Carbon Trust	Carbon management and reduction
Centre for Sustainable Energy	Consumer conultancy
Centrica	Energy supplier
Citizens Advice	Statutory consumer advice body
Clean Heat Directorate	BEIS
Danish Board of DH	Trade
EASAC	European Academies Science Advisory Council
Energy Ireland	Energy forum
Energy Savings Trust	Not-for-profit
Engie	Energy utility
EuroHeatandPower	International network for district energy
National Energy Action	CEO
New Anglia Energy	Local energy markets company
Scottish Renewables	Trade
The Smart City Alliance	West-Midlands cross-sector network

Results and analysis

Stage 1: EPPI-Reviewer

Included documents were read and coded (assigned categories/tags) first in EPPI-Reviewer to extract high-level themes. The codeset used in this stage is consistent with that used in the previous two reviews in this landscape series (see Morris & Hardy, 2019; Morris et al, 2020), with some additional codes added for this topic. Tables 1a and 1b show cross-tabulations of the number of documents coded with heat-related technologies/vectors and cross-cutting issues, respectively. Line-by-line coding of the text was conducted; due to the limitations of the software, text was assigned only one code at this stage.

All coded text was exported from EPPI-Reviewer and subsequently imported into NVivo software.

Table 5a: Cross-tab showing the number of documents that were coded with heat-related technologies.

Code: Technologies	Count
Biogas	13
Biomass	15
Cooling	10
Electrification (not-pumps)	25
Energy efficiency	79
Fossil gas	29
Hest incentives	23
Heat networks	69
Heat pumps	39
Heat storage	10
Hydrogen	34
Solar thermal	4
Process heat	13
None of the codes above	18

Table 5b: Cross-tab showing the number of documents that were coded with wider cross-cutting issues

Code: Cross-cutting issues	Count
Assets / infrastructure	3
Behaviours	13
Benefits / issues	13
Business models	14
Consumer protection	23
Data	20
Definitions	25
EU	3
Flexibility	13
Government incentives	7
Industry codes	2
Innovation	12
Investment	8
Local authorities	16
Local energy	22
Markets	14
Planning	10
Resources	1
Roles & responsibilities	39
Security of system	2
Smart	23
Standards	12
Interoperability	2
None of the codes above	81

Stage 2: NVivo

For more thorough thematic analysis, line-by-line coding was subsequently conducted using NVivo, based on an inductive coding process. In this stage, text was assigned multiple codes. The codeset used in this stage was similar to that used in the previous stage, but differed slightly.

Figure 8 shows, schematically, the proportion of text assigned codes under the main themes of 'cross-cutting' (turquoise), 'technology/activity' (dark green), and 'region' (orange).

Further interrogation of the literature was performed in NVivo using matrix coding queries, for example to identify co-incident codes,

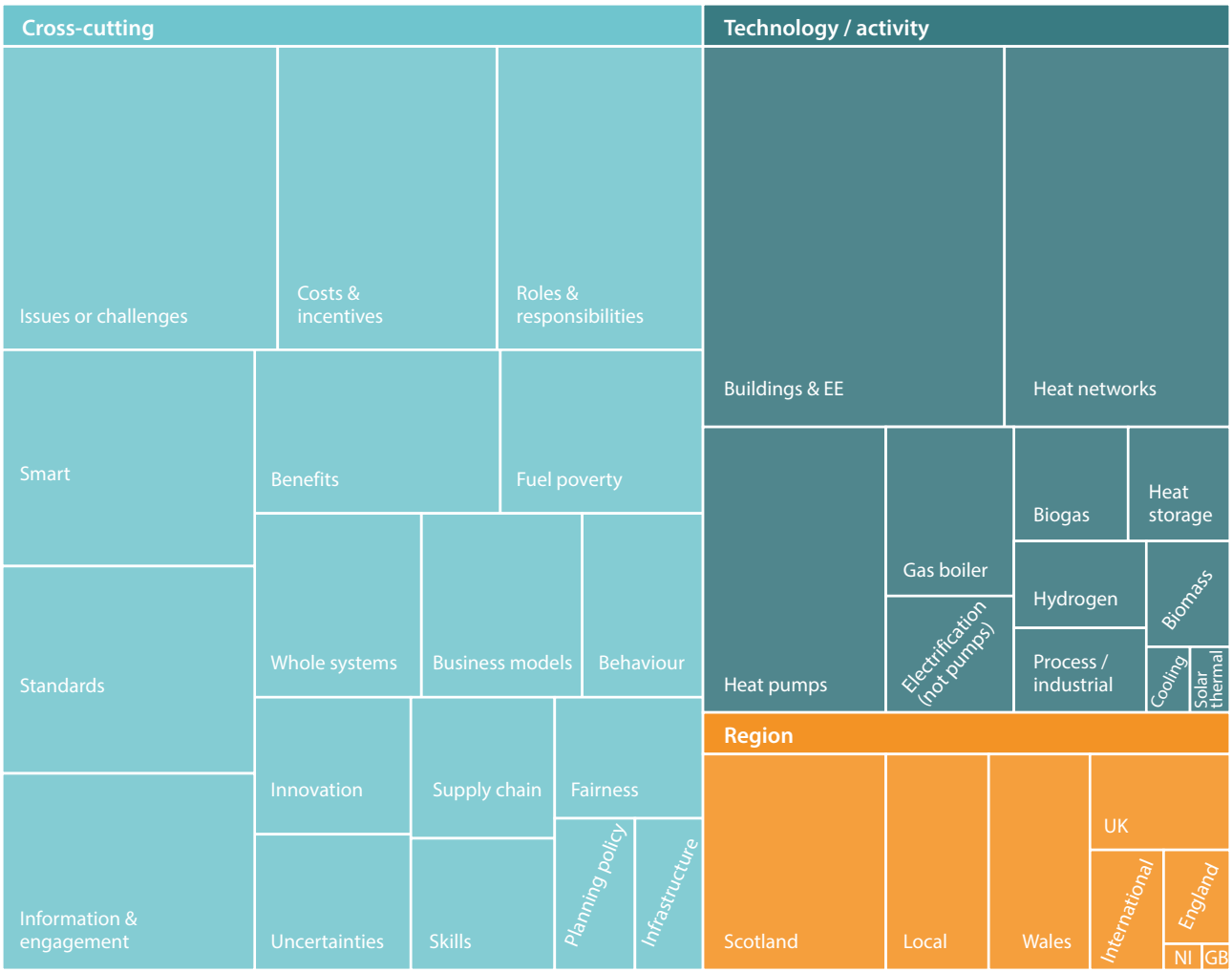


Figure 8: Treemap of code hierarchy. Rectangles are proportionate to the number of pieces of text assigned to a given code.

Stage 3: SLES prism mapping

Once all literature had been inductively coded using the coding structure outlined in the previous section, cross-cutting issues were mapped onto the six facets of the SLES prism according to relevance, as shown in Table 5.

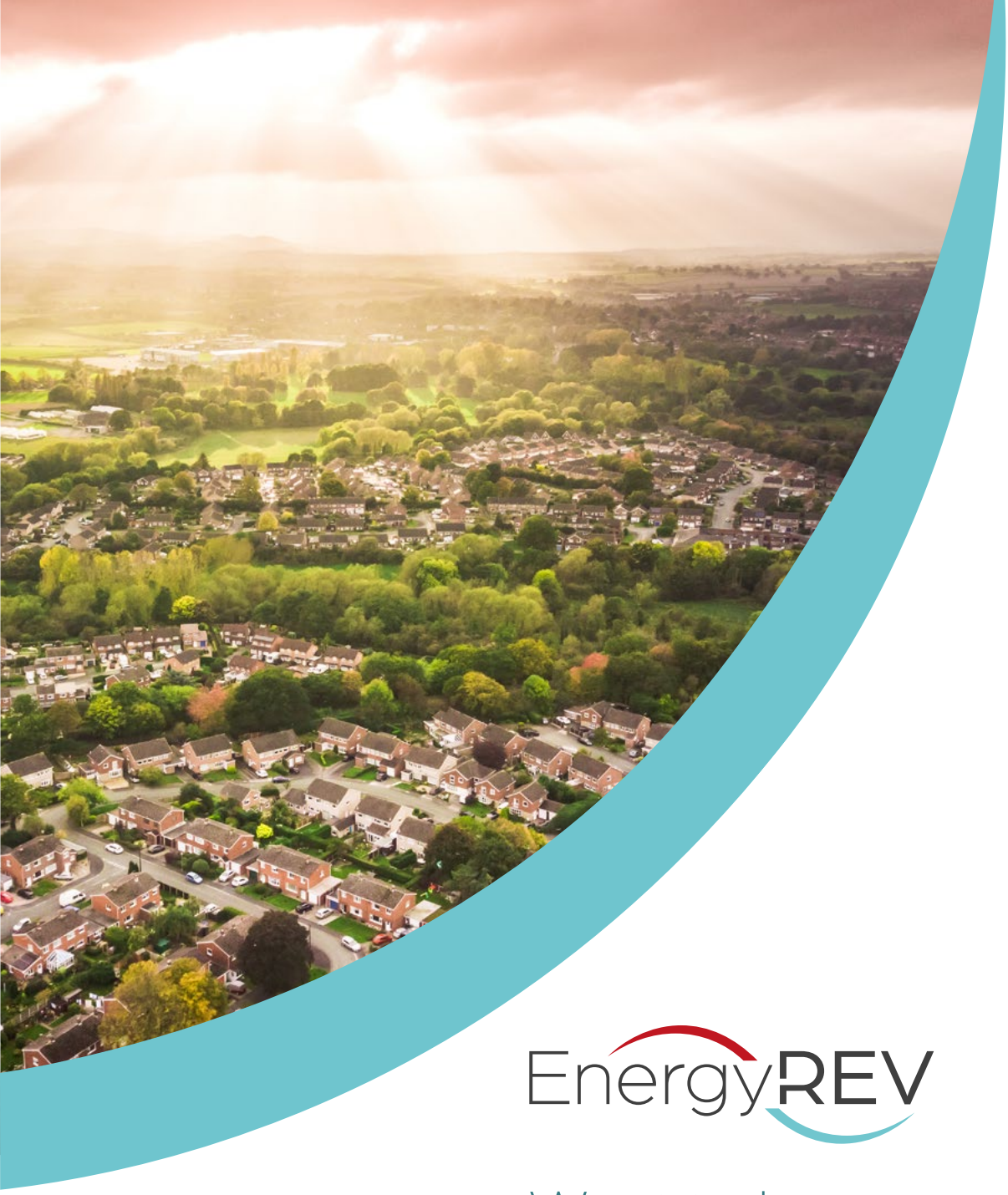
Evidence coded with cross-cutting issues were further coded in the context of the corresponding SLES prism facets, to identify instances where:

a. a smart and local approach could address a particular cross-cutting issue/aspect

b. a cross-cutting issue had inherently smart and/or local aspects

Table 6: Cross-cutting issues were mapped onto SLES prism facets. An 'X' indicates a co-incidence of the cross-cutting issue and SLES prism facet.

Cross-cutting issue	SLES prism						Exogenous
	Local Knowledge	Engagement & trust	Coordinated planning	Economic strategy	Unlocking co-benefits	Scaling up	
Issues or Challenges							
Roles & responsibilities	X	X					X
Smart							
Costs and Incentives							X
Standards							X
Information & engagement		X					
Benefits					X		
Fuel poverty				X	X		
Whole systems			X				
Business models	X			X			X
Behaviours							
Uncertainties							
Innovation							
Supply chain	X		X	X			
Skills	X						
Fairness					X		X
Planning policy			X				
Infrastructure				X			X



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About EnergyREV

EnergyREV was established in 2018 (December) under the UK's Industrial Strategy Challenge Fund Prospering from the Energy Revolution programme. It brings together a team of over 50 people across 22 UK universities to help drive forward research and innovation in Smart Local Energy Systems.

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