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UKERC Synthesis Report

Decarbonising Residential Heating

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Summary – Decarbonising Heat Synthesis Report

Heating our homes is important for our health and wellbeing, and while there is recognition of the need to stop using fossil fuels, many are happy with the current gas central heating systems. With only 5% of homes currently using clean heating systems, few people are aware of the alternatives and the benefits they could bring. Yet, over the next 25 years, most of the 29 million homes in the UK will need to switch to a new heating system.

Huge investment is needed in national and local energy infrastructure, along with developing the new skills to design and fit the new heating systems. Building new manufacturing capacity for the equipment presents an economic opportunity to replace the UK's world-leading boiler industry. But these decisions are dependent on which heating technologies are deployed and how quickly, and, in particular, the cost and constraints on retaining the gas network. The efficiency of heat pumps and heat networks means they have the potential to reduce energy demand and lower energy bills to consumers. This has wider impacts on the energy system and national energy security. In contrast, hydrogen is expected to increase overall energy demand.

How the transition is funded could have significant social and economic impacts. The upfront cost of some clean heating options raises concern, but public acceptance is likely to depend on fairness and ensuring that those who need it most are able to benefit. Many people feel that the energy companies and government should do more to support the transition. Providing grants to cover installation costs enables households to benefit from the lower running costs which in turn could put money back into the wider economy.

Different options require different approaches – a top-down market led approach does not work for all options. Capturing the benefits of heat networks, and possibly even hydrogen, will mean devolving powers to the local and regional authorities where significant decisions and interactions will need to be made.

Over the last five years, UKERC's independent analysis has delivered valuable insights into the diverse factors that need to be addressed in order to accelerate the decarbonisation of heat. This synthesis report brings together the findings.

Three clear and common conclusions emerge from across the work. They are closely interrelated and emphasise the need for a long-term coordinated approach that is in line with the scale and time constraints of the challenge and brings together the economic, social, technical and governance aspects.

- A long-term plan is crucial: it must be realistic about the timeframes and the scale of investment and financial support that will be needed.
  - Mobilise the investment in the energy infrastructure, technology manufacturing and skills that will be needed.
  - Lead the narrative – raise awareness of the importance of decarbonising heat and the options available.
  - Support mechanisms need to be realistic about the future costs of heat pumps and incorporate the public attitudes into the design of interventions.

- Realistic about the future of the gas network and the limitations and uncertainties of using hydrogen for domestic heating.
- Balance electricity and gas prices to ensure energy bills reflect the energy efficiency gains of using a heat pump.

- Provide a clear governance framework, which enables local and regional authorities to lead the transition.
  - Decarbonisation of heat is widely recognised as a local issue. Local authorities need to be empowered to engage with communities and businesses to facilitate the planning decisions and implementation.
  - Local authorities will need support to build the capability and capacity to undertake technical assessments to identify suitable options for the houses and communities.
  - Local energy infrastructure will require investment and upgrading. Energy companies will need to interact with local and regional energy authorities to facilitate planning and decision making.
  - Facilitate shared learning between the local authorities through consistent rules.
- Engage the public – the transition will require a large majority of households to make changes to their heating systems. Developing the transition around an understanding of what is important is likely to be important in ensuring public acceptance.
  - Raise awareness of the technologies and provide clarity about their potential, to ensure customers are adequately involved in the decision making.
  - Engage the public in decision making. This is important at a local level where local energy plans are being developed, particularly for heat networks.
  - Policy making and design of interventions should be based on an understanding of public attitudes.

The Challenge of Heat

A major theme for UKERC's Phase 4 programme was the transition to low carbon heat. Taking a multi-disciplinary approach, it addressed the issue from a number of research perspectives: the core technical and operational aspects; the economic impacts of transforming the heating industry; the implications for governance at a local and national level, including an international comparison; and understanding the response from the public.

The range of perspectives suggests that decarbonising heat presents unique and significant challenges compared to other transitions in the energy system. UKERC's independent research provides a robust evidence base to inform the bold policy decisions that need to be made. Achieving an efficient, low-cost heating future will see a range of solutions being deployed. As the findings illustrate, this will require a coordinated set of interventions and cannot be delivered solely through a top-down market approach.

During Phase 4 UKERC produced a wide variety of research regarding aspects of the heat transition. Each provides valuable evidence and insights that have been used by policymakers, national and local, industry and academia, to inform decisions and the wider debate.

This synthesis report draws out the key conclusions from the various perspectives: the need for a clear long-term plan, a governance framework that empowers local and regional decision-making, and, critically, engages the public and responds to their concerns. These three highly interdependent conclusions were common across all the strands of work and were dependent on a clear understanding of the technologies that will be needed. The report draws on an extensive literature review and supporting interviews. Each area of research presents important insights and findings about the transition to low carbon heat.

Heat in the UK

Decarbonising residential heat presents one of the biggest challenges for tackling the UK's carbon emissions.

Residential heating accounts for 17% of the UK's carbon emissions[1], with 85% of homes connected to the gas grid[2], accounting for 34% of annual gas demand (DESNZ, 2024a). Every year 1.6-1.7 million new gas boilers are sold[3]. Low carbon heating systems currently account for only 5% of total heating demand[4]. The UK also has some of the least energy efficient housing stock in northern Europe.

Most of the UK's 29 million households will be affected by the transition over the next 25 years. Yet, as UKERC's work shows, people generally regard tackling how they heat their homes as a lower priority than transport and recycling[5]. While support for addressing environmental concerns appears to be strong, making the switch to a clean heating system in their home raises a range of concerns. Understanding these concerns are important for developing interventions.

Decarbonising residential heating will lead to a complete shift in the technology being used and the infrastructure needed to supply the energy. A mix of technologies is expected to be deployed, the majority of which are expected to be either electric heat pumps or local heat networks[6]. Disconnecting these consumers from the gas grid and switching them onto either the electricity supply system or a local heat network will require investment in the energy infrastructure and management of the declining demand for gas. Furthermore, the

shift in energy demand will change how the energy networks operate, with potentially big variations between summer and winter.

Very different approaches and policies are needed to support the deployment of heat pumps and heat networks. While heat pumps can be incentivised through top-down market interventions, heat networks require a decentralised approach with decisions and planning made locally, drawing on local knowledge and engaging with communities to raise awareness and develop solutions that are suitable for the specific area[7].

New skills and expertise will be needed across the industry, to manufacture, design and install the new technologies in nearly every home and building.

Mixed progress

Progress is mixed across the nations of the UK, but the pace of change overall lags behind the scale and urgency of what is needed to meet decarbonisation targets. National support mechanisms are fragmented and too short term, and investment risks being disrupted and delayed due to ongoing uncertainty about the use of hydrogen in the gas network[8]. In 2021, the Heat and Building Strategy set a target of installing 600,000 heat pumps per year by 2028; by 2022 only 54,000 heat pumps had been installed[9]. To meet the climate targets, the Climate Change Committee recommended the rate will need to reach 1.9 million per year by 2035[10]. Heat networks, which are more complex to deploy, might supply up to 19% of heat energy, but currently deliver 3%, having risen from 2% in 2015[11]. Furthermore, the delay in banning new build houses from connecting to the gas grid, from 2016 to 2025[12], means that these properties will have to be retrofitted in the future.

Imposing a ban presents a clear opportunity to illustrate the direction of travel for the future of heating, and energy use more widely, whilst also creating a market for the new technologies. Scotland introduced the ban in April 2024[13].

More progress has been made in the devolved nations, particularly Scotland, where the Heat in Buildings Strategy 2021 sets out approaches for public engagement, along with a requirement for local authorities to develop Local Heat and Energy Efficiency Strategies by 2023[14]. However, their progress is constrained by UK-wide policies that are decided by central government, including balancing gas and electricity prices, and making a decision about the future of the gas network[15].

Efforts across England are more fragmented and inconsistent as there is a lack of clarity about delivery and the role of local and regional authorities[16]. Progress has been made more recently including the Energy Act 2023, which brought regulation of heat networks into Ofgem and made provision to implement heat network zoning in England[17]. Regional whole system planning across electricity, gas and heat networks, including working with local authorities, was given a boost with Ofgem introducing the new Regional Energy Strategic Planners (RESPs)[18].

The UK can learn from the progress being made in the Netherlands. With 90% of households connected to the gas grid it ranked just above the UK as having the highest gas dependency for heating across Europe and the OECD. However, it has put in place targets for decarbonising heating and implemented a governance framework focussed on local and regional authorities[19]. Since banning new build from connecting to the gas grid in 2018, 70% of new homes have heat pumps installed, boosting the market and allowing the sector to scale up and develop the necessary skills and supply chains[20].

Box 1: Heating options

Two heating systems are expected to meet a majority of the demand, but they require very different incentives and interventions.

Heat pumps are expected to make up a large proportion of the low carbon heating systems installed, replacing gas boilers. Heat pumps provide individual heating solutions and can replace a gas boiler, whereas heat networks deliver an area-based or whole building solution. Heat pumps are highly energy efficient compared to a gas or hydrogen boiler, using roughly one-third of the energy to deliver the same heating[21]. In addition to reducing the overall energy needed for heating, heat pumps have the potential to cut energy bills. However, as discussed above, this is dependent on the relative price of gas to electricity. The recent high energy prices have meant that electricity has been close to five times the price of gas, making the running costs of heat pumps higher than gas boilers. Reforms to gas and electricity prices will be critical in delivering lower energy bills to consumers.

Heat networks work best with higher density of heat demand. Heat zoning arrangements in development in Scotland and England (and under consideration in Wales) will indicate areas of greatest potential. Plans for these areas will need to engage with local residents so they are aware of the benefits and to resolve any concerns.

Alongside changing the heating systems, improvements will be needed to the energy efficiency of many homes to ensure they benefit from improved comfort and lower energy bills[22]. Upgrades to the building fabric could be delivered when the heating system is installed, but this will depend on the advisors and the funding available.

The Need for a Long-Term Perspective

A common message from across the UKERC outputs is that addressing heat requires setting out a long-term plan that fits with the scale and urgency of the challenge and is based on what we know about the technical, economic, financial and social aspects of the transformation. Investment is needed in local and national energy infrastructure and to develop the supply chains to build the technologies. A new skills base is needed that can deliver high quality installations, which deliver the performance improvements, and are deployed at a scale that will ensure installation targets are achieved.

Stimulating these needs clarity and assurance of funding and the economics of energy supply. UKERC's analysis highlights the economic opportunities from building a domestic manufacturing capacity, whilst providing a realistic assessment of the technology costs[23]. It emphasises the need to press ahead with ensuring rapid deployment of deploying technologies that are known to work, such as heat pumps and heat networks, and avoid letting these be delayed by the uncertainties of hydrogen and the future of the gas system[24].

An essential part of the long-term plan is to raise awareness of the need to decarbonise heat.

While the public are supportive of moving away from fossil fuels, the priority people give to addressing heat does not match its significance in terms of its importance to decarbonisation[25]. Knowledge of the technology options is low among the public and the heat installation sector alike.

Decarbonising heat is politically challenging, made more complex by the current high energy prices. Future heating options have the potential to reduce energy bills, improve energy security and decarbonise heating, but it requires a long-term multi-disciplinary plan[26].

Investment in infrastructure and the supply chain

Over the next 25 years, low carbon heating will shift from being primarily gas-based to a majority using electricity to power heat pumps. Investment will be needed in local energy infrastructure and consequently on the national energy supply systems. Decarbonisation of heat is highly dependent on public policy decisions, which in turn has a strong influence on investments in national energy infrastructure. Uncertainty in the public policy decisions for decarbonising heat will affect the cost of investment in renewable generation and the wider energy system[27].

In addition to changes in the energy networks to each household, there will be a shift in the equipment used. A huge opportunity exists to build manufacturing capacity within the UK for the technologies that will be needed for the transition. Currently 75% of gas boilers installed are manufactured in the UK[28]. It is unclear whether manufacturing companies will switch this capacity to the new heat technologies. Heat pumps are a globally mature technology and could easily be imported to meet the growing demand. Analysis by UKERC indicates that investing in heat pump manufacturing capability, and their ancillary components, will be a critical factor in the cost of the transition, bringing benefits to national and regional GDP[29]. Furthermore, building domestic capability enables heat pumps to be better tailored to the market, and is important in developing skills within the sector.

Investment will also be needed in the construction industry to build the capacity for retrofitting buildings. UKERC research found that the construction sector was not keeping up with the energy sector in terms of being prepared for the energy transition[30].

Transitioning to new heating technologies will require building up the skills, capability and capacity to meet demand, but in a way

that will ensure confidence and trust in the new systems. Attention is also needed to how to transition the existing work force and industries to ensure that the economic benefits are realised in an equitable manner.

An area of uncertainty that is affecting investment is the possible role of hydrogen for decarbonising heat. While the potential of heat pumps and heat networks is largely understood, trials are underway to determine the safety and suitability of hydrogen. A decision as to whether hydrogen will be considered a viable option is not expected until 2026. However, these trials have either been scrapped or delayed due to public mistrust of the process and the companies involved and concerns about safety raised by the participants[31].

Even if hydrogen was permitted in 2026 uncertainties remain about the price of the hydrogen supplied to customers, and the capital cost of repurposing the gas network: it may be some time before there is a clear understanding of the potential scale of hydrogen deployment (see Box 2: Hydrogen)[32].

In the meantime, it creates uncertainty for the deployment of other options, at a time when the scale and urgency of the challenge requires clear decisions. UKERC's work highlights the need for efforts to focus on deploying known and cost-effective technologies, such as heat pumps and heat networks[33].

UKERC has also identified concerns that hydrogen is being promoted by the incumbent gas providers, to support repurposing the gas grid[34]. Surveys indicate that this is undermining the trust of the public, as it conflicts with the narrative of reducing fossil fuel use[35].

Box 2: Hydrogen

Hydrogen has risen up the agenda as an option for residential heating, but it has become increasingly controversial.

Analysis of the role of hydrogen in residential heating highlights that much of the supply of hydrogen is likely to come from natural gas. Inherent inefficiencies of producing blue hydrogen, extracted from natural gas along with the cost of disposing of the carbon dioxide produced, means that household energy bills for heating will rise, as the unit cost of hydrogen supplied to homes will have to increase relative to natural gas. While the capital cost of boiler installation may be lower, the ongoing costs are, as yet, uncertain.

More broadly, hydrogen will also have wider impacts on where the primary energy comes from, and the infrastructure investment required to support it. Furthermore, the continued use of gas will affect the UK's energy security. Producing green hydrogen, from renewable electricity, offers some system benefits. However, the inefficiencies in the production process mean that each unit of heat provided in a home using hydrogen will use several times more electricity compared to using a heat pump; with consequential increase in residential energy bills.

Trials proposed to demonstrate hydrogen heating technologies in small communities have either been scrapped altogether or delayed due to disagreements about what safety measures were needed. While some members of the communities reportedly welcomed being part of the trial others felt like 'lab rats' for the new technology when known safe alternatives were available[36].

Invest in skills

Investing in skills is critical to ensure the capability to design and install the new technologies and the capacity to meet the scale of demand that is needed. Investment in skills for installation and improving the energy efficiency of the housing stock will create jobs across the UK for several decades. Analysis indicates that the sector could create the most jobs per unit of investment[37].

Training and apprenticeships will be needed to develop the specialist skills and knowledge associated with low-carbon heating technologies. The current capacity building is far behind the required scale to meet the anticipated demand. Investment in skills needs to anticipate demand, but investment in retraining for heat pump installations is being held back by the weak demand from customers and uncertainty about the future of the gas network and the potential role of hydrogen: evidence shows that hydrogen heating has been actively promoted to engineers in the sector[38].

A lack of awareness and detailed knowledge amongst the current heating installation sector means that they are unable to provide advice and options to the public about the low carbon alternatives. Switching is therefore restricted to those customers who have the time and resource to research alternatives and find the opportunities for support funding[39]. Customers faced with changing their system are therefore unlikely to be presented with alternative to a replacement gas boiler. Where heat networks might become an option, or even hydrogen might be offered, a customer should be able to expect a heating services company to be able to provide insights into the full range of options. Such local knowledge will be an important part of local area planning (see section below).

A skilled workforce is vital to ensure that quality of the installation and its operation meets the advice and expectations given to the customer. Ensuring that the system delivers factors such as improved thermal comfort and lower energy bills will depend on the system design and on the advice given to customers on how to operate the system. Meeting expectations is vital for building trust in the low carbon heat transition. It is important to note that the advice given should recognise that delivering lower energy bills is highly dependent on the relative prices of electricity and gas (see below), to avoid negative stories perpetuating in the media.

Standards for installations and certification of expertise will be an important part of building trust. Interviews with the public highlighted that customers want reassurance that the installation they have chosen will not become outdated or expensive[40].

Pricing of gas and electricity

A significant factor affecting the ability to deliver cost savings when switching from a gas heating system to an electric heat pump is the relative prices of gas to electricity.

Heat pumps could reduce the energy consumed to heat a home by up to 40%, as the technology is about three times more energy efficient than a gas boiler[41]. However, the price of electricity is considerably higher than gas, and the variability between the two means that switching to a heat pump may not lead to substantially lower energy bills. Electricity prices are largely determined by the cost of generation from gas. Recent high gas prices have pushed up electricity prices to 5 times more expensive than gas, making heat pumps more expensive to run, and therefore less attractive[42]. Analysis by UKERC indicates that heat pumps are cheaper to run if the price differential for gas to electricity is below 1:3.59 (see Figure 1)[43].

Reviewing the market mechanisms and policy interventions that determine the price of electricity will be an important determinant of the attractiveness of heat pumps. Furthermore, modelling showed that as electricity prices

are lowered the financial savings from running a heat pump could be spent on other goods and services, bringing wider benefits to the economy[44].

Future heating options offer the potential to reduce overall energy demand of the home. Not only could this mean lower energy bills for consumers, but switching to electricity will reduce dependency on gas imports and improve national energy security. Reductions in energy in overall energy demand can be enhanced by upgrading the building fabric, to reduce heat loss. This will also have direct benefits to the household, through reduced bills and comfort.

It is worth noting that if hydrogen is approved for heating in homes there is uncertainty about its unit price as it will be produced from neither electricity or natural gas. Efficiency losses in these processes will make the unit of hydrogen energy more expensive than the initial fuel. If natural gas is used the hydrogen could be a third more expensive. Although, if a sufficiently high carbon price is applied to the natural gas, and abatement technologies are used to lower the carbon emissions, then the hydrogen produced could be cheaper than the initial fuel[45]. Defining the cost of hydrogen produced from electricity is more complex as the costs and unit price electricity vary greatly. By contrast, heat pumps use the electricity directly and their high efficiency makes this much cheaper than converting the electricity to hydrogen.

Financing

Heat pumps are expected to be the primary means for decarbonising residential heating systems[46]. However, installing heat pumps can be four times more expensive than a gas boiler, because of the cost of the equipment and additional labour[47]. Cost may come down, as more heat pumps are fitted, but a review undertaken by UKERC, indicates that this is unlikely to be as low as the ambitions set by policymakers (see Text Box)[48]. In some properties additional work may be required to improve the performance of the heat pump. While this may reduce the running cost, it will raise the capital cost of the conversion.

How the higher installation costs are funded has a significant bearing on the economic impact of the transition. Modelling by UKERC suggests that providing grants is the most effective funding option (see Figure 2). If households are expected to pay the full cost, it will reduce household budgets, which will suppress national GDP up to 2050, as they have less money available to spend on other activities. Offering interest-free 10-year loans has a similar impact as the household paying, but takes longer to recover[49].

Figure 1. Impact of different GB energy market conditions on the electricity to gas retail price difference ratio (source Corbett et al., 2023)

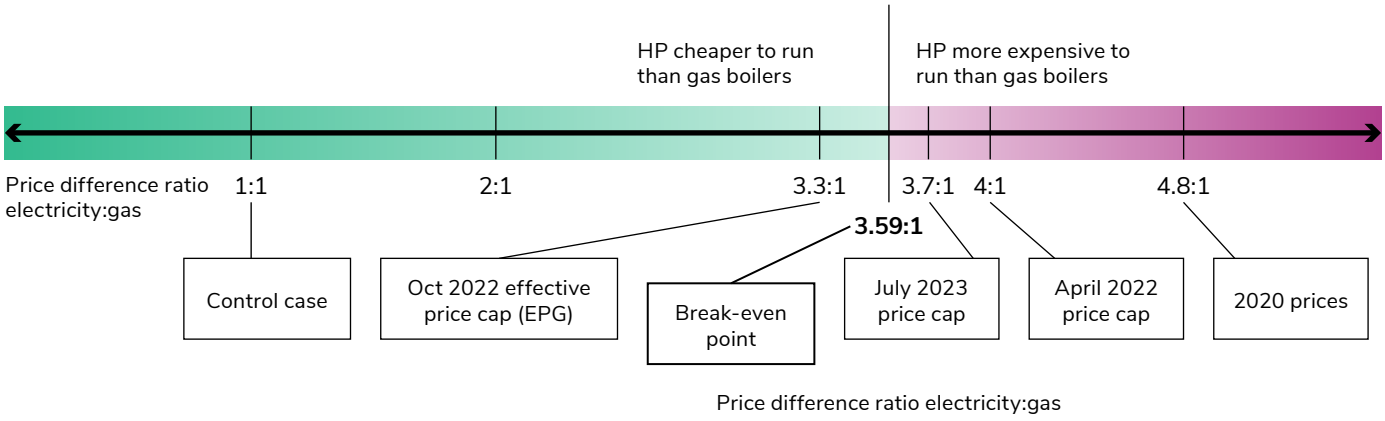
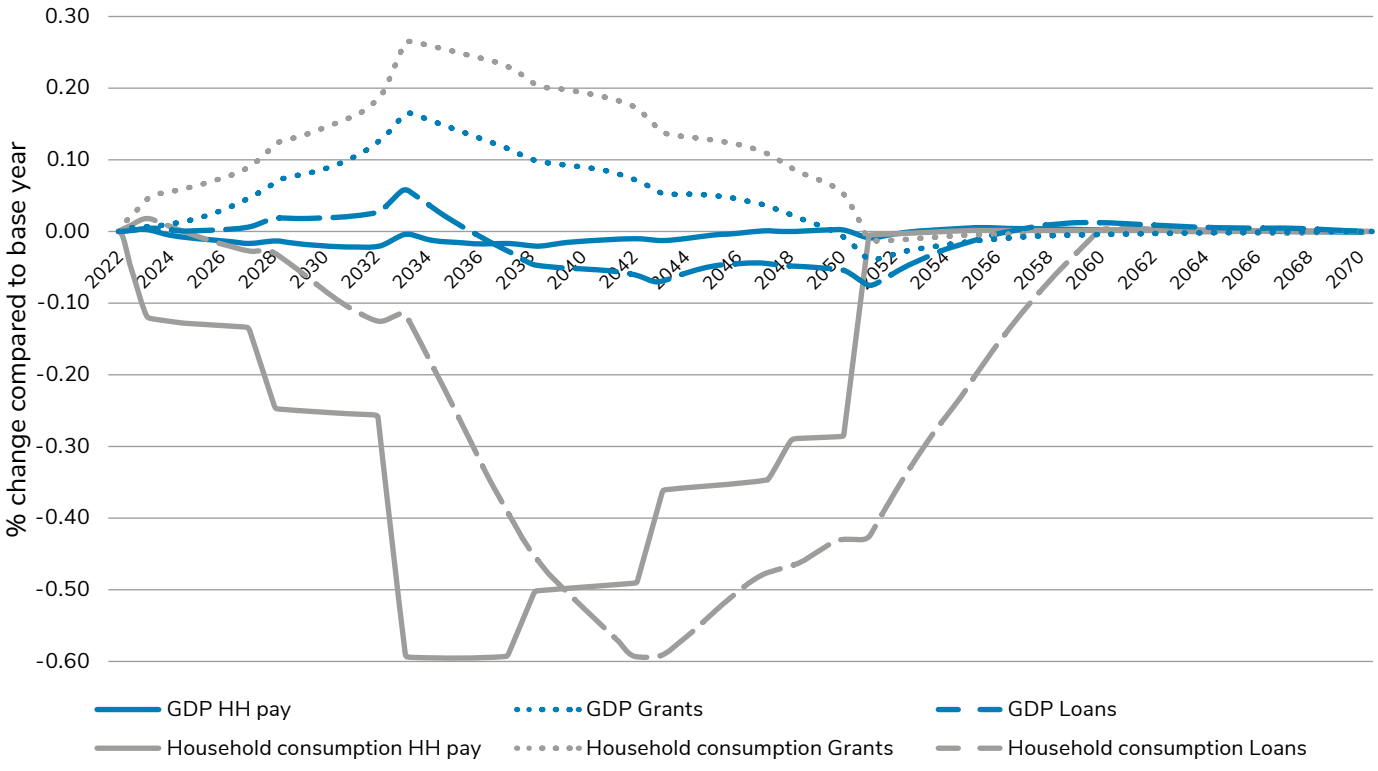


Figure 2. Impact on UK GDP and household consumption of non-heat pump goods and services due to manufacturing and installation of heat pumps. 'HH pay' = Household pays full upfront cost. 'Grants' = costs covered by grant. 'Loans' paid for by zero-interest 10-year loan. (source Katris, 2023)



Switching to other clean options, such as a heat network, biogas or hydrogen, are likely to have higher initial capital cost than fitting a replacement gas boiler. Hydrogen, for example, may require a new hob and oven and possibly replacement of the internal gas pipes.

Historical experience suggests that a transformation of this scale is unlikely to succeed without concerted action and significant government involvement. The current approach relies heavily on consumer choice, which contrasts with the switch to natural gas from coal-gas in the 1960-70s, which was government-led. The higher capital cost means many people will be unable to afford the new technologies or energy efficiency measures, without financial support. Long-term funding schemes, led by government, will be critical.

The need for increased government involvement was echoed by research into public perceptions. Greater responsibility was assigned to the government and energy companies to pay for the transition as it was felt they were not contributing to costs sufficiently[50].

How the costs of decarbonising heat are distributed is likely to be a key aspect of public acceptance. Policies to support deployment of future heating options should ensure that different groups or communities are not disproportionally disadvantaged by the transition. Interventions also need to be tailored so that most people can take advantage of the potential improved thermal comfort and reduced bills[51].

Box 3: Heat pump installation costs

While heat pumps are expected to deliver lower running costs, installation can be four times more expensive than a gas boiler. Initial installations are complex requiring additional skills to assess the property and design the system, along with electrical and plumbing skills for the fitting.

In 2012, the Heat and Buildings Strategy set an ambition to reduce the cost of heat pumps by 25-30% by 2025, and to be no more expensive to buy and run than gas boilers by 2030[52]. This was based on experience in other sectors of the energy transition, such as solar, where a growing market has led to cost reductions.

Analysis by UKERC of the growing international heat pump market, over recent decades, concluded that it is unclear whether large cost reductions could be achieved[53]. Experience in other countries suggests that savings of 20-25% could be achieved by 2030, mainly from learning and competition in the installation market, as heat pumps are a mature technology.

Cost parity with gas installations could be achieved but is likely to require a combination of targeted funding schemes, grants and emerging business models, which incorporate the reduced running costs. Octopus Energy are already marketing low-cost installations that incorporate the Government's Boiler Upgrade Scheme subsidy with their heat pump specific tariff[54].

Lead the narrative

Research into the public attitudes towards heat decarbonisation indicate that the public are supportive and understand the need to remove fossil fuels, but it is not regarded as very high on people's priorities[55]. Not only are the new technologies unfamiliar, but the benefits of changing are not perceived as immediately obvious[56]. This is in part due to the high satisfaction levels with the current gas boilers[57].

Given the receptiveness of the public to the potential environmental benefits, raising awareness should include highlighting the other potential benefits associated with low carbon heating options, such as improved thermal comfort and possible improved health through the reduction of damp and mould in homes[58]. However, Lowes and Woodman found that policymakers themselves perceive little benefit in heat decarbonisation and often view it as disruptive and uncertain[59]. This lack of awareness of cross-policy opportunities is, by itself, likely to be a barrier to effective communication about potential benefits of the transition.

Up until now, policymakers have relied heavily on consumer choice to deliver the transition, but this is precarious as it is dependent on awareness and knowledge of the options and the ability of the customer to be able to undertake the necessary works[60]. Current demand for heat pumps is mainly from those who have the resources to access the information and advice and can afford the disruption and additional costs. However, they are unlikely to be those who would benefit the most from the lower running costs and wider benefits.

New build housing presents a clear opportunity to illustrate the direction of travel for the future of heating and energy use more widely. Currently new build properties in the UK are not expected to be required to be off the gas grid until 2025, which does not send a confident signal about the urgency to address the low carbon heat transition[61].

Raising awareness is therefore a vital part of a long-term plan, but it needs to be integrated with a clear vision of the future costs and disruption. Communications and policies must therefore seek to address the attitudes and concerns highlighted by the public engagement work including that undertaken by UKERC.

The Need for Multi-Level Governance

While setting out a long-term perspective will be valuable to stimulate investment in the sector and skills, the decisions that affect delivery are recognised as being fundamentally local, and will be made across a range of levels of government. The overarching UK approach has remained largely centralised, focussed on supporting the market approach. Greater decentralisation of governance is likely to be needed particularly to support the proposed growth in heat networks[62].

In 2012 the Government recognised in its Strategic Framework for the Future of Heating that the transition was not just a national transformation to be led by central government, but "*also a local one*"[63]. Local and regional governments are widely recognised as playing a central role in delivery of energy efficiency in buildings and supporting planning and delivery of heat networks and the wider concept of local energy systems. The latter offers the potential to integrate the various energy systems in the area or region to realise opportunities to improve their efficiency and manage their operation. Local governments are also able to integrate and prioritise other policy agendas including fuel poverty, housing, health and jobs[64]. Some of these agendas might promote an energy efficiency approach over converting the heating system.

It is clear from the studies undertaken that within this multi-level governance approach there needs to be a clear mandated role for local governments and other local actors, to enable the planning needed for investment in the necessary networks and wider infrastructure[65].

Coordinate local and national delivery

Heat pump systems are projected to deliver about 75% of the heating conversions in the UK. A further 19% of properties could be connected to an area-based heat network (see Box 4)[66]. A key question is how the policy frameworks to support these will fit together, as the approaches to promote the deployment are distinctly different. The market-based approach for heat pumps risks undermining the efficiency of a planned area-based network. Identifying heat zones where the energy will be supplied through networks risks undermining the concept of consumer choice.

Decarbonising heat is happening at the same time as the electrification of transport and increasing decentralisation of generation. The impact on local energy networks has led to the concept of Local Energy Systems where heat, power and storage are integrated to balance supply and demand[67].

Effective, viable solutions for clean heat systems vary across localities, and there is an acknowledged need for local government to have a planning and enabling role.

Strengthen governance structures

While there is a lot of activity and experimentation in heat and energy planning in the UK, there is no overall formal framework for the role of local actors, especially in England and Wales[68]. Both the Climate Change Committee and the National Audit Office, amongst others, have called for a

direct mandate for English local authorities in planning and delivering net zero[69]. UKERC's work has explored the institutional structures and capability that such a framework would need to provide.

Powers over local government are devolved to the Scottish and Welsh parliaments, with UK government responsible for only English local authorities. In Scotland, statutory Local Heat and Energy Efficiency Strategies are in progress for all 32 local authorities, with delivery plans for the first five years under consultation[70]. In principle, these set out a solution for every building, including zoning for heat networks[71]. In Wales, the Welsh Government has supported the development of Local Area Energy Plans (LAEPs) for all 22 local authorities, which will be integrated into regional plans and inform a national Energy Plan for Wales[72].

However, there is no consistent policy framework or regulatory strategy to support its development across Great Britain, with the devolved governments appearing to adopt differing policy approaches[73], and Scotland and Wales placing more emphasis on demand-side changes[74]. Wales and Scotland place stronger emphasis on heat, community energy and social objectives in their approaches to Local Energy Systems, partly as these are areas where they have formal powers to influence activity.

In England, numerous local and combined authorities have prepared Local Area Energy Plans (LAEP) and are increasingly involved

through their likely role as Heat Network Zoning Coordinators and as key stakeholders in RESP developments[75].

Considerable learning is being generated from projects such as the public-private partnership approach of the Bristol City Leap. However, there is as yet no common framework for local energy planning, with the Energy Systems Catapult warning this could lead to "*a lack of consistency, coordination, and risk of duplicative cost*"[76].

Strategic planning is needed to develop local energy systems, but it is being thwarted by regulatory uncertainty and fragmented funding landscape[77].

Opportunities to improve cross-sector coordination are emerging through the development of the Regional Energy Strategic Planner (RESP) and the evolution of the approach to heat network zoning, bringing together the interests of both national and local government, and market-based incentives for renewable heat[78].

In addition to developing local energy systems, regional and local administrations have an interest in the opportunity for new manufacturing capacity to deliver the new technologies. These will deliver jobs and will require training programmes, for the industry and for the deployment skills to design and install the equipment[79].

Box 4: Heat networks

Heat networks provide a collective solution, linking local heat sources to consumers. Most of the proposed 19% of homes connected to a network are expected to be in towns and cities where there is a higher density of demand[80].

Innovation is improving efficiency and enabling a wider range of heat sources that can be used[81]. The latest fourth-generation heat network greatly lowers the temperature in the pipes. With lower energy losses it is more efficient and needs less insulation on pipes, which lowers costs and simplifies installation[82]. A simple heat pump raises the temperature and transfers it into the property: the higher input temperature from the network makes it more efficient than a stand-alone air-source heat pump.

Providing demand-side flexibility to the local and national electricity system is a potentially important benefit of heat pumps. Modelling by UKERC indicates that heat pumps on fourth generation heat networks have the potential to provide far greater services to the electricity grid network than stand-alone heat pumps, and with very little loss of heating service to the consumer[83]. Collectively managing electricity demand could be a valuable consideration in the design of Local Energy Systems.

Integrating large-scale thermal storage into a heat network could improve the system performance and increase the options for capturing heat. UKERC analysis indicates that boreholes offer potentially much larger heat and cooling storage capacity and lower costs than other options[84]. The UK lags behind other countries in using borehole storage, but it should be considered an integral part of most heat networks.

Being able to use a wider range of heat sources will be important. Increasing regulatory scrutiny of conventional high temperature sources such as power generation or waste incinerators, raises doubts about whether they can be classified as zero carbon. Local authority heat network projects looking to use heat from a waste incineration plant, such as Bristol City Leap, will have to look at contingency plans for any long-term contracts with heat suppliers[85].

Local Energy Systems

Analysis of what is needed to deliver Local Energy Systems (LES) noted that the potential benefits are widely acknowledged and could deliver better outcomes than top-down planning, understand local challenges and benefits, and have the potential to coordinate actors, and plan across vectors[86]. Local powers would allow authorities to integrate the heat transition with other local priorities such as fuel poverty, jobs and housing quality[87].

However, UKERC's analysis goes on to highlight that the institutional frameworks to support development of Local Energy Systems are fragmented and underdeveloped[88].

Scotland and Wales have made more progress towards developing Local Energy Systems, but they are constrained as it will require changes to the electricity regulation and markets. These are centrally managed through the UK Parliament, which has been slow to implement the relevant changes.

This highlights the need to establish a working consensus between the UK Government and the devolved administrations on heat policy.

With decisions yet to be made about changes to the energy market licensing, taxation and regulation relating to heat in buildings, including the future of the natural gas grid, the administrations risk making decisions that could be rendered redundant. In the meantime, Ofgem's proposed Regional Energy Strategic Planners (RESP) will be an important intermediary for Scottish Government to ensure the effectiveness of a Heat in Buildings Bill and legislation[89].

Clarity is also needed about the roles of electricity network operators (DNOs) and the heat network companies and the powers of the local authorities that will have to interact with them on planning issues. This will also include the future of local gas networks. Planning in the local areas is further complicated as the local and regional governance boundaries often do not coincide with those of the network operators[90]. Network companies may end up interacting with more than one local authority. Any governance framework for devolving powers should therefore seek a consistent approach to planning whilst allowing flexibility to address local needs. This will also facilitate shared learning,

Local capability and capacity

Whilst decentralising governance and putting greater emphasis on local and regional governance will be important the new framework needs to include support for local authorities to ensure they have the capacity and capability to deliver on national net-zero targets[91]. This needs to go beyond competitively allocated funding as it is essential to build the new capabilities that will be required. These roles need to be underpinned by technical support, and systems that encourage knowledge-sharing and mutual learning.

Underlying the capacity building is the need for shared learning and openly available data and insights into the demand heating and how and where energy is used. UKERC's Energy Data Centre[i] provides a central access point for publicly funded energy research in the UK. The resource covers a wide range of aspects that are of importance to planning local energy systems and the interventions that are needed. Data sets include spatio-temporal heat demand profiles across England and Wales, and Scotland[92]. Additional data includes surveys of energy efficiency performance of buildings, postcode level detail of homes on the gas grid[93], detailed analysis of how energy is used in homes[94] and modelling of the potential for new heating technologies to help balance the electricity system[95].

Along with building the technical capacity needed to plan and design local energy systems and interventions, there is a need to build capability in the implementation, with an emphasis on engaging the public (see next Section). The Dutch government established a central body to share knowledge and learning, both on the technical aspects and citizen engagement (see Box 5). Similar to the Energy Data Centre, UKERC's Public Engagement Observatory[ii] seeks to map and share learning about engagement strategies.

i To explore the Energy Data Centre, access here.

ii To find out more about UKERC's Public Engagement Observatory, access here.

Box 5: Shared learning - International comparison with the Netherlands

The Netherlands has the highest dependence on gas for residential heating of any European and OECD country, which had 90% of homes connected to the gas network[96]. The UK is second with 85%[97]. UKERC undertook a comparative study to explore the potential for shared learning.

Many of the issues raised in the UK have already been explored by the Dutch government, and progress towards decarbonisation is moving faster. In Scotland, progress has some comparisons to the Dutch approach, while lessons could be learnt elsewhere, particularly in England[98].

Emphasis on local authorities

The Dutch government approved the Climate Agreement in 2019, setting out a clear plan for decarbonising heat[99]. In addition to clear targets for the rate of decarbonisation, a crucial element has been the multi-level governance framework, which gave a clear role for local government[100]. Local authorities – municipalities – were given the lead role in defining local heat decarbonisation plans, along with key responsibility for planning and implementing the heat transitions[101]. Each municipality developed detailed action plans, which set out how many homes could be switched to sustainable heating by 2030, along with a timetable and an indication of which technologies would be most cost-effective in each area of the authority.

Capability support

In addition to devolving powers to local government, the governance framework included a programme of support. Technical support for assessing the options is provided by a designated central body, the Heat Expertise Centre (HEC), which gives guidance on how to: include local data in the assessment model; develop heat transition visions; interface with network operators; and assess the technical and commercial feasibility of heat networks.

A pilot programme was also created for establishing gas-free districts, called Programma Aardgasvrije Wijken (PAW). PAW facilitates a learning-by-doing approach, with a strong emphasis on sharing the knowledge gained through a national Knowledge and Learning Programme. The pilots are aimed at trialling citizen engagement strategies, identifying opportunities for cost reduction, and analysing the role of existing laws and regulations.

Initial funding of €2.6 billion was committed by the Dutch government to support local and provincial planning and implementation between 2022 and 2026. In 2023 this was extended to 2030 with an additional €5.38 billion[102].

The outcome of the Climate Agreement has been that the heat pump market for individual dwellings has grown rapidly. The expansion of heat networks has been held back by a wait for new legislation.

Shared challenges

Like the UK, energy planning boundaries do not align with administrative and political ones creating tensions, particularly between municipalities and the regional level. Both countries could learn from each other.

Engage the Public

A core finding from across the UKERC work on heat is the importance of understanding the human perspective and the value it could bring to the development of policy and interventions, at all levels of government. The research shows that current policy decisions are not always aligned with nuanced perspectives that emerge from engagement with households[103].

Public engagement studies indicate that the public's perceptions and acceptance of the low carbon heating transition cannot be assumed. While the research showed that there is general approval for decarbonising heat and moving away from fossil fuels, acceptance of new heating systems will depend on how well solutions are tailored to local and household circumstances. Furthermore, when presented with the possibility of converting their heating, they are looking for assurance that installing a particular heating option will bring benefits and was the right thing to do[104]. Concerns were also raised about the disruption and costs. This indicates that any awareness raising needs to be set within a comprehensive approach to policy and governance. At the local and household level engagement can bring valuable insights to inform planning and improve outcomes, if done well.

The approach to public engagement varies across the UK nations. In 2021, the Scottish Heat in Buildings Strategy established an engagement programme, which will be led by a new agency, Heat and Energy Efficiency Scotland. A strategic framework followed in late 2023, aimed at coordinating engagement for energy efficiency and clean heat and raising awareness of the benefits[105].

By contrast, England and Wales have no formal mechanisms for developing public engagement on the heat transition. This reflects on the more technocratic and centralised approach of the UK government, despite recognising the importance of a more local approach in the 2012 heat strategy. This contrasts with the consensus-building approach adopted by the Netherlands (see Box 5)[106].

Communicate

While there may be general support to move away from fossil fuels, UKERC's research shows that awareness of the need to decarbonise heat, and the benefits it can bring, is generally low[107]. This is a driver behind the Scottish strategic framework and points to a clear need to communicate the value of decarbonising heat and the benefits the technology options can bring.

In recent years the UK Government has relied heavily on consumer choice to deliver the transition, particularly in England. However, this approach may prove risky as awareness of decarbonised heating options, and the benefits they can bring, is low, combined with widespread satisfaction with the current gas central heating. Furthermore, the rate of decarbonisation that is needed means that if uptake is slow, or an option proves difficult to deploy, then the consumer will be left with fewer options and less time will be available to deploy the necessary infrastructure[108].

Concern about the attitudes behind the government's approach was raised by a survey of policymakers that indicated that few saw the potential benefits of decarbonising heat, instead it was often regarded solely as disruptive and uncertain[109]. Whereas research indicates that public attitudes towards heat decarbonisation are likely to be shaped by the benefits that could come with it, such as improved thermal comfort, possible improved health and addressing wider social equity concerns[110].

Developing the skills base will support the wider communication and awareness objectives. A lack of information about the options and uncertainty about which options are effective undermines decision making. This is exacerbated by a lack of knowledge of the technologies in the installation sector[111].

Build trust

In addition to raising awareness of the transition, the public need confidence that the technologies they are installing will deliver the levels of comfort they were expecting and potentially reduce bills[112]. They are also seeking reassurance that the option will not be superseded, and that any support mechanism will remain in place[113].

UKERC's research also explored the role of consumer choice. While choice was important, the study indicates that it is equally important that the public believe that they are installing the right option for them, and they are given confidence about the effectiveness. Participation in the decision-making process is an important component and providing guidance as to the most suitable and effective option from the range of technologies and installation requirements[114].

Trust will also be built by ensuring that the installation sector has the knowledge and skills to address householders' concerns about the quality of installations and the advice given about the effectiveness of the work that needs to be undertaken. Installation and running costs of new heating systems were consistently raised as primary concerns by research participants.

Obtaining trusted advice about the technology options is important. Unlike a gas boiler replacement, installing a heat pump system, or connecting to a heat network, requires a detailed assessment of the building. Additional work may be recommended to upgrade the energy efficiency and amount of insulation, and radiators may need to be replaced.

While building trust in the choice of technologies is important, homeowners also need to be part of the installation design. In Bolton, a heat pump project was delayed by a failure of the housing managers to engage the residents in the design of the installation, with concerns about noise and vibrations[115].

The Renewable Heat Incentive scheme provides a list of registered companies, but the sector lacks the regulation and certification to give assurance to the customer. For heat networks, the introduction of regulation for how the energy is priced and the system managed will build confidence in the technologies.

Building confidence in the available technologies, such as heat pumps, has been mired by controversy about the effectiveness of the options (with the media playing a role in fuelling controversy in the UK[116]). This is compounded by the lack of trust in energy companies, and the impression that parts of the fossil fuel sector are using their incumbency and vested interests to promote options that protect their interests, whilst spreading misinformation about the effectiveness of specific options[117]. Uncertainty about the role of hydrogen in domestic heating is particularly relevant with the public questioning the motivations behind its promotion[118].

First-mover experience can build trust. Analysis of heat pump deployment indicates that they often occur in clusters[119]. Where one first-mover household has a heat pump installed, other households nearby are more likely to convert, having seen what the work that is required and the benefits it can bring.

Inform and shape interventions

UKERC's public engagement work revealed some striking findings about what aspects of the transition were of most concern to the public. While awareness of the different technologies was low, when presented with the options and what they entailed, concerns were mainly about how will it be managed, how the cost of installation will be paid for, and whether the costs be distributed fairly[120]. This contrasts with attitudes of politicians who regarded heat decarbonisation as disruptive.

Similarly, research into the attitudes towards the relative disruption of installing a heat pump versus a replacement gas boiler or digging up the road to lay a heat network, revealed various aspects that affected the level of tolerance[121]. Several social factors were revealed that meant residents were less prepared to tolerate changes to the heating system than other types of disruption to the home or street, including local identity, which, in some places, was closely tied to historic features and aesthetics in the street or homes, and could be vulnerable to disruption or be incompatible with the new technologies.

Attitudes towards the transition, revealed through engagement with the public, provide valuable insights that can help shape and target interventions.

Learn from the public

Being able to draw on local knowledge and expertise is an important element of empowering local authorities to deliver the heat transition. This is important for developing heat maps and identifying zones where particular options are more viable. Engaging the public in the decision-making process is important.

UKERC's work has shown that while people have been shown to be generally supportive of the need for the transition, and are prepared to cope with some disruption, responses to proposals raised issues about local identity and precarity[122]. These aspects could create barriers or reluctance to change and need to be addressed. This type of understanding and learning will be important to embed as projects progress.

Public engagement needs to be prioritised with an emphasis on learning from communities about what works in heat decarbonisation delivery. Sharing these findings will be valuable to improve outcomes in other areas. UKERC's Public Engagement Observatory maps examples of different types of engagement methods and includes examples of what can happen if it is poorly implemented. In the Netherlands a central resource has been provided to pilot projects and a focus on sharing learning[123]. However, even with its more consensual political culture, some municipalities are facing pushback, making it clear that a one-size-fits-all approach is not always appropriate.

Conclusions

Decarbonising residential heating is a complex challenge requiring a multi-disciplinary response, that encompasses the technical, societal, economic and governance aspects. It will affect a large proportion of households over the next 25 years, yet progress has been mixed across Great Britain, with England, in particular, lagging behind.

Deployment rates are far below the required targets, with investment mired in uncertainty about the future of the gas grid. New homes are being built that will need to be retrofitted in the future due to delays in implementing zero carbon standards for construction. Policies should focus on maximising deployment of currently viable technologies, such as heat pumps and heat networks, as the risks of delay will make the task harder.

The current centralised, market-led approach is out of step with the scale of the challenge offering fragmented and short-term support mechanisms, based on an overly optimistic assessment of the potential to reduce the cost of heat pumps. Implementing the necessary funding mechanisms needs to consider the impact on the wider economy; namely burdening householders with the higher upfront costs of installation risks reducing national GDP over the course of the transition. Furthermore, ensuring that those in most need and that costs are distributed fairly could be an important factor determining public acceptability of the transition.

Public attitudes and awareness of the transition should shape and inform policies development and interventions. The current top-down approach relies heavily on consumer choice, but this is risky as the public do not place a high priority on changing their heating system. Furthermore, the lack of skills means there are a limited number of engineers able to advise and install clean heating systems.

Local and regional governance have an important role in delivering the heat transition. Heat networks are depending on local mapping and planning of opportunities, with the potential to deliver heat to up to 19% of households. Enabling this requires a clear governance framework that empowers local decision making.

Investment will be needed to develop the new skills needed for installing the new technologies. These will be needed in advance of deployment to ensure capacity can meet demand and importantly to help inform customers about the options. Investment will also be needed in manufacturing the new equipment to replace the UK's leading gas boiler capacity.

As UKERC's independent analysis shows, realising the potential benefits of decarbonising heat and ensuring it can deliver within the timeframe requires a multi-disciplinary approach.

Clear conclusions emerge from across the work. Multiple interrelated issues need to be addressed as part of a comprehensive plan and restructuring of the governance.

- A long-term plan is crucial. It must be realistic about the timeframes and the scale of investment and financial support that will be needed.
  - Mobilise the investment in the energy infrastructure, technology manufacturing and skills that will be needed.
  - Lead the narrative – raise awareness of the importance of decarbonising heat and the options available.
  - Support mechanisms need to be realistic about the future costs of heat pumps and incorporate the public attitudes into the design of interventions.
  - Realistic about the future of the gas network and the limitations and uncertainties of using hydrogen for domestic heating.
  - Balance electricity and gas prices to ensure energy bills reflect the energy efficiency gains of using a heat pump.
- Provide a clear governance framework, which enables local and regional authorities to lead the transition.
  - Decarbonisation of heat is widely recognised as a local issue. Local authorities need to be empowered to engage with communities and businesses to facilitate the planning decisions and implementation.
  - Local authorities will need support to build the capability and capacity to undertake technical assessments to identify suitable options for the houses and communities.
  - Local energy infrastructure will require investment and upgrading. Energy companies will need to interact with local and regional energy authorities to facilitate planning and decision making.
  - Facilitate shared learning between the local authorities through consistent rules.
- Engage the public – the transition will require a large majority of households to make changes to their heating systems. Developing the transition around an understanding of what is important is likely to be important in ensuring public acceptance.
  - Raise awareness of the technologies and provide clarity about their potential, to ensure customers are adequately involved in the decision making.
  - Engage the public in decision making. This is important at a local level where local energy plans are being developed, particularly for heat networks.
  - Policy making and design of interventions should be based on an understanding of public attitudes.

References

1 HM Govt. 2021. Heat and Buildings Strategy. Access here.

2 BEIS. 2018. Clean Growth - Transforming Heating - Overview of Current Evidence. Access here. (Accessed: 9 August 2024)

3 HM Govt. 2021. Heat and Buildings Strategy. Access here.

4 Rosenow, J. et *al.* 2020. The pathway to net zero heating in the UK: A UKERC policy brief Key findings. Access here.

5 Becker, S. et al. 2023. "Public perceptions of heat decarbonization in Great Britain", *Wiley Interdisciplinary Reviews: Energy and Environment*. John Wiley and Sons Ltd. Access here.

6 Rosenow, J. et *al.* 2020. The pathway to net zero heating in the UK: A UKERC policy brief Key findings. Access here.

7 Becker, S. et al. 2023. "Public perceptions of heat decarbonization in Great Britain", *Wiley Interdisciplinary Reviews: Energy and Environment*. John Wiley and Sons Ltd. Access here.

8 Lowes, R., Woodman, B. and Clark, M. 2018b. Incumbency in the UK heat sector and implications for the transformation towards low-carbon heating. Access here.

9 HM Govt. 2021. Heat and Buildings Strategy. Access here.

10 CCC. 2022. Progress in reducing emissions. 2022 Report to Parliament. Access here.

11 DESNZ. 2024. UK Heat Networks: Market Overview.

12 DLUHC. 2023. The Future Homes and Buildings Standards: 2023 consultation, Department for Levelling Up Housing & Communities. Access here.

13 Scottish Govt. 2023. The Building (Scotland) Amendment Regulations 2023, Building and Buildings. Scottish Statutory Instruments. Access here.

14 Scottish Govt. 2021. Heat in buildings strategy: achieving net zero emissions in Scotland's buildings. Access here.

Scottish Govt. 2022. Local Heat And Energy Efficiency Strategies And Delivery Plans: Guidance. Access here.

Scottish Govt. 2023. Starting a National Conversation on the Heat Transition in Scotland: Introducing a Strategic Framework for Public Engagement 2023 - 2026. Access here.

15 Scottish Govt. 2023. Heat in Buildings: progress report 2023. Access here.

16 Britton, J. and Webb, J. 2024. "Institutional work and social skill: the formation of strategic action fields for local energy systems in Britain", *Environmental Innovation and Societal Transitions*, vol. 50. Access here.

Webb, J. 2022. Institutional Landscapes for Local Energy Systems: Mapping England, Scotland and Wales. Access here.

17 HM Govt. 2023. Energy Act 2023, Energy Act 2023. HM Government. Access here.

18 Ofgem. 2023. Decision: Future of local energy institutions and governance. Access here.

UKERC EDC. 2024. Non-gas map, UKERC Energy Data Centre. Access here.

19 Lockwood, M., Devenish, A. and Kerr, N. 2022. The governance of residential heat transitions in the Netherlands and the UK. Access here.

20 Devenish, A. and Lockwood, M. 2024. "Locally-led governance of residential heat transitions: Emerging experience of and lessons from the Dutch approach", *Energy Policy*, 187. Access here.

21 Turner, K. et *al.* 2023. "Unlocking the Economy Wide Benefits of Heat Pumps The Role of Electricity and Gas Prices Policy brief". Access here.

22 Rosenow, J. et *al.* 2020. The pathway to net zero heating in the UK: A UKERC policy brief Key findings. Access here.

23 Heptonstall, P. and Winskel, M. 2023. Decarbonising Home Heating: An Evidence Review of Domestic Heat Pump Installed Costs Technology and Policy Assessment Research Report. Access here.

Turner, K. et *al.* 2023. "Unlocking the Economy Wide Benefits of Heat Pumps The Role of Electricity and Gas Prices Policy brief". Access here.

24 Rosenow, J. et *al.* 2020. The pathway to net zero heating in the UK: A UKERC policy brief Key findings. Access here.

25 Smith, W. et *al.* 2024. "Mapping the Landscape of Public Attitudes Towards Low-Carbon Heating Technologies". Access here.

26 Turner, K. et *al.* 2023. "Unlocking the Economy Wide Benefits of Heat Pumps The Role of Electricity and Gas Prices Policy brief". Access here.

27 Blyth, W. et *al.* 2023. Transition Risk: Investment signals in a decarbonising electricity system. Access here.

28 Turner, K. et *al.* 2023. "Unlocking the Economy Wide Benefits of Heat Pumps The Role of Electricity and Gas Prices Policy brief". Access here.

29 Turner, K. et *al.* 2023. "Unlocking the Economy Wide Benefits of Heat Pumps The Role of Electricity and Gas Prices Policy brief". Access here.

30 Ketsopoulou, I. et *al.* 2019. Disrupting the UK energy system: causes, impacts and policy implications. Access here.

31 Edie. 2024. UK struggling to get hydrogen home heating trials off the ground. Access here. (Accessed: 8 October 2024).

32 Lowes, R. and Woodman, B. 2020. Models of governance for energy infrastructure UKERC Working Paper. Access here.

33 Rosenow, J. et *al.* 2020. The pathway to net zero heating in the UK: A UKERC policy brief Key findings. Access here.

34 Lowes, R., Woodman, B. and Clark, M. 2018. Incumbency in the UK heat sector and implications for the transformation towards low-carbon heating. Access here.

35 Lowes, R. and Woodman, B. 2020. Models of governance for energy infrastructure UKERC Working Paper. Access here.

36 BBC. 2023. Ellesmere Port hydrogen heating trial scrapped after protests, BBC. Access here. (Accessed: 8 October 2024)

37 Hanna, R., Heptonstall, P. and Gross, R. 2022. Green job creation, quality and skills: A review of the evidence on low carbon energy UKERC Technology and Policy Assessment. Access here.

38 Lowes, R., Woodman, B. and Clark, M. 2018. Incumbency in the UK heat sector and implications for the transformation towards low-carbon heating. Access here.

39 Becker, S. et al. 2023. "Public perceptions of heat decarbonization in Great Britain", *Wiley Interdisciplinary Reviews: Energy and Environment*. John Wiley and Sons Ltd. Access here.

40 Smith, W. et *al.* 2024. "Mapping the Landscape of Public Attitudes Towards Low-Carbon Heating Technologies". Access here.

41 Turner, K. et *al.* 2023. "Unlocking the Economy Wide Benefits of Heat Pumps The Role of Electricity and Gas Prices Policy brief". Access here.

42 CCC. 2022. Progress in reducing emissions. 2022 Report to Parliament. Access here.

43 Corbett, H. et *al.* 2023. Briefing Note: Unlocking the benefits of the low-carbon heat transition. Access here.

44 Turner, K. et *al.* 2023. "Unlocking the Economy Wide Benefits of Heat Pumps The Role of Electricity and Gas Prices Policy brief". Access here.

45 BEIS. 2021. Hydrogen Production Costs 2021. Access here.

46 Rosenow, J. et *al.* 2020. The pathway to net zero heating in the UK: A UKERC policy brief Key findings. Access here.

47 Turner, K. et *al.* 2023. "Unlocking the Economy Wide Benefits of Heat Pumps The Role of Electricity and Gas Prices Policy brief". Access here.

48 Heptonstall, P. and Winskel, M. 2023. Decarbonising Home Heating: An Evidence Review of Domestic Heat Pump Installed Costs Technology and Policy Assessment Research Report. Access here.

49 Turner, K. et *al.* 2023. "Unlocking the Economy Wide Benefits of Heat Pumps The Role of Electricity and Gas Prices Policy brief". Access here.

50 Becker, S. et al. 2023. "Public perceptions of heat decarbonization in Great Britain", *Wiley Interdisciplinary Reviews: Energy and Environment*. John Wiley and Sons Ltd. Access here.

51 Becker, S. et al. 2023. "Public perceptions of heat decarbonization in Great Britain", *Wiley Interdisciplinary Reviews: Energy and Environment*. John Wiley and Sons Ltd. Access here.

52 HM Govt. 2021. Heat and Buildings Strategy. Access here.

53 Heptonstall, P. and Winskel, M. 2023. Decarbonising Home Heating: An Evidence Review of Domestic Heat Pump Installed Costs Technology and Policy Assessment Research Report. Access here.

54 Octopus Energy. Access here. (Accessed: 30 September 2024)

55 Becker, S. et al. 2023. "Public perceptions of heat decarbonization in Great Britain", *Wiley Interdisciplinary Reviews: Energy and Environment*. John Wiley and Sons Ltd. Access here.

56 Gross, R. and Hanna, R. 2019. "Path dependency in provision of domestic heating", *Nature Energy*, 4(5), pp. 358–364. Access here.

57 Smith, W. et *al.* 2024. "Mapping the Landscape of Public Attitudes Towards Low-Carbon Heating Technologies". Access here.

58 Becker, S. et al. 2023. "Public perceptions of heat decarbonization in Great Britain", *Wiley Interdisciplinary Reviews: Energy and Environment*. John Wiley and Sons Ltd. Access here.

59 Lowes, R. and Woodman, B. 2020. Models of governance for energy infrastructure UKERC Working Paper. Access here.

60 Becker, S. et al. 2023. "Public perceptions of heat decarbonization in Great Britain", *Wiley Interdisciplinary Reviews: Energy and Environment*. John Wiley and Sons Ltd. Access here.

61 Wade, F., Britton, J. and Webb, J. 2024. "Credible and comprehensive? Comparing policy mixes for Local Energy systems in England, Scotland and Wales", *Energy Research and Social Science*, 110. Access here.

62 Lowes, R. and Woodman, B. 2020. Models of governance for energy infrastructure UKERC Working Paper. Access here.

Wade, F., Britton, J. and Webb, J. 2024. "Credible and comprehensive? Comparing policy mixes for Local Energy systems in England, Scotland and Wales", *Energy Research and Social Science*, 110. Access here.

63 DECC. 2012. The Future of Heating: A strategic framework for low carbon heat in the UK. Access here.

64 Nolden, C. et *al.* 2023. "Bristol City Leap: A Novel Finance and Public Procurement Model for Delivering Net Zero Policy brief 2 • Bristol City Leap: A novel finance and public procurement model for delivering net zero Motivation and aims of Bristol City Leap". Access here.

65 UKERC. 2021. The Net Zero Strategy and local government: do commitments meet calls for change? Access here.

66 Lowes, R. and Woodman, B. 2018. Incumbency and the transformation towards low carbon heating in the UK-Implications for policy. Access here.

67 Arvanitopoulos, T. and Wilson, C. 2021. Where might local energy system (LES) projects flourish? Local conditions associated with local energy system projects. Access here.

Britton, J. and Webb, J. 2024. "Institutional work and social skill: the formation of strategic action fields for local energy systems in Britain", *Environmental Innovation and Societal Transitions*, vol. 50. Access here.

Wade, F., Britton, J. and Webb, J. 2024. "Credible and comprehensive? Comparing policy mixes for Local Energy systems in England, Scotland and Wales", *Energy Research and Social Science*, 110. Access here.

68 Tingey, M. and Webb, J. 2020. "Governance institutions and prospects for local energy innovation: laggards and leaders among UK local authorities," *Energy Policy*, vol. 138. Access here.

69 CCC. 2020. Local Authorities and the Sixth Carbon Budget. Access here.

NAO. 2021. Local government and net zero in England HM Government. Access here.

UKERC. 2021. The Net Zero Strategy and local government: do commitments meet calls for change? Access here.

70 Scottish Govt. 2022. Local Heat And Energy Efficiency Strategies And Delivery Plans: Guidance. Access here.

71 Wade, F., Webb, J. and Creamer, E. 2022. "Local government capacities to support net zero: Developing comprehensive heat and energy efficiency strategies in Scotland", *Energy Research and Social Science*, 89. Access here.

72 Welsh Government. 2021. Net Zero Wales Carbon Budget 2 (2021-25). Access here.

73 Wade, F., Webb, J. and Creamer, E. 2022. "Local government capacities to support net zero: Developing comprehensive heat and energy efficiency strategies in Scotland", *Energy Research and Social Science*, 89. Access here.

74 Wade, F., Britton, J. and Webb, J. 2024. "Credible and comprehensive? Comparing policy mixes for Local Energy systems in England, Scotland and Wales", *Energy Research and Social Science*, 110. Access here.

75 Britton, J., Lockwood, M. and Webb, J. 2024. Clean Heat without the Hot Air: British and Dutch lessons and challenges. Access here.

76 Webb, J. 2022. Institutional Landscapes for Local Energy Systems: Mapping England, Scotland and Wales. Access here.

ESC. 2023. Local Area Energy Planning: The Time and Place is Now. Access here.

77 Wade, F., Britton, J. and Webb, J. 2024. "Credible and comprehensive? Comparing policy mixes for Local Energy systems in England, Scotland and Wales", *Energy Research and Social Science*, 110. Access here.

78 Britton, J., Lockwood, M. and Webb, J. 2024. Clean Heat without the Hot Air: British and Dutch lessons and challenges. Access here.

79 Turner, K. *et al.* 2023. "Unlocking the Economy Wide Benefits of Heat Pumps The Role of Electricity and Gas Prices Policy brief". Access here.

80 Rosenow, J. *et al.* 2020. The pathway to net zero heating in the UK: A UKERC policy brief Key findings. Access here.

81 Woodman, B. and Wu, J. 2023. The Future of District Heating and Cooling Networks. Access here.

82 Woodman, B. and Wu, J. 2023. The Future of District Heating and Cooling Networks. Access here.

83 Canet, A. and Qadrdan, M. 2023. "Quantification of flexibility from the thermal mass of residential buildings in England and Wales", *Applied Energy*, 349. Access here.

84 Gao, W. et *al.* 2023. Seasonal Storage of Heat in Boreholes Technical note. Access here.

85 Nolden, C. et *al.* 2023. "Bristol City Leap: A Novel Finance and Public Procurement Model for Delivering Net Zero Policy brief 2 • Bristol City Leap: A novel finance and public procurement model for delivering net zero Motivation and aims of Bristol City Leap". Access here.

86 Webb, J. 2022. Institutional Landscapes for Local Energy Systems: Mapping England, Scotland and Wales. Access here.

87 Nolden, C. et *al.* 2023. "Bristol City Leap: A Novel Finance and Public Procurement Model for Delivering Net Zero Policy brief 2 • Bristol City Leap: A novel finance and public procurement model for delivering net zero Motivation and aims of Bristol City Leap". Access here.

88 Webb, J. 2022. Institutional Landscapes for Local Energy Systems: Mapping England, Scotland and Wales. Access here.

89 Winskel, M. et *al.* 2024. Scottish Government Heat in Buildings Bill.

90 Britton, J. and Webb, J. 2024. "Institutional work and social skill: the formation of strategic action fields for local energy systems in Britain", *Environmental Innovation and Societal Transitions*, vol. 50. Access here.

91 Nolden, C. et *al.* 2023. "Bristol City Leap: A Novel Finance and Public Procurement Model for Delivering Net Zero Policy brief 2 • Bristol City Leap: A novel finance and public procurement model for delivering net zero Motivation and aims of Bristol City Leap". Access here.

92 Canet, A. 2018. Residential heat demand in LSOAs in Scotland. Access here.

Canet, A. 2021. Spatio-temporal heat demand for LSOAs in England and Wales. Access here.

93 UKERC EDC. 2024. Non-gas map, UKERC Energy Data Centre. Access here.

94 UKERC EDC. 2018. Domestic Heating Data from the Energy Systems Catapult Living Lab, Energy Systems Catapult. Access here.

95 Canet, A. 2018. Quantification of inherent flexibility from electrified residential heat sector in England and Wales. Access here.

96 CBS. 2021. 92 percent homes on natural gas in early 2019, Centraal Bureau voor de Statistiek. Access here. (Accessed: 17 October 2024).

97 BEIS. 2018. Clean Growth - Transforming Heating - Overview of Current Evidence. Access here. (Accessed: 9 August 2024)

98 Devenish, A. and Lockwood, M. 2024 "Locally-led governance of residential heat transitions: Emerging experience of and lessons from the Dutch approach", *Energy Policy*, 187. Access here.

99 Netherlands Govt. 2019. Climate Agreement. The Hague. Access here.

100 Lockwood, M. and Devenish, A. .2024. "Institutional context and the governance of heat transitions: The cases of the Netherlands and the UK", *Environmental Innovation and Societal Transitions*, 50. Access here.

101 Lockwood, M., Devenish, A. and Kerr, N. 2022. The governance of residential heat transitions in the Netherlands and the UK. Access here.

Britton, J., Lockwood, M. and Webb, J. 2024. Clean Heat without the Hot Air: British and Dutch lessons and challenges. Access here.

102 Devenish, A. and Lockwood, M. 2024 "Locally-led governance of residential heat transitions: Emerging experience of and lessons from the Dutch approach", *Energy Policy*, 187. Access here.

103 Smith, W. et *al.* 2024. "Mapping the Landscape of Public Attitudes Towards Low-Carbon Heating Technologies". Access here.

104 Smith, W. et *al.* 2024. "Mapping the Landscape of Public Attitudes Towards Low-Carbon Heating Technologies". Access here.

105 Scottish Govt. 2023. Starting a National Conversation on the Heat Transition in Scotland: Introducing a Strategic Framework for Public Engagement 2023 - 2026. Access here.

106 Lockwood, M., Devenish, A. and Kerr, N. 2022. The governance of residential heat transitions in the Netherlands and the UK. Access here.

107 Becker, S. et al. 2023. "Public perceptions of heat decarbonization in Great Britain", *Wiley Interdisciplinary Reviews: Energy and Environment*. John Wiley and Sons Ltd. Access here.

108 Becker, S. et al. 2023. "Public perceptions of heat decarbonization in Great Britain", *Wiley Interdisciplinary Reviews: Energy and Environment*. John Wiley and Sons Ltd. Access here.

109 Lowes, R. and Woodman, B. 2020. Models of governance for energy infrastructure UKERC Working Paper. Access here.

110 Becker, S. et al. 2023. "Public perceptions of heat decarbonization in Great Britain", *Wiley Interdisciplinary Reviews: Energy and Environment*. John Wiley and Sons Ltd. Access here.

111 Smith, W. et *al.* 2024. "Mapping the Landscape of Public Attitudes Towards Low-Carbon Heating Technologies". Access here.

112 Becker, S. et al. 2023. "Public perceptions of heat decarbonization in Great Britain", *Wiley Interdisciplinary Reviews: Energy and Environment*. John Wiley and Sons Ltd. Access here.

113 Smith, W. et *al.* 2024. "Mapping the Landscape of Public Attitudes Towards Low-Carbon Heating Technologies". Access here.

114 Thomas, G.H. et *al.* 2024. "A relational approach to characterizing householder perceptions of disruption in heat transitions", *Nature Energy*, 9(5), pp. 570–579. Access here.

115 UKERC PEO. 2022. Bolton heat pump protest, UKERC Public Engagement Observatory. Access here.

116 Cooke, P. 2023. Media Blitz Against Heat Pumps Funded by Gas Lobby Group, DeSmog Blog. Access here. (Accessed: 30 September 2024).

117 Lowes, R. and Woodman, B. 2018. Incumbency and the transformation towards low carbon heating in the UK-Implications for policy. Access here.

118 Becker, S. et al. 2023. "Public perceptions of heat decarbonization in Great Britain", *Wiley Interdisciplinary Reviews: Energy and Environment*. John Wiley and Sons Ltd. Access here.

119 Smith, W. et *al.* 2024. "Mapping the Landscape of Public Attitudes Towards Low-Carbon Heating Technologies". Access here.

120 Smith, W. et *al.* 2024. "Mapping the Landscape of Public Attitudes Towards Low-Carbon Heating Technologies". Access here.

121 Thomas, G.H. et *al.* 2024. "A relational approach to characterizing householder perceptions of disruption in heat transitions", *Nature Energy*, 9(5), pp. 570–579. Access here.

122 Thomas, G.H. et *al.* 2024. "A relational approach to characterizing householder perceptions of disruption in heat transitions", *Nature Energy*, 9(5), pp. 570–579. Access here.

123 Devenish, A. and Lockwood, M. 2024. "Locally-led governance of residential heat transitions: Emerging experience of and lessons from the Dutch approach", *Energy Policy*, 187. Access here.

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