Accelerating adoption: A network+ road map for residential heat pumps

November 2024
Network+ for Decarbonisation of Heating and Cooling

net-zero research network
A Network+ for the Decarbonisation of Heating and Cooling

Durham University

Contents

Engineering and Physical Sciences Research Council

This road map was written by Jake Barnes based on research associated with the Network+ and was overseen by Tina Fawcett, David Jenkins, and Jacki Bell.

Barnes, J. et al. (2024): Accelerating adoption: A network+ road map for residential heat pumps. Durham University. DOI: **http://doi.org/10.15128/r2jd472w527**

Executive summary

Residential space and water heating accounted for 18% of all greenhouse gas emissions in the UK in 2021. Heat pumps are expected to be one of the main technical options to address these emissions and decarbonise residential space and water heating, but their deployment and use remains low. Whilst an estimated 1.3m gas boilers are installed in the UK every year, only 60,000 heat pumps were installed in 2023.

In October 2021 the UK Government launched the Heat and Building Strategy. It aimed to accelerate the deployment of residential heat pumps installing at least 600,000 units per year by 2028. The number of heat pumps sold in the UK has increased since 2021 but more must be done to meet national targets.

This report, developed by EPSRC Network+ for Decarbonisation of Heating and Cooling addresses this issue. It gathers relevant insights from across its activities (e.g. workshops), and associated research projects, including those funded under the EPSRC 'Decarbonising Heating and Cooling programme and projects undertaken with support of the Network's flexible fund as well as associated research projects.

The road map demonstrates how the network+ is contributing to knowledge generation and cross sector collaboration. It collates insights at the forefront of scientific research on challenges of increasing deployment of heat pumps and outlines where further research efforts could be directed.

Seven key messages arise:

1. Increasing R&D will help deliver more efficient, affordable, flexible heat pumps that are suitable for a wider range of homes and households. Areas for investment include: increasing system efficiencies, developing robust control interfaces and enabling flexible use.
2. Installing energy efficiency measures prior to heat pumps should continue in most cases but this general principle should not inhibit adoption of heat pumps where efficiency measures are impractical or too costly.
3. Preparing the ground for flexible use will be vital in limiting future electricity system demand.
4. A coherent, long-term strategy with a comprehensive package of policy will be central to accelerating deployment.
5. Business model innovation including in value propositions, financing models, and installer industry structures will be important to engaging consumers and scaling up deployment.
6. Costs must be reduced to make heat pump adoption and use affordable to different customer segments.
7. Simplifying the customer journey should ease adoption.

Introduction to the Network+

The EPSRC Network+ for Decarbonisation of Heating and Cooling is a four-year funded programme which aims to provide leadership, coordination and facilitation for EPSRC research funded in this challenging area.

The Network+ is led by researchers from Durham, Heriot-Watt, Oxford, Leeds, Brunel and Northumbria Universities who aim to bring together disciplines across 5 cross-cutting themes within the decarbonisation of heating and cooling to create a "world leading" network of expertise and support for developing research and researchers through connecting all national and international stakeholders relevant to a net zero carbon heating and cooling future for residential, business and industry sectors.

Outputs from the Network+ include; funding for early career researchers in areas of developing interest, policy and technology roadmaps, an established community of researchers, knowledge sharing events, secondments and travel bursaries and public engagement activities as well as development of academic expertise and capacity building.

Further information about the Network+ can be found here: **Our Network | Net Zero Research Network (net-zero-research.co.uk)**

Introduction to the road map

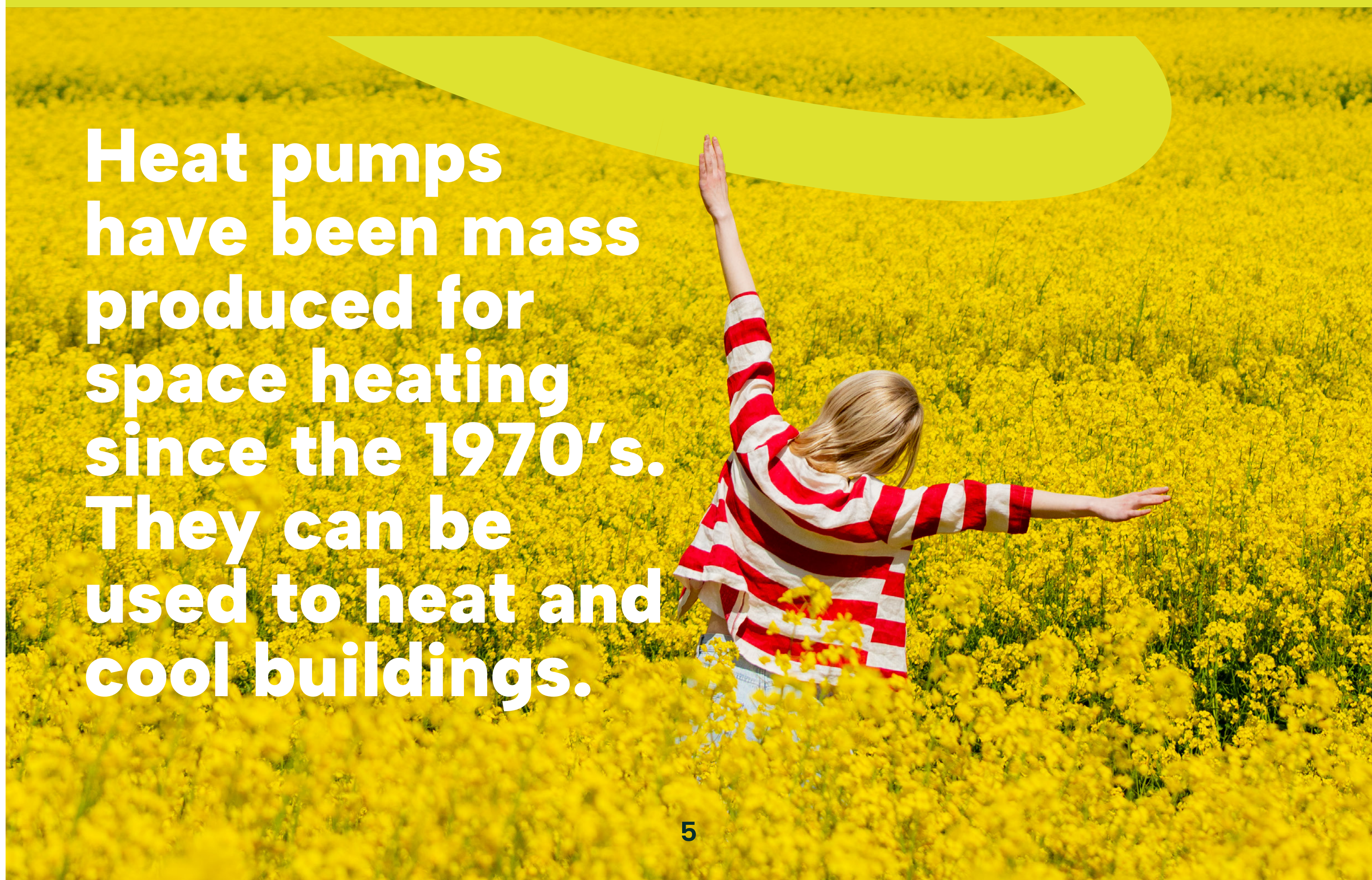
This road map provides an accessible, up-to-date assessment of heat pumps as a critical technology in the UK's path towards decarbonised residential space and water heating. It was developed by the EPSRC Network+ for Decarbonisation of Heating and Cooling building on the diverse insights generated across projects associated with the Network+. It takes a whole system perspective reporting on insights generated across technology, infrastructure, policy, markets, business models, cultures, norms, and use, whilst drawing out where additional research would add value.

The road map is split into six main sections.

- Technology research and development,
- Infrastructure,
- Policy support and leadership,
- Business and market innovation,
- Cultural adoption, and
- Consumer experience.

Heat Pumps.

Heat pumps are electrical devices that transfer heat from the ground, air, or water to the inside of a building by circulating a refrigerant through a cycle of evaporation and condensation. Heat pumps have been mass produced for space heating since the 1970's. They can be used to heat and cool buildings. They can also be used in industrial processes. This roadmap focusses on their use to deliver residential space and water heating in the UK.



Heat pumps have been mass produced for space heating since the 1970's. They can be used to heat and cool buildings.

UK deployment status

Heat pump deployment in the UK is low compared both with other European countries and with UK government targets.

In 2023, just over 60,000 heat pumps were installed across the UK, representing 4% market expansion in 2023 compared to 35% market expansion in 2022 **(Figure 1)**.

Continued market growth was driven by a variety of factors. Increased awareness of climate change alongside capital grants provided by the UK and Scottish governments are thought to have driven domestic demand.

Meanwhile, high energy prices, a result of increasing economic activity following the pandemic, and Russia's invasion of Ukraine in 2022, are thought to have driven interest in heat pumps across the European continent.

Across Europe heat pumps sales grew by 37% to 2.77million units in 2022[1] before contracting by 5% to 2.64 million units sales in 2023[2].

Compared to many other European countries, including Norway (where heat pumps are fitted in 60% of households), Sweden (43% of households), Finland (41% of households), and Estonia (41% of households), the UK has a low share of heat pumps (approximately 2% of households)[3].

To meet the UK Government's target of installing 600,000 units per year by 2028, reaching a total of 4 million installed heat pumps by the decade's end, rapid market expansion is required.

Figure 1: UK heat pump deployment against UK Government targets[4]

1 EHPA (2023) **European heat pump market and statistics report 2023**
2 EHPA (2024) **Heat pump sales fall by 5% while EU delays action**
3 Rosenow, J., Gibb, D., Nowak, T., Lowes, R., 2022. **Heating up the global heat pump market**. Nature Energy 7, 10–13.
4 UK Heat Pump Association (2024) **Statistics**

Road map

Key
Gov.t action
Target

	Short term (before 2030)	Medium term (2030–2040)	Long term (2040+)	Network+ role
Technology research and development	• Improve in situ performance via learning by doing • Legislate for smart controls • Develop smart control interfaces • Investigate characteristics of operational decline of gas boilers	• Roll out flex enabled heat pumps	• Minimum in situ SCOP 3	• knowledge exchange
Infrastructure	• Focus on improving system design and installation	• Target: at least 50% of HPs to be smart enabled by 2035 • Minimum EE for housing.	• 75% smart operation	• Engaging networks
Policy support and leadership	• Set out a clear and coherent strategy for residential heat decarbonisation • Set out a framework for data collection • Implement a framework for place-based heat decarbonisation planning in England	• Monitor and refine approach as market scales • Refine approach based on experience		• Synthesise insight and communicate to policy audiences
Business and market innovation	• Recognise shared ground loop installers as utilities • Rebalance taxes and levies • Develop understanding of how installer industry is changing • Experiment with new business models to reduce cost, ease adoption and enable flexible use	• Foster 'smart heating' market • Scale new business models		• enabling innovation across research and business
Cultural adoption	• Recognise heat decarbonisation as a societal challenge • Support & scale new approaches to consumer engagement			• Communicating to wider audiences, • facilitating interdisciplinary, challenge-led research
Consumer experience	• Explore changes in cultures, practices and use trail engagement techniques	• scale up engagement		• facilitating relationships with consumer bodies

Technology R&D:

Heat pump technology is widely considered to be mature, having been brought to mass market in the 1970's. The manufacture and installation of the current market product could, in principle, be scaled quickly and effectively. Despite this, heat pumps continue to face a variety of technical and non-technical obstacles to their deployment and further R&D is expected to facilitate their adoption in the UK.

Network+ research suggests continued R&D in three areas will assist deployment.

- **Increasing system performance** – To compete against incumbent gas boilers, used in 85% of UK homes, improving the average installed performance of heat pumps beyond 3 would help. Shared ground loop systems offer the potential to both increase system performance and deploy heat pumps where building design and space constraints restrict the use of individual units.[5]
- **Controls** – Further work to develop user controls that are well designed, robust, and reliable is required. Standard control interfaces, to facilitate control over a heat pump via different consumer facing apps or interfaces, would enable competition between smart heat providers. Open control protocols and common hardware standards have the potential to facilitate third party control required by aggregators to pool sufficient numbers of households and provide demand side flexibility at scale.
- **Encouraging flexible use** – Changes to heat pumps and system designs, including retrofitting controls to existing systems, will be required to facilitate the flexible use of heat pumps with different patterns of flexibility – e.g. reducing power use from the heat pump during hours of peak electricity demand. Advances in thermal storage, to reduce cost and size, will also be important.

Increasing technical performance requires common metrics

To further in situ performance common heat pump performance metrics are required. Performance data must be both standardised and accessible, helping industry and consumers understand performance. The Committee on Climate Change has initiated work to create standardised data but further progress is required.

Future research avenues:

- System performance, controls, and flexible use.

Key technologies:

- **Air-source heat pumps** absorb thermal energy from the outside air and transfer it inside to heat buildings. Air-to-water (hydronic) heat pumps use captured energy to heat water which is passed through water-based (wet) central heating systems. Air-to-water heat pumps have a CoP of 2.0-4.0 and account for 85% of the installed heat pumps in the UK . Air-to-air heat pumps follow the same principle but push heat air into buildings rather than heat wet central heating systems.
- **Ground-source heat pumps** utilise thermal energy from the ground and transfers this heat into buildings. They have a CoP of 3.0-5.0.
- **Water-source heat pumps** utilise thermal energy present in the sea, rivers, lakes, slurries or effluent sources.
- **Hybrid heat pumps** combine a heat pump with a fossil-fuel boiler.
- **Smart control of heat pumps:** Smart control systems enable pre-heating and smoother heat control, lowering the peak heat demand (which can be 5x larger in winter), and provide the potential to respond to grid signals.
- **Shared ground loops:** comprises a single ground heat exchanger connected to two or more heat pumps serving two or more properties.

5 Bale, C., Barns, D., Turner, J., 2022. **Shared ground heat exchange for the decarbonisation of heat**. University of Leeds.

Infrastructure issues

To work, heat pumps must be installed within diverse households and connected to and integrated with the national electricity grid.

Housing

Improving the energy efficiency of the UK housing stock is expected to aid heat pump adoption. Both capital and running costs of heat pumps will be lower in energy efficient homes, though the cost of energy efficiency measures may be greater than savings made. Reduced energy demand from smaller heat pumps will also minimise investment in electricity generation and grid upgrades.

Fabric-first, within limits
Current industry best practice is that low-cost fabric efficiency improvement measures, such as loft and cavity wall insulation, should be installed alongside heat pumps. This should continue in most cases but this general principle should not inhibit adoption where efficiency measures are impractical or too costly[6].

Recent research suggests there is no property type or architectural era that is unsuitable for a heat pump[7]. Advances in high temperature heat pumps will continue to expand the use of heat pumps in housing with poor thermal efficiency whilst reducing reliance on immersion heaters for prevention of Legionella within hot water cylinders.

A sharper focus on system design
With appropriate sizing heat pumps can meet any scale of residential heating demand. By implication, appropriate sizing of systems in the design and specification stage, is more important than household heat demand for system performance.

Electricity systems

The mass adoption of heat pumps is expected to add considerable demand to the UK's electricity system in the future. There is evidence to suggest current deployment is not slowed by power system constraints. The Heat Pump Ready programme, funded by the UK Government with the aim of generating insights on the feasibility of large-scale, high-density deployment across the UK will generate important insights about future potential issues.

Maximising flexible use
Expert deliberation undertaken by the Network+ suggests most heat pumps (50-90%) are expected to be operated flexibly by 2035 to mitigate peak demand[8]. Experts suggested heat pumps can provide within-day flexibility, with evening peak load smoothing thought to be a key potential contribution. Evidence from recent trials conducted within the Network+ suggests heat pumps can provide flexibility to the low voltage network and to national demand reduction by shifting space heat between 1-3 hours[9]. Hot water has the potential to be shifted up to 12 hours depending on local social and technical factors but requires thermal storage taking up space in homes. Because a high concentration of units in a particular location will be required to provide location specific low voltage network support, the capacity for heat pumps to provide national demand reduction is likely to be realised more quickly.Network+ research suggests whilst flexible use can reduce peak demand on electricity systems there are few energy savings to be gained from deferring heat demand because deferred energy use tends to be higher to compensate. Managing this 'snapback' – where units need to operate at higher loads to compensate for previous inactivity – will be important.

Flexibility provided by heat pumps will be in competition with other forms of flexibility on both the demand and supply side, including from batteries and EVs. Which will prove the most viable at least cost remains unclear.

Future research avenues:

- Investigation of which circumstances 'fabric first' remains a cost-effective pre-requisite of heat pump installation.
- Balance of demand reduction and supply-side decarbonisation at whole system level.
- Simplifying and improving system design to increase system efficiencies.
- Impacts of flexible operation and high-density deployment on electricity system operation
- Exploration of value derived from the flexible operation,
- Interaction between with domestic photovoltaics (PV) systems and electric vehicles (EVs) at a household and network level.
- Integrated network planning to enable consideration of heat pump, electric vehicle and solar PV roll out in network upgrades

6 Eyre, N., Fawcett, T., Topouzi, M., Killip, G., Oreszczyn, T., Jenkinson, K., Rosenow, J., 2023. **Fabric first: is it still the right approach?** Buildings and Cities 4, 965–972.

7 Energy Systems Catapult **All housing types are suitable for heat pumps, finds Electrification of Heat project**

8 Crawley, J. Higginson, S. Eyre, N. 2023. **Summary of findings from heat pump flexibility expert workshop** and Crawley, J. Moore, G. Higginson, S. Elwell, C and Eyre, N. 2024 **Heat Pump Flexibility – Towards a UK Vision**

9 Turner, Philip, Rushby, Tom, James, Patrick, Gauthier, Stephanie, Manfren, Massimiliano and Bahaj, Abubakr (2023) **Acceptability of heat pump energy deferral for mitigating peak electricity demands: findings from a UK field trial**. 20th International Conference on Sustainable Technologies, University of Nottingham, Nottingham, United Kingdom. 15 - 17 Aug 2023.

Policy support and leadership

The UK Government's Heat and Building Strategy put forward a portfolio of policies to grow annual rates of deployment and achieve government aspirations to realise at least 600,000 heat pump installations per year across the UK by 2028[10].

Developing a coherent, long-term strategy is essential

Network+ research suggests the UK Government strategy is incomplete, lacks coherence, and is unlikely to meet stated ambitions[11]. Creating a clear, coherent strategy that combines multiple policy instruments into a credible strategy will be essential to driving deployment.

At present industry and consumers are receiving mixed signals from the UK Government and investment decisions are being put off[12].

Developing a coherent strategy cannot be limited to heat pump deployment. Future Government strategy needs to encompass all residential energy use, the adoption of energy efficiency measures, as well as other zero carbon heating and cooling technologies.

Increased data collection – around technologies, installers, and installations – will be required to track and respond to market developments over time.

Required policies to accelerate progress

Reforming taxes and levies
Narrowing the 'spark gap' – the price difference between electricity and gas – through reforms to taxes and levies is necessary to continue to improve the operational cost performance of heat pumps, relative to gas boilers.

Regulations
Establishing minimum external control protocols or standards will facilitate third-party access and control of heat pumps. Revising the methodology underpinning energy performance certificates should ensure heat pumps are no longer penalised through the process.

Consider implementing minimum performance standards of heat pumps and other consumer protection mechanisms to build consumer confidence.

Recognise developers of shared ground loops as regulated utilities to unlock investable and scalable business models[13].

Electricity market reform
Locational pricing has the potential to result in significant geographical disparities in heat pump operating costs[14]. Varying levels of grant funding between regions may be required to mitigate the negative impacts of this.

Local planning
Local planning and coordination will be vital to residential heat decarbonisation[15]. Local planning authorities can encourage housing developers to install heat pumps and other low carbon systems through the planning system using local technology-specific policy (e.g. limiting the use of direct electric heating), rather than local energy efficiency standards which are set nationally[16].

Future research avenues:

- Comparative international research on heat decarbonisation strategy and policy
- Implications of locational pricing and its distributional impacts spatially, financially, and socially.
- Coordination between actors and levels of governments, their roles, responsibilities and resources to organise and deliver local heat decarbonisation.

10 Heat policy is partly devolved to the Scottish Government with policy on gas remaining the responsibility of the UK Government. The Scottish Government's Heat in Buildings Strategy (2021) set out an ambition to convert the majority of off-gas properties and at least 1 million on-gas properties to zero emission heating by 2030, and set out its own portfolio of policies to achieve this.

11 Barnes, J. Silvonen, T. Taylor, M, Rosenow, J (2024) **Accelerating heat pump diffusion in the UK: emergent tensions and priority areas for change**, Oxford Open Energy, and Killip, G. Barnes, J. (2024) **Governance of heating decarbonisation: workshop report**

12 Fawcett, T 2023. **Heat pump trial workshop report**

13 Bale, C. Barns, D. Turner, T. 2022. **Shared ground heat exchange for the decarbonisation of heat**

14 Lyden, A., Alene, S., Connor, P., Renaldi, R., Watson, S., 2024. **Impact of locational pricing on the roll out of heat pumps in the UK.** Energy Policy 187, 114043.

15 Killip, G. Barnes, J. (2024) **Governance of heating decarbonisation: workshop report**

16 Barns, D.G., Bale, C., Taylor, P., Owen, A., 2024 **Heat and the planning system: how can local authorities encourage deployment of low and zero-carbon heating?** Frontiers in Sustainable Cities 6.

Business and market innovation

The UK government has committed to making the UK one of the largest markets for heat pumps in the world. To meet government targets, scaling up UK-based manufacture and supply of heat pumps to over 300,000 unit per year by 2028 is desired as is increasing the number of qualified heat pump installers.

Network+ research indicates the market is responding to government targets. Competition between UK energy suppliers to offer lowest-cost heat pump installation emerged In January 2023 and has been sustained since. New finance models and deployment approaches are also emerging, including around shared ground loops and the growth of installer 'umbrella schemes'[17]. Increased competition between manufacturers and installers should help drive down installation costs.

Installers

In the absence of rapidly growing demand there are few incentives beyond grants to encourage people to become qualified heat pump system designers and installers.

The capacity of the heat pump installer workforce is widely seen as a barrier to accelerated deployment. Recent data from the Heat Pump Association indicates 7856 individuals completed training to become qualified heat pump installers in 2023, up from 2951 individuals in 2022[18]. Meanwhile, Association members have the capacity to train up to 40,000 installers per year. Accelerating the growth of training will be essential as demand grows.

The installer industry is changing
Network+ research suggests the installer industry maybe experiencing increased specialisation with different roles being developed around design and specification, installation, and accreditation, previously undertaken by a single 'installer'. The rise in umbrella schemes, in which one installer or manufacturer oversees and manages a large number of locally-based, trained engineers is likely contributing to this. The specialisation of roles suggests future heat pump installer industries need not look like the existing gas boiler installation industry dominated by sole traders.

Business models and value propositions

Innovative installation methods that minimise disruption, particularly when extensive work is needed to radiators, hot water cylinders, and pipework are required. Installation offers emphasising reduced disruption should be appealing.

Until it is possible to install an ASHP quickly (or deliver an immediate bridging option), distress purchases – where a gas heating system fails unexpectedly and is replaced like for like because it is the most expedient option – will continue to present a barrier to heat pump uptake. Identifying signs of operational decline could provide part of the answer. Developing utility-style business models for shared ground loops prior to need, could provide another avenue[19].

Future research avenues:

- Simplifying the installation processes.
- Identifying operational decline, to better predict and target heat pump installations
- Evolution of the installer industry and its potential impacts
- Scale and viability of business models providing grid balancing services to DNOs and the national system

17 Barnes, J., Taylor, M., Silvonen, T., 2023. **Domestic heat pumps: A rapid assessment of an emerging UK market.**

18 Heat Pump Association. 2024. **New Industry data shows a 166% Increase in Qualified Heat Pump Installers**

19 Bale, C. Barns, D. Turner, T. 2022. **Shared ground heat exchange for the decarbonisation of heat**

Cultural adoption

In recent years, interest in and knowledge about heat pumps has increased in the UK.

Network+ research suggests the creation of a clear narrative from government is the most important element to accelerating deployment in the short to medium term[20]. Increased knowledge of heat pumps and the climate impacts of heating are important preconditions for heat decarbonisation, however awareness raising alone is unlikely to be sufficient to motivate mass uptake of heat pumps[21].

A societal challenge

Heat decarbonisation is perceived as a societal rather than an individual challenge[22]. This perception leads to the idea that additional costs and risks above incumbent heat systems, should be borne by government and the taxpayer rather than individual households.

Heat pumps are currently viewed as risky, due to upfront costs and the potential financial and material disruptions involved. Choosing the wrong installer or the incorrect package of heat pump, thermal storage and insulation measures is thought to amplify this risk. Concerns over noise and space requirements have also been raised across projects.

For financially precarious households, particularly those living in privately rented accommodation, heat pumps present additional risks. Any obligation on landlords to install heat pumps may inadvertently increase rents. Landlord underinvestment, to meet minimum standards, may also result in tenants paying higher bills than homeowners with heat pumps installed, further exacerbating social inequality. If either concern is left unaddressed, obligations to install heat pumps in the private rented sector have the potential to lead to claims of injustice and a cultural backlash over the impacts of net-zero policies on low-income households.

Engaging publics

There is a need for more experimentation in the way in which publics are engaged with heat pumps and heat decarbonisation[23]. In the short-term, high quality, independent advice, tailored to specific homes and family circumstances is likely to be required to give householders confidence.

Potential options include:

- Enabling people to experience heat pumps, through site visits via open home networks, e.g. Superhomes, or more extensive experience of staying overnight in properties with a heat pump installed
- Exploring different approaches to engagement lead by public, private, or community organisations to assessing their efficacy with diverse publics
- Neighbourhood trials and approaches to exploring how and in what ways customer knowledge and behaviours change in the neighbourhoods where heat pump trials take place.

Shifting cultural norms

Retrofitting heat pumps into existing properties may impinge on and alter personal and cultural identities. Heritage buildings already enjoy a degree of protection but all building types have distinct identities that are shaped and shared by individuals and communities.

Future research avenues:

- Experimentation with and evaluation of diverse engagement approaches.
- Implications of adoption on changing cultural norms and practices.

20 Barnes, J. Silvonen, T. Taylor, M, Rosenow, J (2024) **Accelerating heat pump diffusion in the UK: emergent tensions and priority areas for change**, Oxford Open Energy

21 Thomas, G.H., Flower, J., Gross, R., Henwood, K., Shirani, F., Speirs, J., Pidgeon, N., 2024. A relational approach to characterizing householder perceptions of disruption in heat transitions. Nat Energy. **https://doi.org/10.1038/s41560-024-01506-w**

22 Thomas, G., Pidgeon, N., Henwood, K., 2023. Hydrogen, a less disruptive pathway for domestic heat? Exploratory findings from public perceptions research. Cleaner Production Letters 5, 100047. **https://doi.org/10.1016/j.clpl.2023.100047**

23 Fawcett, T 2023. **Heat pump trial workshop report**

Consumer experience

At present there is little aggregated evidence on consumer experience with the adoption and use of heat pumps. A user survey, conducted for Nesta[24] presents an exception. It found that between heat pump and gas boiler users satisfaction levels are very similar.

Network+ research suggests

The customer journey needs to be simplified
This includes reducing complexity of design, reducing installation time, and developing simplified financing options. Many households lack the time or skills to make detailed comparisons between different systems.

Running costs need to be reduced
At current electricity and gas prices and with average system performance, there are few, if any, financial gains to made from using a heat pump for residential heating[25] compared to a gas boiler. Whilst different assumptions can result in different outcomes, reducing running costs, via improving system efficiencies, rebalancing energy prices between electricity and gas or through a combination of measures, remains important.

However, recent research undertaken by the Network+ using expert deliberation suggests continued focus on upfront and running cost compared to gas boilers may be misplaced given the scale of the challenge. Instead, expert deliberation suggested shifting the narrative away from achieving cost parity, towards making heat pumps affordable to diverse demographics is likely to be more achievable and impactful[26]. Developing new financing mechanisms is widely seen as being important to achieving this and may include leasing models, green mortgages or heat as a service models.

Maintaining hot water on demand
Household practices around hot water are likely to be harder to shift than practices around space heating. Recent heat pump trials[27] suggest participants have more concerns over the loss of the 'hot water on demand' associated with a switch from combi boilers to heat pumps (with hot water tanks) than loss of control over space heating. In the long term, this expectation may change as households adapt to new systems. In the short to medium term this expectation risks generating negative narratives of heat pumps as an old fashioned, inconvenient technology.

Future research avenues:

- Simplifying the customer journey.
- Meeting comfort needs via heat pumps.
- Consumer acceptance of heat pumps and third-party control.
- Adoption of flexible operational practices.
- Motivations for adoption both financial and non-financial.
- Appeal of alternative finance mechanisms.

24 Nesta. 2023. **Heat pumps: a user survey**.

25 Rosenow, J., Barnes, J., Galvin, R., O'Mara, S. 2024 **Economics of Heat Pumps and Policy Choice: The Case of the UK**,

26 Barnes, J. Silvonen, T. Taylor, M, Rosenow, J (2024) **Accelerating heat pump diffusion in the UK: emergent tensions and priority areas for change**, Oxford Open Energy

27 Turner, Philip, Rushby, Tom, James, Patrick, Gauthier, Stephanie, Manfren, Massimiliano and Bahaj, Abubakr (2023) **Acceptability of heat pump energy deferral for mitigating peak electricity demands: findings from a UK field trial**. 20th International Conference on Sustainable Technologies, University of Nottingham, Nottingham, United Kingdom. 15 – 17 Aug 2023.

Supporting material

Network+ associated Decarbonisation of Heat projects

1. **Integrated heating and cooling networks with heat sharing enabled smart prosumers** – Professor Meysam Qadrdan, Cardiff University
2. **INTEGRATE** – Professor Daniel Friedrich, Edinburgh University
3. **Solar S&HP** – Dr Zhiwei Ma, Durham University
4. **LATENT** – Professor Patrick James, Southampton University
5. **Barocaloric materials for zero-carbon heat pumps** – Dr Xavier Moya, Cambridge University
6. **FASHION** – Professor Zhibin Yu, Liverpool University

Network+ funded projects

7. **Heat4All** – Dr Lirong Liu, Surrey University
8. **The impact of REMA on heat pump roll out** – Dr Andrew Lyden, Edinburgh University
9. **Pump Priming** – Dr Jake Barnes, University of Oxford

Workshops:

1. **Heat pump flexibility** – Birmingham, January 2023
2. **Heat pump trials** – London, June 2023
3. **Heat Governance** – Durham, November 2023

Reports from all of these events and projects are located on the Network+ webpages here: **Funded EPSRC Projects | Net Zero Research Network (net-zero-research.co.uk)**

Additional project contributions

1. **Renewable heat infrastructure network operating system (RHINOS)** – Leeds City Council
2. **Network Headroom, Engineering Upgrade and Public Acceptability (NEUPA)**, Professor Rob Gross
3. **Smart Energy for our Future, (FLEXIS)**
4. **Living Well in Low Carbon Homes (LWLCH)**, Professor Karen Henwood and Professor Nick Pidgeon

Contributions

***** *Indicates reviewers*

Andrew Lyden *(University of Edinburgh)*
Andrew Smallbone *(University of Durham)*
Bakr' Bahaj *(University of Southampton)*
Catherine Bale *(University of Leeds)*
Dan Logue *(Energy Systems Catapult)**
Daniel Friedrich *(University of Edinburgh)**
David G. Barns *(University of Leeds)*
Dave Jenkins *(Heriot-Watt University)*
Dominic Burrin
Fiona Shirani *(Cardiff University)*
Fleur Loveridge *(University of Leeds)*,
Floris Bierkens
Gareth Thomas *(Cardiff University)*
Ishanki De Mel
Jenny Crawley *(University College London)*
Joshua Turner *(University of Leeds)*
Karen Henwood *(Cardiff University)*
Lirong Liu *(University of Surrey)**
Martin Fletcher *(Leeds Beckett University)*
Massimiliano Manfren *(University of Southampton)*
Matthew Aylott, *Department for Energy Security and Net Zero**
Matthew Leach *(University of Surrey)*
Michael Short *(University of Surrey)*
Mona Chitnis *(University of Surrey)*
Nick Eyre *(University of Oxford)*
Nick Pidgeon *(Cardiff University)*
Patrick James *(University of Southampton)*
Phillip Turner *(University of Southampton)*
Sarah Higginson *(University of Oxford)*
Simon Rees *(University of Leeds)*
Stephanie Gauthier *(University of Southampton)*
Taru Silvonen *(University of Bristol)*
Tina Fawcett *(University of Oxford)*
Xinyao Liu *(University of Surrey)*

EPSRC Decarbonising Heat projects relevant to domestic heat pumps

1. Integrated heating and cooling networks with heat sharing enabled smart prosumers

Professor Meysam Qadrdan, Cardiff University

This project researched solutions for integrated supply of zero carbon heating and cooling using near ground temperature networks that enable buildings to use heat pumps and cooling machines to exchange thermal energy with the network and meet their heating and cooling demand. Work packages included the review of seasonal heat storage, ammonia and Carbon dioxide for heat transport mediums, the design of local heat markets and the identification of barriers to market.

Contributing researchers included: Jianzhong Wu, Hywel Thomas, Peter Connor, Bridget Woodman, Muditha Abeysekera, Manju Manju, Richard Lowes and Xiandong Xu.

Publications: **GtR (ukri.org)**

2. INTEGRATE

Professor Daniel Friedrich, Edinburgh University

This project considered Seasonal Thermal Energy Storage (STES) systems as a vital part of a future zero carbon energy system and evaluated the interplay between regulation and market frameworks, heating/cooling demands, energy storage systems and different energy sources. The outputs included the design of integrated STES systems that provide affordable, flexible and reliable thermal energy for the customers while also providing flexibility services for the wider energy system.

Contributing researchers included: Ronan Bolton, Adriaan Hendrik Van Der Weijde, Gioia Falcone, Ben Hughes, Robert Westaway, David Banks, Andrew Lyden, Gareth Harrison and Mark Winskel.

Publications: **GtR (ukri.org)**

3. Solar S&HP

Dr Zhiwei Ma, Durham University

This project sought to develop a seasonal solar energy storage that can effectively store abundant but relatively low temperature solar heat in summer and utilise this at the desired temperature for space and hot water heating in winter, so that 100% solar fraction can be used for space and hot water 'zero-carbon' heating. The whole SSTES system can provide heating at near zero carbon intensity as its carbon emission is approximately 92% and 85% lower compared to gas boiler and electric heat pump technology, as revealed by the preliminary calculation results.

Contributing researchers included: Huashan Bao, John Counsell, Anthony Roskilly and Yousaf Khalid.

Publications: **GtR (ukri.org)**

4. LATENT

Professor Patrick James, Southampton University

This project aimed to predict the impact of customers with electrical heating (predominantly ASHP) operating with 3rd party deferrable heating control on the LV network at the feeder / substation level. 3rd party control in this context would be through the energy service supplier, with whom, unlike the DNO, a household has an existing financial contract relationship. LATENT will inform industry of the potential of 3rd party control of deferrable heat through a rigorous field experiment, and, in doing so, accelerate the transition to decarbonised household heating.

Contributing researchers included: Stephanie Gauthier, A. Bahaj and Massimilano Manfren

Publications: **GtR (ukri.org)**

5. Barocaloric materials for zero-carbon heat pumps

Dr Xavier Moya, Cambridge University

This project aimed to develop an energy-efficient barocaloric heat pump based on novel barocaloric hybrid composite materials that combine the best properties of organic barocaloric materials, namely extremely large pressure-driven thermal changes, and the best of inorganic barocaloric materials, namely high thermal conductivity and low hysteresis. The achievement of heat pumps that operate using barocaloric materials instead of gases will permit decarbonising heating and cooling, provide energy independence, and enable the UK to become the world leader on this emerging technology.

Contributing researchers included: Jonathan Radcliffe, Lesley Cohen, David Boldrin, Donald MacLaren

Publications: **Xavier Moya | Department of Materials Science & Metallurgy (cam.ac.uk)**

6. FASHION

Professor Zhibin Yu, Liverpool University

This project, Flexible Air Source Heat pump for domestic heating decarbonisation (FASHION) is based on the PI's pending patent (Application number: 2015531.3), and aims to develop a novel flexible, multi-mode air source heat pump (ASHP). This offers energy-free defrosting and is capable of continuous heating during frosting, thus eliminating the backup heater that is required by current ASHPs. The project will address the key technical and non-technical challenges through interdisciplinary innovations.

Contributing researchers included: Yongliang Li, Hanshan Dong and Kenneth Gibb

Publications: **Zhibin Yu – University of Liverpool**

net-zero research network

A Network+ for the Decarbonisation of Heating and Cooling

UKRI Engineering and Physical Sciences Research Council