SPECIAL COLLECTION: NET ZERO RETROFIT OF THE BUILDING STOCK

RESEARCH

Local area energy mapping approach for high-density heat pump deployment

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ABSTRACT

A localised, data-driven approach is presented for the rapid and scalable deployment of heat pumps in high-density areas. This novel hyper-local methodology evaluates the technical feasibility and readiness of dwellings for heat pump deployment. The local area energy mapping (LEMAP) approach integrates diverse datasets, including energy use, building characteristics, socio-economics, digital engagement and local electricity distribution. The study of dwellings (*n* = 865) in a suburban area of Oxford, UK, was conducted in three stages: local grid loading, technical suitability and household capability. To bridge the gap between technical potential and practical adoption, a capability assessment framework was applied, examining the social, digital and financial readiness of heat pump suitable, ready and priority dwellings. Over 600 dwellings (71%) were technically suitable for heat pumps, with 60% of these households being affluent, while 33% were classified as fuel poor. Notably, households with high financial and social capabilities often had lower digital capabilities, suggesting a need for digital literacy support to enable the effective adoption of smart heat pump technologies. Although many dwellings were technically suitable, only a small proportion demonstrated strong capabilities across all three dimensions, highlighting the importance of targeted interventions to ensure successful heat pump deployment.

POLICY RELEVANCE

Heat pumps play a crucial role in strategies to decarbonise residential heating and achieve its legally binding net zero target. The local area energy planning tool presented here improves the precision of energy planning and fosters collaboration between local authorities, electricity network operators and communities. By integrating technical, socio-economic and demographic data, the tool connects policy objectives with dwelling-specific decisions, enabling a more comprehensive approach to heat pump deployment.

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The findings from this research have already been put into practice by the local council and its partners in the Clean Heat Streets project to identify suitable properties and streamline heat pump installation. As a result, over 100 in-home consultations and 30 heat pump installations have been carried out to date. The study provides actionable insights for replicating place-based heat pump deployment strategies in other regions, supporting the transition of building stock towards net zero targets.

1. INTRODUCTION

Decarbonising the building sector is pivotal to achieving the UK government's ambitious carbon emissions targets, which include a 78% reduction by 2037 and a net zero economy by 2050 (Burnett *et al.* 2024). In response, local authorities across the country are actively promoting low-carbon initiatives (Banks 2022). The residential sector, responsible for approximately 20% of the UK's CO_2 emissions (Rowe & Rankl 2024), is a key focus of these efforts. Furthermore, as nearly 38% of UK buildings were constructed before the mid-20th century—substantially higher than in many European countries—retrofit is a critical decarbonisation strategy (Merchant & Wentworth 2025; Nicol *et al.* 2021).

Heating is a primary source of residential emissions, with 80% of homes in England and Wales still relying on traditional gas boilers in 2023 (ONS 2023). While gas boilers have become more efficient over time, their reliance on fossil fuels remains a barrier to decarbonisation. Heat pumps, by contrast, harness energy from the increasingly decarbonised electricity grid and deliver greater heating efficiency per unit of energy. Without heat pumps and appropriate insulation to complement, the economic cost of reaching net zero will be far more expensive than not (Williams & Thomson 2023). Recognising their potential, the UK government has prioritised heat pump deployment as a cornerstone of its strategy to decarbonise residential heating (Chiu & Lowe 2020). It has set an ambitious target of 600,000 installations annually by 2028 (BEIS & DESNZ 2023). One policy initiative is the Boiler Upgrade Scheme (BUS), which is a grant for people in England and Wales to receive up to £7500 off a low-carbon heating system. The scheme covers three systems, air-source heat pump (ASHP), ground-source heat pump (GSHP) or biomass boilers (EST 2025). However, despite government grants, only 61,000 heat pumps were installed in 2023, highlighting the scale of the challenge (George 2024).

1.1 NEED FOR LOCAL AREA ENERGY PLANNING

According to Williams & Thomson (2023), there is a real danger of not meeting net zero targets if a large-scale retrofitting campaign does not begin immediately. Scaling up heat pump adoption requires more than policy ambition: it necessitates the careful identification of suitable dwellings to ensure efficient operation and minimise peak demand. Rapidly identifying dwellings with the appropriate levels of insulation is also critical, as poorly insulated homes lose heat far more quickly than retrofitted ones (Voet & Dethier 2024). When installed in poorly insulated buildings, heat pump size and electrical demand increases. This can lead to barriers in the uptake of heat pumps or require disruptive upgrades to infrastructure (Lingard 2021).

Local area energy planning (LAEP) tools have emerged as powerful instruments for tackling these challenges, offering a detailed understanding of both the barriers to and pathways for achieving net zero transformation. These tools enable local authorities, low-carbon technology (LCT) installers, and communities to collaboratively assess and target suitable areas and dwellings for LCT installation, including heat networks and heat pumps (Energy Systems Catapult 2025). Importantly, they provide a replicable framework for place-based strategies that can be adapted to different regions striving for net zero. As an example, a survey-based demographic and socio-economic investigation demonstrated that in the US (highly extensive, widespread survey) (Antonopoulos *et al.* 2024), motivation for the adoption of or a willingness to adopt heat pumps and other LCTs can vary by region. In order to construct LAEP tools, local data are needed that enable policymakers, planners and researchers to develop a detailed understanding of the socio-economic, demographic and infrastructural context of a neighbourhood, district or region (Fremouw *et al.* 2020).

1.2 BEYOND TECHNICAL SUITABILITY AND CAPABILITY

Beyond physical infrastructure, successful heat pump deployment requires a consideration of social, digital and economic capabilities, which can significantly influence adoption rates and carbon reduction outcomes. This contextual understanding beyond purely the technical need and suitability is critical for identifying the opportunities for and barriers to decarbonisation, as well as for designing targeted interventions that align with local needs and priorities. In a review of the literature on the social and market acceptance of photovoltaic (PV) panels and heat pumps in Europe, Peñaloza *et al.* (2022) synthesised the three most common barriers preventing further adoption of renewables:

- low availability of information about the technology
- financial concerns
- socio-demographic factors (*e.g.* income level and educational level).

Understanding the capability of the user is necessary for overcoming barriers to uptake. For example, negative feelings and experience can arise from not being informed about how to operate a new heating system properly (Moore *et al.* 2015).

Accurate use of technology in the home is highly dependent on the users' understanding and preconceived ideas which may lead to misuse or disuse (Parrish *et al.* 2021). For example, Parrish *et al.* (2021) found that many interviewees in a heat pump-controls trial did not understand heat pumps to be the sole space and water-heating technology. Sweetnam *et al.* (2019) found that even with a user-friendly control interface for a heat pump system, users lacked confidence when they did not consider themselves 'tech-savvy'. Even when simple misunderstandings were corrected, the perception was still negative. Furthermore, disruptive installation processes and inequitable cost distribution can also foster resistance (Tewari & Rajagopalan 2025). These misunderstandings and negative experiences can spread through a community, thereby increasing barriers.

Along these lines, Middlemiss *et al.* (2024) explained that to understand why people make certain energy choices (behaviour), *e.g.* how much energy they use or whether they install energy-saving upgrades, one needs to look at their social relationships and how they interact with others. The key is that energy decisions are dependent not only on the buildings and infrastructure or technology but also on relationships, past experiences, emotions and perceived roles. As a result, policy and practice also require a relational approach. Thomas *et al.* (2024) used a 'relational approach' to show that disruption is felt when changes threaten people's personally and culturally valued objects and relationships. This can include care for family, the cultural meaning of home and one's financial situation. LAEP tools have the potential to provide this relational approach which is needed through user-friendly accessibility and a deeper understanding of the socio-economic and demographic backgrounds of the householders.

According to Middlemiss *et al.* (2023), the net zero agenda presents a clear opportunity for progressive, inclusive change; there is a need to integrate social inclusion concerns systematically into net zero policy and planning. The authors identified the following, among others: ensuring social, cultural and economic participation (*e.g.* providing funding where needed; prioritise hard-to-treat properties; address the split incentive for rented properties by supporting landlords). These points of inclusion amplify the need to identify these individuals (households) through socio-economic mapping, for example. Additionally, political participation was also identified, *e.g.* placing the locus of control closer to people by empowering local authorities. This can also be strengthened through LAEP mapping tools that provide a wide array of household characteristics for enabling retrofit.

This paper introduces the local energy mapping and planning (LEMAP) tool, a hyper-local geographical information system (GIS)-based LAEP approach. LEMAP was applied to 865 dwellings in a suburban area of Oxford, UK, to support high-density ASHP deployment. It integrates spatial data on energy use, building characteristics, socio-demographics and electricity networks to identify dwellings suitable for heat pump installations. The study evaluates the feasibility of deployment using a capability assessment framework that classifies dwellings as heat pump-suitable (requiring insulation and support), heat pump-ready (with adequate insulation) and heat pump-priority (currently using direct electric heating). This approach highlights how localised energy mapping can inform scalable, place-based strategies for transitioning to low-carbon residential heating systems, addressing the UK's decarbonisation goals.

1.3 RELATED MAPPING AND DECISION SUPPORT TOOLS

GIS-based LAEP and/or decision support tools have emerged as innovative solutions for local authorities addressing complex energy planning decisions. These tools are generally software platforms designed to integrate and interconnect diverse datasets, including energy consumption, building characteristics, socio-economic factors and renewable energy resources. By providing actionable insights, they support informed decision-making processes (Bush & Bale 2019). Occasionally, developers strive to create tools that are also user-friendly in order to empower those who live in the areas being mapped and studied (Carbon Action Alliance 2025; Jankowski 2009). A few models or tools are presented here which (such as LEMAP) use a variety of energy-related data sources and assist in localised energy planning. All tools are summarised in Appendix A in the supplemental data online.

Several existing GIS-based mapping tools demonstrate a visual approach to energy planning. For instance, the London Heat Map identifies districts with high heat demand which are suitable for district heating, combining address-level modelling with area-based average heating fuel consumption (CSE 2018). ENERGIS (Moral *et al.* 2019) is described as an easy-to-use tool that can identify areas in need of energy actions, offering appropriate solutions that align with the Energy Performance of Buildings Directive. The model generates an Energy Performance Certificate (EPC) calculation, considers the cost-effectiveness of solutions and can monitor the results. All data used in ENERGIS are publicly available and maintained by official authorities, *e.g.* the Spanish Cadastre, providing geometry and year of construction for buildings.

Though not specifically focused on dwelling energy retrofit, Loomans & Alkemade (2024) describe a GIS-based tool to aid policymakers in devising local renewable energy transition pathways by increasing knowledge of crucial trade-offs and a system perspective in the Netherlands. The tool operates at two levels: provincial and neighbourhood, and uses a mix of open and closed data sources, *e.g.* building insulation characteristics, annual household energy demand and cost assumptions. Likewise, the Colorado Decision Support Tool (Carbon Action Alliance 2025) is a GIS map-based, user-friendly tool enabling project managers and community members to review carbon management projects' potential social and environmental impacts and identify development locations where a project would generate the fewest negative impacts and most positive outcomes. Data used to inform the maps include demographics, health, exposure, proximity to environmental hazards and public service gaps. The Leeds Heat Planning Tool connects commercial opportunities with community needs to address social objectives such as fuel poverty. It incorporates data categories, including techno-economic, governance and social factors (Bush & Bale 2019). However, even tools that address socio-economic considerations often stop short of integrating these insights into actionable, hyperlocal strategies.

GIS-based tools such as ENERGIS or the Colorado Decision Support Tool typically provide more sophisticated geographical area classifications and possess better capabilities for data representation and analysis. Conversely, Google Maps-based tools, such as the UK's National Community Energy Map, are more user-friendly, offering simple interfaces and functionality/accessibility even to users with minimal knowledge of web-based systems. The limitations of existing tools also extend beyond data inclusion to user experience and functionality. Tools such as CityBES, MIT UBEM and UrbanFootprint provide advanced simulation, analysis, and energy performance benchmarking (Davila *et al.* 2016; Hong *et al.* 2016; UrbanFootprint 2024). However, while these tools are invaluable for detailed energy planning, their complexity can make them challenging for non-expert users, such as community stakeholders or residents, to engage effectively. On the other hand, tools with simpler interfaces, such as the Bristol Community Energy

Mapping Tool and Community Energy Hub, prioritise accessibility for users outside traditional energy planning roles. These tools enable public participation by providing easily navigable platforms for exploring local energy projects (CEE 2022; Open Data Bristol 2020).

Among the tools reviewed, the conflict between user-friendly design with advanced analytical capabilities surfaced. Furthermore, despite their strengths, only a few of the tools reviewed incorporate socio-economic characteristics. For example, the Energy Spatial Planning Tool for Dublin integrates socio-economic data, but its resolution is limited to the district level (Gartland 2023). This gap highlights a broader challenge in existing energy mapping tools: they often lack the socio-economic data necessary to understand the interplay between building characteristics and the social and economic factors that influence local climate action. As a result, developers of community energy projects may struggle to design interventions tailored to the unique needs of specific areas.

This paper addresses these gaps by leveraging the capabilities of LEMAP, which has been trialled in this study to expedite decarbonisation through the replacement of conventional gas boilers with heat pumps using a hyperlocal method. Mapping tools often focus individually on the technical, social or economic dimensions required to design effective decarbonisation strategies. To go beyond this, the study demonstrates how the hyperlocal approach can effectively combine these elements to target dwellings for heat pump deployment. By bridging the gap between technical feasibility and practical implementation, this research not only accelerates localised decarbonisation efforts but also advances the development of LAEP tools, making them more effective and impactful for achieving net zero goals.

2. METHODOLOGY

2.1 THE LEMAP TOOL

The LEMAP tool was developed as a comprehensive solution to support community energy project developers, local authorities, regional network operators, community groups and residents in driving local decarbonisation efforts. It was first tested as a part of the LEO project in south Oxford and in the town of Eynsham, Oxfordshire, and used to provide spatial analysis and communication of baseline energy use, energy resources and potential for take-up of LCTs at property, postcode and neighbourhood levels. The tool's functionality was evaluated as part of the EnergyRev research project (Hamilton & Devine-Wright 2023).

The development of LEMAP encompassed several key steps:

- *Data collection*

  (described in the next section)
- *Data integration and mapping*

  Processing and integrating the collected data to generate accurate maps and energy profiles. LEMAP was built on the ESRI ArcGIS platform, leveraging advanced spatial data resources to enable precise analysis and visualisation.
- *User interface design*

  A website was developed to serve as the user interface of the tool. The website displayed the already intuitive and interactive ArcGIS maps and allows users to select data categories at any scale with respect to their neighbourhood or dwelling. The interface made it simple for users, with a few clicks, to access all their current data, public characteristics in relation to their neighbours and forecasted energy consumption contrasting heat pumps with their current boiler. Users could also complete a survey to update their details if they were found to be out of date.
- *Engagement features*

  Two-way communication with users, enabling ongoing feedback and community involvement.

- *Continuous improvement*

  Refining the tool iteratively based on user feedback obtained during trials, ensuring the tool remains responsive to the needs of its users.

LEMAP was structured into four key technical elements, designed to meet the needs of various stakeholders. These mappable elements were:

- *Baselining*

  Current energy demand patterns in the area.
- *Targeting*

  Identifying suitable, ready and priority properties for ASHP installations based on a range of criteria.
- *Forecasting*

  Predicting future energy demand profiles to assess the long-term impact of LCT deployment.
- *Capability*

  Evaluating the capabilities of householders to enable the successful installation and operation of LCTs.

Within the Clean Heat Streets (CHS) project, which seeks to promote ASHPs for local area decarbonisation, LEMAP was employed to assess and target suitable dwellings for ASHP installations while predicting energy outcomes. The primary objective of LEMAP was to provide detailed, actionable maps for experts at both household and postcode levels, visualising key variables and outcomes critical for informed decision-making in energy planning. The objective for community stakeholders including residents was to keep them informed about their carbon emissions relative to the community and what makes their homes ready or suitable for heat pumps. LEMAP is not currently available as a commercial offer.

2.1.1 Spatial datasets

The datasets used to build the tool included publicly available datasets (open access and free of charge), private datasets (generally acquired through purchase) and crowdsourced data (surveyed households). The owner, purpose, scale and accessibility for each dataset are provided in Appendix B in the supplemental data online. The datasets provided mapping capability (OS AddressBase); general dwelling data, including floor area, building form, age and type, and vital technical data including primary heating system and fuel type, glazing type, envelope insulation, window type, *etc.* (EPC and Geomni); and demographic, economic and social data (Mosaic and Acorn).

The household survey intended to capture what was missing from households without EPC data. These data included the number of people in the house, annual fuel consumption (from bills), type of glazing, wall insulation, ownership of PV and or electrical vehicle (EV), *etc.* The request to complete the survey was sent out via the local low-carbon community group's website and newsletter. The survey was an online form accessible via the LEMAP site and utilised ArcGIS Survey123. Appendix C in the supplemental data online lists the survey questions. An additional section on privacy explained that the data collected would not be displayed on the map but aggregated with all other data collected for the project. Furthermore, the respondent had to allow their anonymised data to be used by responding 'yes'. Survey responses were received from February to March 2022 and within that time there was a total of 122 respondents. Though the survey only intended to collect technical data to reinforce the underlying data used to build LEMAP, an awareness of and access to the local low-carbon community group's website or newsletter, and further access to the online survey and the ability to complete it were the factors contributing to sample bias.

Some datasets had overlap, *e.g.* EPC, Geomni and Mosaic provide building age, type and form; EPC and Geomni both provide roof type, wall type, glazing type, *etc.* In cleaning and compiling the data, if there were inconsistencies, the EPC was prioritised as Geomni uses EPC data for their common variables. Acorn and Mosaic both provided demographic, social and economic data. Both Acorn and Mosaic used census data. A total of 30% of the crowdsource survey respondents had EPCs from which they used to answer several questions. Crowdsourced data were used to fill in the gaps where EPCs were missing. EPC data took precedent over crowdsourced data, and survey data that covered variables already accessed via EPCs were not compared with evaluate the discrepancy between EPCs and householder perception. Where data were missing, other datasets were used to fill in the gaps or make general assumptions about like-dwellings that shared characteristics. Where total floor area was unavailable, the area of neighbouring dwellings with similar form were used. The total floor area, where unknown, was a proportion of the neighbouring dwellings' known floor area versus its geospatial outline area, as provided in OS AddressBase.

2.1.2 Limitations

The analysis was performed early in 2022. Much of the data were gathered throughout 2021; therefore, most datasets were dated 2020 and 2021. For example, the subnational energy consumption data were from 2021 and several of the private datasets were dated 2020. The most significant limitation was in the Acorn and Mosaic datasets, though updated for use in 2020/21 they were both heavily based on the 2011 census (not performed again until 2021). The data for the 2021 census were officially released in summer 2022. Though the timing of the analysis was not ideal, the methodology stands to be used again and updated in future work. The EPC only provided data for 65% of households in the area. Comparatively, on a national level in 2022, 64% of dwellings in England had EPCs. In addition, 7% of dwellings in the area did not have Geomni data. Finally, the crowdsourced data in some cases requested technical data that may not be as obvious to some householders to understand. Generally, about 20–30% of respondents did not know the answer to questions regarding the presence of wall insulation and 'Is your home equipped with a heat pump?'.

2.2 TARGETING APPROACH

Because the CHS project assessment was performed to identify homes for immediate outreach to install heat pumps in the next phase, the supplier–partner specified three scope-defining limitations:

- Only residential properties would be considered.
- National heritage-listed dwellings were excluded due to the protection of their architectural or historical significance, which could restrict the necessary building improvements to optimise heat pump efficiency. As a result, the area boundary does not include the first two limitations.
- Flats were considered 'unsuitable' (a term explained below) *at this stage* due to potential space constraints (EUA 2021).

Though flats were included in the boundary they were excluded from the analysis. Flats represented 13% of the total 865 dwellings in the case study boundary.

The assessment considered both insulation and glazing performance as key factors to ensure the efficient operation of heat pumps. Properties with low insulation or single glazing were considered to have poor energy performance and were deemed unsuitable for heat pumps. However, as mentioned, EPCs were available for only 65% of dwellings, necessitating assumptions for properties without available data. For these dwellings, assumptions were made based on UK government statistics (BEIS 2021). By the end of 2020, 70% of cavity-walled dwellings in the UK were insulated, and 66% of lofts were insulated, which informed the assumption of 'above average' insulation. Additionally, by 2022, 88% of homes in England had double-glazed windows (DLUHC 2023), which informed the assumption of double-glazing for dwellings lacking glazing data.

Based on these criteria, the dwellings were categorised into three targeting groups:

1. *Heat pump-suitable (HP-suitable)*

   Dwellings with sufficient *insulation levels* and/or a *current* or *potential* EPC level D (or better).

2. *Heat pump-ready (HP-ready)*

   A subgroup of HP-suitable dwellings in which the *current insulation levels* are sufficient, *i.e.* only dwellings with a *current* EPC level D or above were considered HP-ready.

3. *Heat pump-priority (HP-priority)*

   HP-suitable dwellings where electricity is already the primary energy source for space heating. These dwellings are prioritised as they would not require a change in primary heating fuel source, allowing for a more straightforward transition to low-carbon heating. This is not necessarily a technical ease but more of a psychological ease for the homeowner. As an example, Parrish *et al.* (2021) found that many interviewees in a heat pump controls trial did not understand heat pumps to be the sole heating technology but only a component in a hybrid system. Additionally, depending on the system currently in place, the upgrade to a heat pump could be a significant efficiency improvement, indicating a priority need.

2.3 CAPABILITY ASSESSMENT APPROACH

2.3.1 Capability profile and socio-economic context

The term 'capability profile' draws from the capability lens approach developed by the Centre for Sustainable Energy (CSE) (Roberts *et al.* 2020). This approach classifies existing, anticipated and potential opportunities for households or dwellings to participate in future smart, flexible energy systems. The capability lens originated in an understanding that a person's ability, suitability and willingness to participate are dependent on a wide range of characteristics and capabilities of the household. These are classified as location-related prerequisites, existing energy profile and technology, digital technology readiness, financial status, and personal and social factors. The capability lens identifies and categorises each household's capacity to engage with these opportunities, including adopting LCTs such as ASHPs (Banks & Darby 2021).

The socio-economic and demographic context is vital for planning and decision-making in the CHS project. Understanding the socio-economic make-up of targeted households allows for a baseline assessment of how implementing energy transition measures—such as the installation of heat pumps—will affect the area's social and economic components. For this, the key dataset used was Mosaic, which includes a comprehensive range of topics, including population, housing, employment, health, qualifications, ethnicity, *etc*. This dataset helped answer important questions, such as:

- What are the social and economic characteristics of the targeted dwellings for heat pump deployment?
- Do the inhabitants have digital literacy to manage the operation of heat pumps?

Statistical and aggregate analyses were applied at both the individual household and postcode levels to assess capabilities. These analyses resulted in the identification of capability profiles for each household, encompassing technical, digital, financial and social capabilities. While the dwelling-level results remain private due to ongoing research and data privacy protections, the postcode-level results are shared. The representative capability for each postcode was calculated by determining the most frequent capability grade among the households in that area. The grading system for each capability was divided into four levels, which indicate the strength of the capability for each household.

2.3.2 Criteria for the four types of capabilities

The four capability types, and their corresponding grades, are outlined as follows:

- *Technical capability*

  Evaluates the physical suitability of dwellings for adopting LCTs such as PVs, battery storage, EV charging and heat pumps. Each type of LCT has specific evaluation criteria outlined by Gupta *et al.* (2021). The higher the number of LCTs that are technically suitable for a dwelling, the higher the grade.
- *Digital capability*

  Measures the household's engagement with digital technology, including smartphone, computer, broadband use and level of digital engagement. This capability assesses the household's ability to manage the operation of an ASHP and the level of digital training that might be required for successful adoption and maintenance of the system.

- *Financial capability*

  Evaluates a household's ability to invest in and manage the financial aspects of deploying LCTs, including heat pumps. The financial capability grade is an average of Mosaic's affluence rating and the equivalised household income bands. Mosaic's affluence uses multiple factors, such as income, property value and mortgage information, to generate 20 bands. These are combined with equivalised household income bands, which adjust for household size and composition to calculate net household income (BEIS 2021).

- *Social capability*

  Assesses the household's motivation and awareness towards LCTs, considering knowledge, skills and social awareness of the potential benefits. Social capability grades were determined by analysing EPC data to observe preexisting LCTs (assuming that where at least one LCT is installed, the social capability for taking up additional LCTs would be high) and Mosaic's consumer behaviour segments ('Financial Strategy Segments'), which contain deeper built-in insights into household attitudes towards environmental issues and energy technologies.

Each of these capability assessments helps to create a comprehensive profile of a dwelling's readiness for adopting LCTs, allowing for targeted interventions in the decarbonisation process based on both technical suitability and socio-economic factors. For the detailed grades' descriptions and the data variables used to formulate the capabilities, see Appendix D in the supplemental data online.

3. RESULTS

The study was implemented in three stages: local grid loading, technical suitability and household capability. The following subsections describe the results for each stage.

3.1 CASE STUDY: THE ROSE HILL AND IFFLEY AREA

3.1.1 Context and local grid loading

The case study for the CHS project was conducted in the Rose Hill and Iffley neighbourhood, located in south Oxford (Figure 1). The area was selected as there has been a longstanding relationship with the low-carbon community group throughout several previous research projects. This area comprises 36 postcode zones, 19 streets and 865 households, which are primarily served by two electricity substations: the Courtland and Fiennes substations. The boundaries for the case study area were selected with help from the community group based on two primary criteria: substation load levels and the socio-economic diversity of the area.

Regarding the first criterion, the substation load levels were crucial in ensuring that the local electricity grid could accommodate the additional demand generated by the installation of ASHPs. Both the Courtland and Fiennes substations had load levels between 40% and 60%, indicating they were not overloaded and could potentially support the extra load from heat pump installations (Gupta & Gregg 2023). The second criterion for selecting the area was the socio-economic variation between the two substation areas. The neighbourhood includes a mix of owner-occupied homes, private rentals and social housing, allowing for a comprehensive understanding of the impact of heat pump adoption across different housing tenures and socio-economic groups. Notably, the Courtland area has far more owner-occupied dwellings, and the fuel poverty rate in Fiennes is significantly higher than that in Courtland. This socio-economic variation provides an important context for assessing the feasibility of the CHS project, as addressing fuel poverty and ensuring that low-income households have access to affordable and sustainable energy solutions is a key priority.

The Rose Hill and Iffley neighbourhood is primarily composed of dwellings built between 1920 and 1945, with a mix of majority semi-detached and terraced homes. Both average gas and electricity use in Fiennes is lower than in Courtland. This is potentially due to two reasons, including the better average energy efficiency rating (EER) (from EPCs) and the smaller homes in Fiennes. According to Galvin *et al.*'s (2024) analysis of the UK government's 'Fuel Poverty Dataset', among all income groups, the greatest impact on energy expenditure was the dwelling's EER, followed by floor area. For more detail on the descriptive statistics of the case study area from the data, see Appendix E in the supplemental data online.

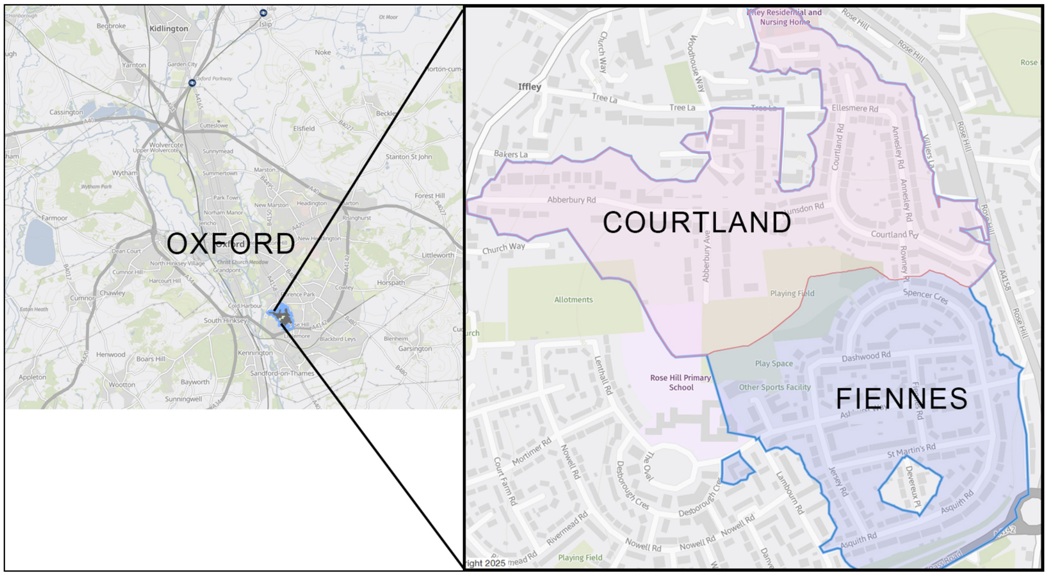


Figure 1: Location map of the Rose Hill and Iffley neighbourhood in south Oxford, with their areas served by the Courtland and Fiennes electricity substations.

3.2 TARGETING ASSESSMENT

Of the total 865 dwellings within the project area, 613 (71%) were identified as meeting the assessment criteria for HP-suitable homes. Among these, 545 (63%) were classified as HP-ready and 15 (2%) were deemed HP-priority homes.

- *HP-suitable homes*

  The Courtland area had a higher proportion of HP-suitable homes, with 331 (90%) of the 368 dwellings meeting the criteria, whereas the Fiennes area had only 282 (57%) of the 497 dwellings. When excluding flats due to scope, Fiennes was 70% HP-suitable. Figure 2 shows the map view of the targeting assessment results for most HP-suitable homes within the project boundary. It also outlines the spatial areas of each postcode within the targeted neighbourhood. One way of prioritising homes for bulk heat pump installations is by identifying the density of suitable homes within each postcode. In the Courtland area, 13 of the 17 postcodes reached 80% of homes suitable for heat pump installation, while only two of the 19 postcodes in the Fiennes area achieved the same density.

- *HP-ready homes*

  Among the 613 HP-suitable dwellings, 545 (89%) were identified as HP-ready, meaning their insulation levels were sufficient for efficient heat pump operation. Of all HP-ready dwellings, 53% were in Courtland. HP-ready accounted for 78% of all dwellings in Courtland. In contrast, HP-ready accounted for only 52% of all dwellings in Fiennes. Figure 3 presents a close-up map view of dwellings identified as HP-ready. Eight of the 17 postcodes in Courtland had 80% or more of their homes ready for heat pump installation, while none of the 19 postcodes in Fiennes reached this threshold. This discrepancy indicates a significant variation in the fabric efficiency and readiness of homes in the Fiennes area, potentially requiring additional retrofit measures before heat pump installation can take place.

- *HP-priority homes*

  Only 15 dwellings (2%) of the 865 had HP-priority, with six requiring insulation improvements (considered HP-suitable) and nine already being HP-ready. Most of these HP-priority dwellings ($n = 11$) were in the Courtland substation area. Notably, one postcode in the northern part of the Courtland area contained five HP-priority homes, making this area an ideal candidate for an initial heat pump installation campaign.

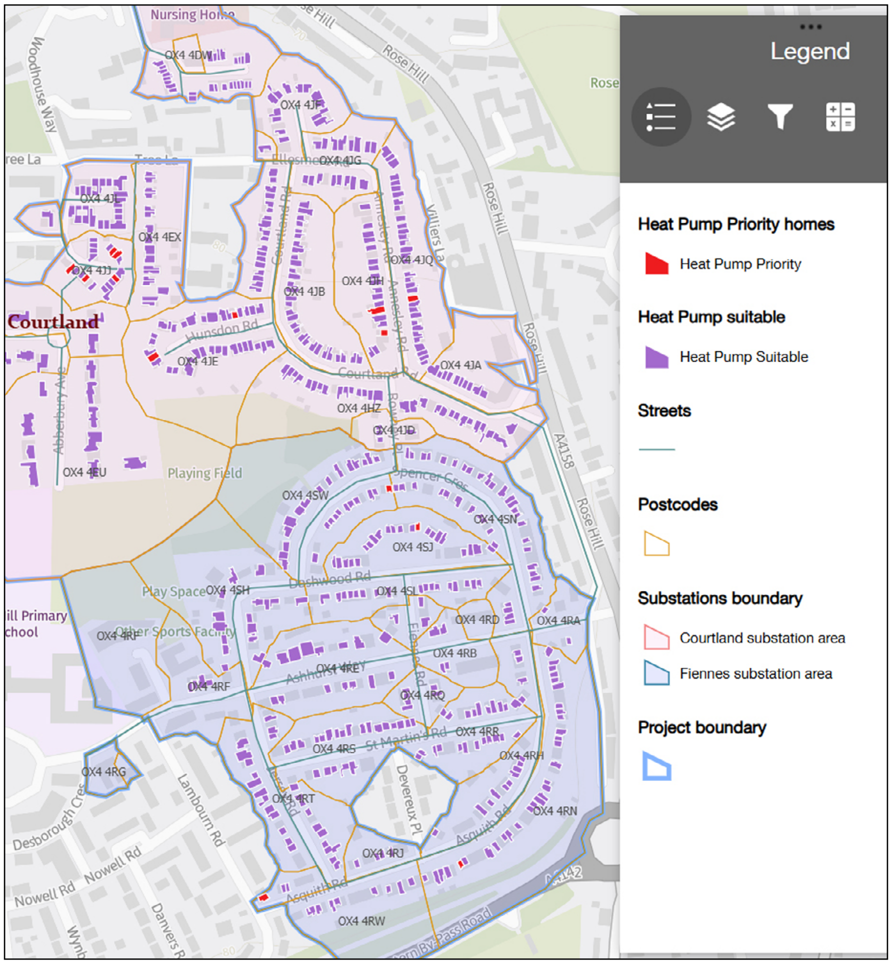


Figure 2: Map view of households that are heat pump (HP)-suitable within a portion of the project boundary.

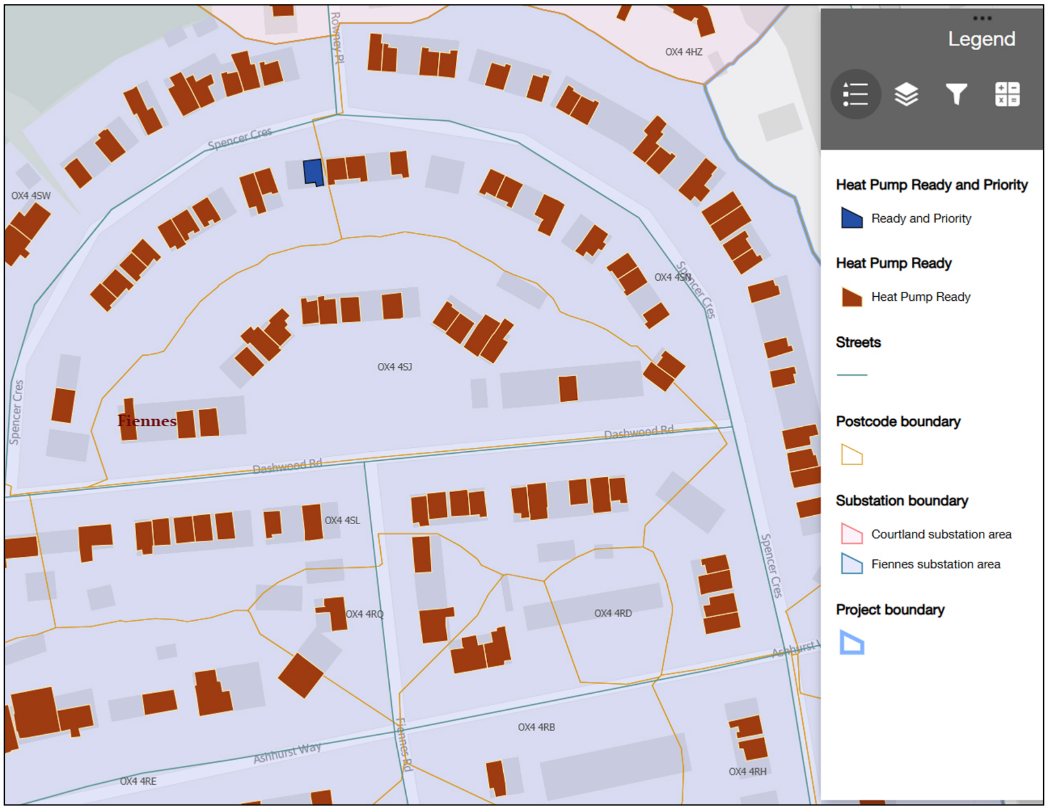


Figure 3: Close-up map view of heat pump (HP)-ready dwellings.

3.3 CAPABILITY ASSESSMENT OF THE TARGETED HOMES

3.3.1 Technical capability

Of the 613 HP-suitable dwellings, a significant portion demonstrated strong technical capabilities for adopting LCTs. (The higher the number of LCTs that are technically suitable for a dwelling, the higher the grade.) Almost half (*n* = 301) were assessed as having ‘full potential’ technical capability, while 40% (*n* = 244) had ‘partial potential’ capability. About 11% (*n* = 68) were classified as needing improvement in their technical capabilities. Courtland had a better technical capability profile compared with Fiennes. In Courtland, most households (221 of 331) were graded as ‘full potential’, indicating a high readiness for LCT adoption. Conversely, Fiennes had a higher proportion of dwellings in the ‘needs improvement’ category (177 of 282).

There were significant differences in technical capabilities across postcodes in the two substation areas. In the Courtland area, 15 of 17 postcodes had a ‘full potential’ grade for technical capability, covering a large geographical area. The remaining two postcodes had ‘some potential’ and ‘unsuitable’ majorities, respectively. In contrast, 10 of 19 postcodes in Fiennes were classified as ‘unsuitable’ for technical capability, indicating a larger gap in readiness. Figure 4 shows the postcode-level distribution of technical capability grades mapped and the percentage of HP-ready dwellings under each grade. HP-ready dwellings are in focus as they are considered directly actionable for outreach in initiating the heat conversion. Among HP-ready dwellings, 55% had ‘full potential’ technical capability, and the remaining 45% were considered to have ‘partial potential’. As expected, the HP-ready homes exhibited superior technical capabilities compared with the broader HP-suitable category. The HP-priority homes (15 dwellings) included nine with ‘full capability’ and six with ‘improvement needed’, reinforcing the notion that these homes had a better foundation for immediate heat pump installations.

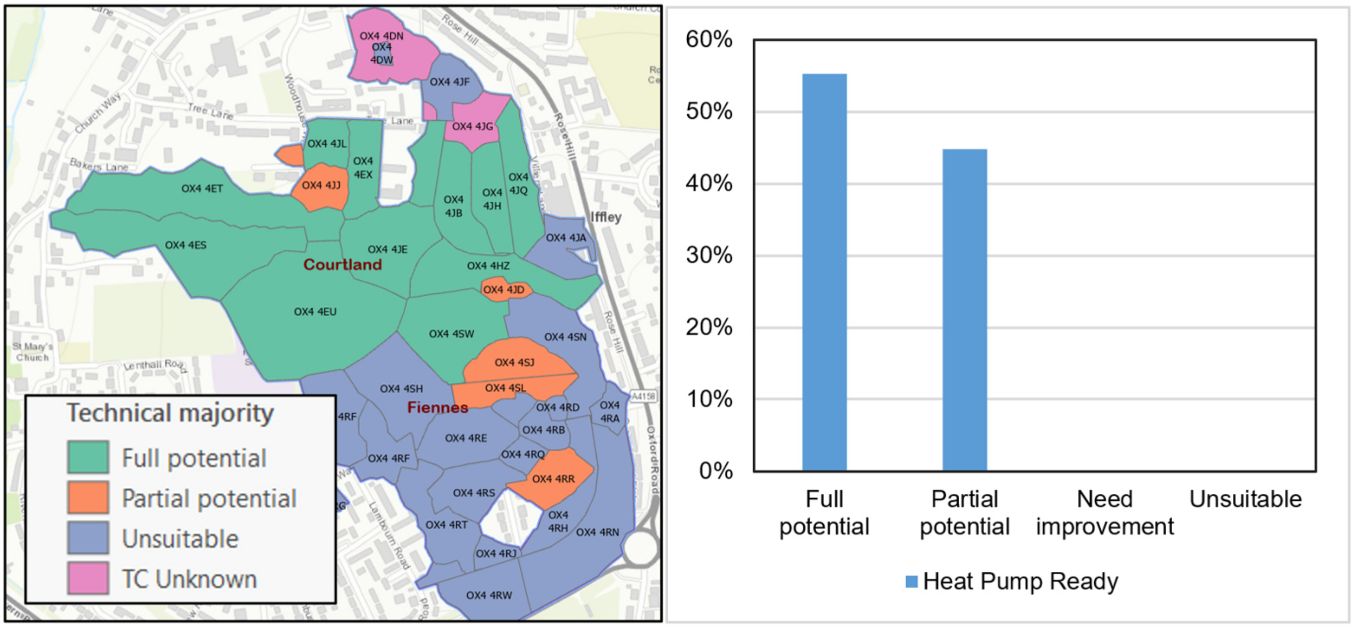


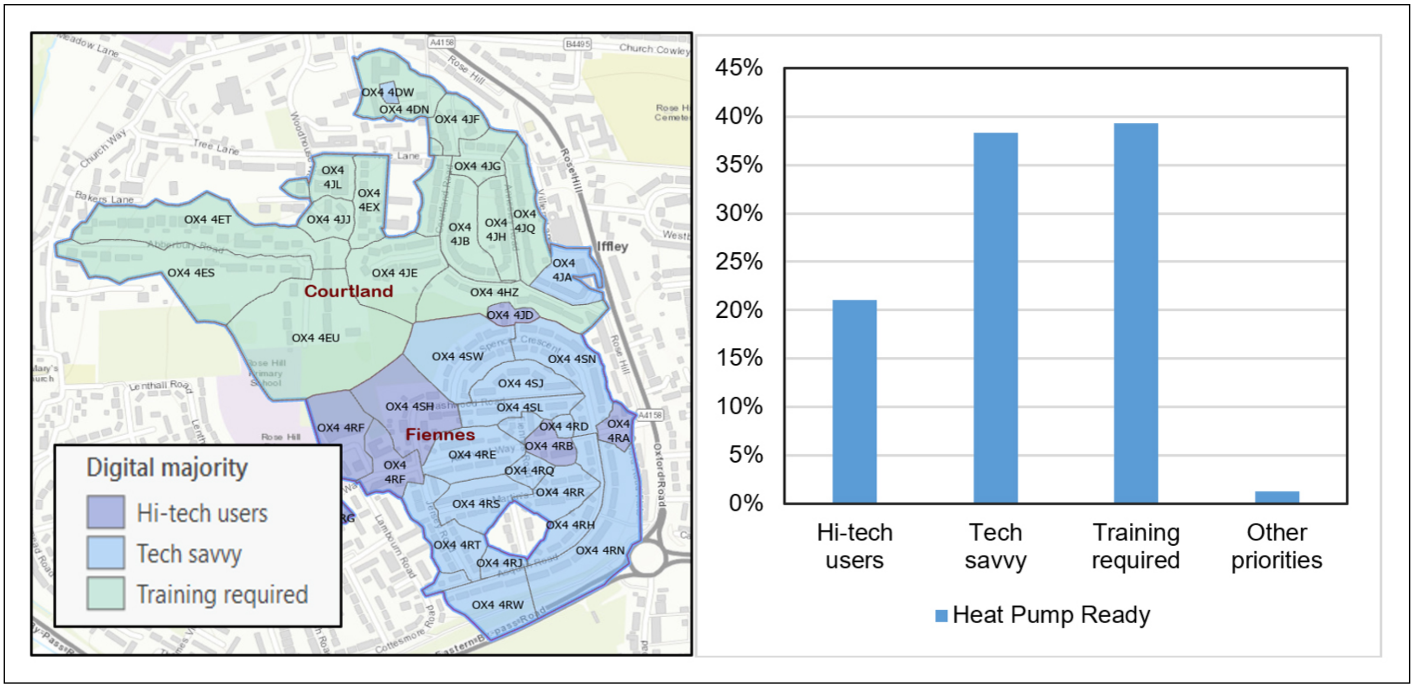
Figure 4: Technical capability at the postcode level and percentage of heat pump (HP)-ready households.

3.3.2 Digital capability

For digital capability, 21% of the 613 HP-suitable dwellings (*n* = 126) were classified as ‘high-tech users’. The largest proportion (41%, *n* = 251) fell into the ‘training required’ category, indicating a significant need for digital literacy support. Another 37% of homes were classified as ‘tech savvy’, with only seven labelled as having ‘other priorities’ regarding digital engagement. Digital capability levels varied between the Courtland and Fiennes substation areas. In Courtland, ‘training required’ was the most common category, accounting for 75% of the homes, suggesting that a considerable portion of households in this area may need assistance with digital skills before adopting technologies such as heat pumps. On the other hand, the Fiennes area had a higher proportion of 'high-tech' dwellings (*n* = 88) compared with Courtland (*n* = 38), with most of the households in Fiennes classified as 'tech savvy' (67%).

Figure 5 shows the postcode-level distribution of digital capability grades mapped and the percentage of HP-ready dwellings under each grade. Both HP-suitable and HP-ready homes had similar proportions of 'tech savvy' and 'training required' categories. However, HP-priority homes had a small number of 'hi-tech users'. Overall, while a significant portion of the targeted homes showed a moderate level of digital capability, a notable proportion may require additional support to enhance their digital literacy and ease the adoption of advanced technologies such as heat pumps.

Figure 5: Digital capability at the postcode level and percentage of heat pump (HP)-ready households.



3.3.3 Financial capability

Among the 613 HP-suitable households, 20% (*n* = 125) were considered 'happy investors', representing the highest financial capability level (all in Courtland). The second and third highest financial capability levels, 'venturers' and 'penny savers', accounted for 37% (*n* = 229) and 32% (*n* = 199) of households, respectively. The remaining 10% (*n* = 60) of households were considered 'deprived'. In Courtland, 'happy investors' and 'venturers' were the dominant grades, making up 87% of the households in the area. The Fiennes area, however, was primarily characterised by households with lower financial capability, with 55% of the households classified as 'penny savers'. Additionally, four postcodes in Fiennes were classified as 'deprived', indicating significant financial disadvantage.

Figure 6 shows the postcode-level distribution of financial capability grades mapped and the percentage of HP-ready dwellings under each grade. The proportions across HP-suitable and HP-ready homes were relatively similar. About half of the HP-priority homes were 'venturers' (*n* = 7) and there were fewer 'penny savers' (*n* = 4) and 'deprived' (*n* = 1) households, indicating that these households may be in a better position to invest in energy-saving technologies. This highlights that a segment of households in the study area, particularly in Fiennes, may face financial constraints when deploying LCTs, necessitating additional support or financial assistance.

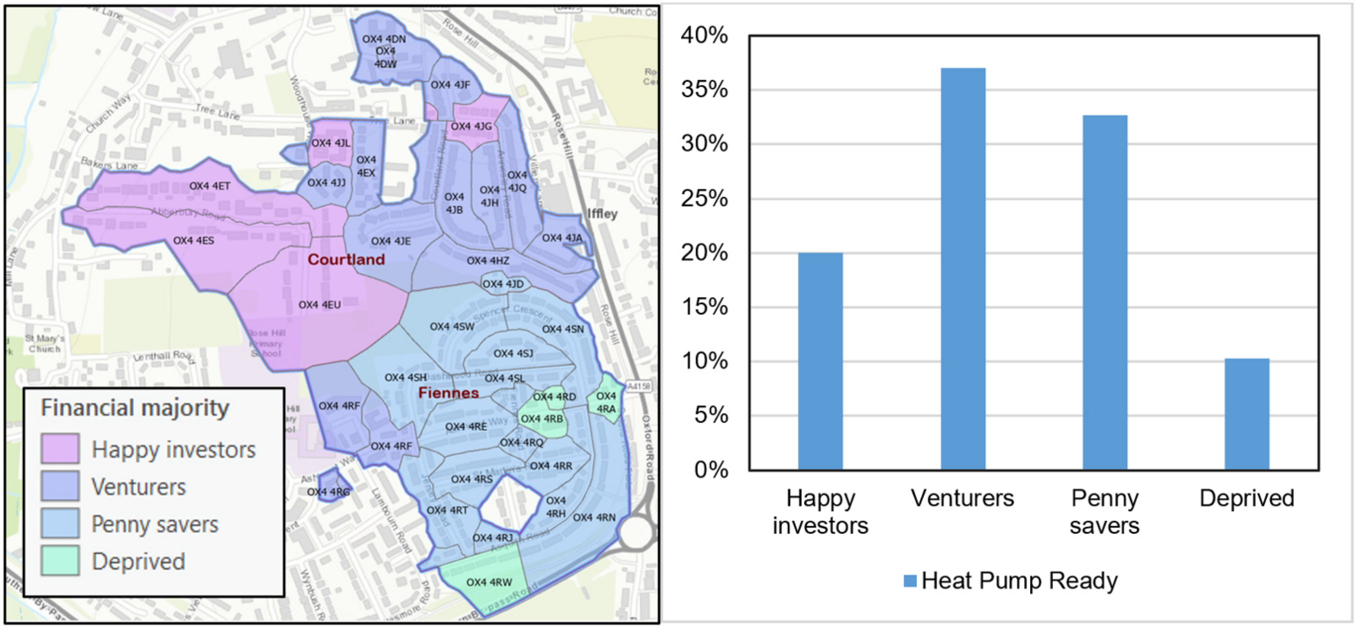


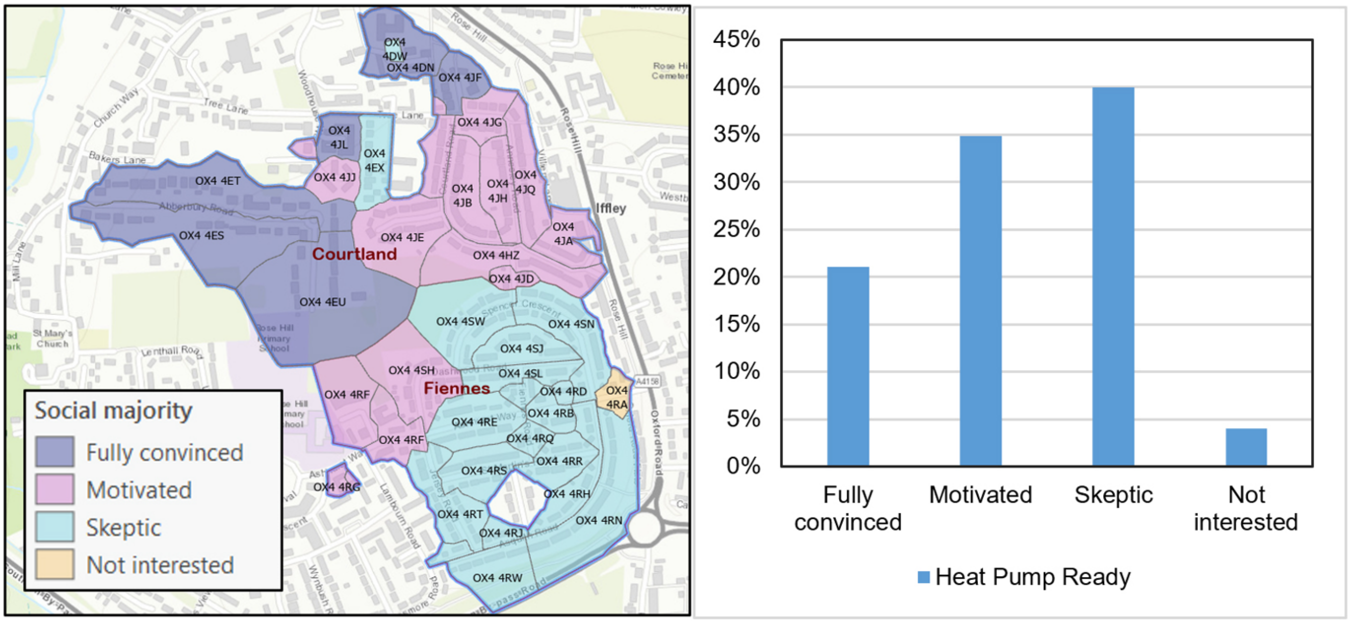
Figure 6: Financial capability at the postcode level and percentage of heat pump (HP)-ready households.

3.3.4 Social capability

In social capability, 23% (*n* = 138) of households were 'fully convinced', indicating strong support for adopting LCTs. However, 33% (*n* = 205), were classified as 'motivated', and 40% (*n* = 247) were considered 'sceptic'. A small fraction of households (4%) were classified as 'not interested'. In Courtland, 90% of dwellings had positive social capabilities, with a combination of 'fully convinced' and 'motivated' households. On the other hand, in Fiennes, 76% of households were classified as 'sceptic', indicating a lower level of social engagement with energy-saving technologies.

Figure 7 shows the postcode-level distribution of social capability grades mapped and the percentage of HP-ready dwellings under each grade. When considering the HP-suitable and HP-ready categories, social capability was more evenly distributed across 'fully convinced', 'motivated' and 'sceptic' households. HP-priority homes showed a slightly higher proportion of 'fully convinced' and 'motivated' households, suggesting that these homes may have greater social engagement and readiness to adopt energy-efficient technologies.

Figure 7: Social capability at the postcode level and percentage of heat pump (HP)-ready households.



4. DISCUSSION

This study highlights the potential of a hyperlocal, data-driven approach to facilitate high-density heat pump deployment, aligning with the overarching ambition of achieving net zero carbon emissions in the UK. The LEMAP approach employed in this research offers a comprehensive framework for evaluating not only technical feasibility but also the social, digital and financial readiness of households for heat pump adoption.

The high proportion of HP-ready homes in the study area demonstrates that many properties have already undergone insulation and energy efficiency upgrades, lowering barriers to heat pump adoption. However, localised retrofitting efforts remain essential, particularly in postcodes with low fabric efficiency. Given the need to scale-up heat pump adoption, the tool is useful for identifying dwellings at the scale needed for targeted improvement at a local level, where the net zero drive is currently focused.

Socio-economic differences between Courtland and Fiennes significantly influenced the outcomes of the capability assessment. Households in the Courtland area were predominantly owner-occupied (72%) and demonstrated higher financial and social capabilities, reflected in the larger proportions of 'happy investors' and 'fully convinced' households. In contrast, Fiennes faced greater levels of fuel poverty (58%) and lower financial capability, with 55% of households classified as 'penny savers' and 10% as 'deprived'. These disparities underscore the need for targeted financial incentives and support mechanisms to bridge the gap between technical suitability and practical adoption.

However, economics alone cannot define a household's readiness for heat pump installation, as is seen in the literature where it is important to understand preconceived ideas regarding retrofit and upgrades (Parrish *et al.* 2021), provide empowerment through technical awareness (Sweetnam *et al.* 2019), be aware of the impact of disruption (Thomas *et al.* 2024), and identify the social and cultural awareness underlying the process, expectations and participation in retrofit (Middlemiss *et al.* 2023).

As an example, digital readiness emerged as a crucial dimension in the capability assessment. Despite the overall technical suitability, only 21% of HP-suitable homes were classified as 'hi-tech users', revealing significant gaps in digital engagement. This aligns with existing research highlighting the importance of digital literacy for the successful deployment of smart LCTs (Sweetnam *et al.* 2019). Furthermore, the findings revealed a tension between financial and digital capabilities. While financially capable households in Courtland are well-positioned to invest in heat pumps, their lower digital capability (with 75% of homes requiring training) could impede the adoption of smart heat pump technologies. Conversely, Fiennes showed a higher proportion of 'hi-tech users' and 'tech-savvy' households, despite their lower financial capability.

These findings underscore the importance of community-based digital training programmes to build confidence and ensure the effective operation of smart heat pump systems (with the dual benefit of social networking). As there will be sceptical households (high among the HP-ready households), there will be a pressing need for targeted outreach and education campaigns to build trust and raise awareness about the benefits of heat pumps in socially disengaged communities. These will also need to be integrated with financial assistance in locations such as Fiennes to address critical barriers to adoption.

The implications of this study are significant for policymakers and practitioners seeking to scale-up heat pump deployment in the UK. First, the socio-economic diversity within neighbourhoods necessitates tailored approaches to address localised challenges. Second, prioritisation strategies should consider the spatial clustering of HP-suitable and HP-ready homes to streamline implementation. For instance, the high density of HP-ready homes in specific postcodes within Courtland presents a strong case for initiating bulk heat pump installations in these areas. Conversely, in Fiennes, a phased approach focusing on retrofitting and community engagement may be more effective.

In practice, this would involve local authorities and installers working collaboratively with LEMAP to identify, model and map priority areas, or those that may be easier to address first. The mapping results can be used to engage communities and share findings clearly with householders. This process would enable faster and more efficient heat pump rollouts through direct engagement with localised groups of householders. As LEMAP was developed as a LAEP tool, rolling it out to other communities would simply require collecting and synthesising the relevant data into the model and mapping it. The findings would provide valuable insights for stakeholder engagement at all levels.

While the study provides valuable insights, some limitations exist. Its focus on a single suburban area may limit the generalisability of the findings to other regions with different socio-economic and housing characteristics. However, as explained above, the model can be used in any community where the data can be accessed. At the model level, the capability assessment framework could be refined by incorporating more granular data on behavioural factors and long-term energy usage. Furthermore, the data would need to be updated to include more recent datasets, particularly those that utilise census data.

5. CONCLUSIONS

This study highlights the effectiveness of the local area energy mapping (LEMAP) tool in facilitating the rapid and targeted deployment of heat pumps in suburban Oxford. By integrating technical and socio-economic analyses, LEMAP categorises dwellings based on suitability and capability, enabling local authorities to make informed decisions about heat pump installation. The findings revealed that the electricity grid in the study area operates well below capacity, allowing for high-density air-source heat pump (ASHP) installations. Over 70% of assessed dwellings were deemed suitable for ASHPs, with nearly 90% already meeting the energy efficiency levels required for immediate deployment. While technical readiness was widespread, variations in the digital, financial and social capabilities of households (dwellings) were evident. A third of the households were fuel-poor, underscoring the need for targeted financial support to enable the adoption of low-carbon technologies (LCTs) such as heat pumps. Moreover, there was a notable gap in digital skills, particularly among households with higher financial and social capabilities, highlighting the importance of digital literacy interventions for effective heat pump operation.

Future research could explore LEMAP's scalability in both urban and rural settings, as well as its applicability to other LCTs beyond heat pumps. Further enhancements to LEMAP could focus on improving targeting accuracy by comparing modelled data with real-world adoption rates. Integrating heat pump installations with other LCTs, such as building retrofits, solar panels and battery storage, would offer a more comprehensive approach to decarbonisation. Regarding the capability assessment, the model could be expanded to incorporate more demographic and social data to better understand the non-technical factors influencing LCT uptake. Data updates would be required, but the householder survey could also be broadened to include questions about social, cultural or perceived attitudes towards retrofit and LCTs.

Since historically preserved properties and flats were excluded in this study, the next step would be to extend the scope to include these types of buildings. Flats, in particular, could be identified as opportunities for heat networks, enabling better contextualisation of both the tool and its alignment with LAEP.

Overall, LEMAP's visual, data-driven approach facilitates the creation of precise and targeted strategies for LCT deployment, fostering collaboration between local authorities, LCT installers, electricity network operators and local communities. The integration of technical, social and financial data in decision-making, as shown by LEMAP, offers a replicable model for other regions, ensuring a more equitable and inclusive shift to low-carbon energy systems. The insights gained have already been applied to identify eligible dwellings for the UK government-funded Clean Heat Streets (CHS) project, resulting in over 100 in-home consultations and 30 heat pump installations to date, demonstrating LEMAP's practical value in accelerating heat pump adoption and contributing to local net zero goals.

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COMPETING INTERESTS

The authors have no competing interests to declare.

DATA ACCESSIBILITY

Appendices A–E in the supplemental data online provide more detail about data sources, survey questions and descriptive statistics.

ETHICAL APPROVAL

Ethical approval for the project was attained from Oxford Brookes University Research Ethics Committee (UREC Registration number 231713).

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SUPPLEMENTAL DATA

Supplemental data for this article can be accessed at: https://doi.org/10.5334/bc.565.s1

REFERENCES

Antonopoulos, C. A., Fuentes, T. L., McCord, K. H., Rackley, A. L., & **Biswas, S.** (2024). Regional assessment of household energy decision-making and technology adoption in the United States. *Energy Policy*, *185*, 113940. https://doi.org/10.1016/j.enpol.2023.113940

Banks, N. (2022). Creating superpowers: Capable communities in smart local energy systems. In ECEEE 2022 Summer Study proceedings, Hyères, France. https://project-leo.co.uk/wp-content/uploads/2022/11/Creating-Superpowers-Capable-Communities-in-Smart-Local-Energy-Systems.pdf

Banks, N. W., & **Darby, S.** (2021). A capability approach to smart local energy systems: Aiming for 'smart and fair'. In ECEEE 2021 Summer Study proceedings, online. https://project-leo.co.uk/wp-content/uploads/2021/06/ECEEE21-Banks-and-Darby_140521_final-1.pdf

BEIS. (2021). *Household energy efficiency detailed release: Great Britain data to December 2020* (Household Energy Efficiency Detailed Release). Department for Business, Energy and Industrial Strategy (BEIS). https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/970064/Detailed_Release_-_HEE_stats_18_Mar_2021_FINAL.pdf

BEIS & **DESNZ.** (2023). *Guidance: Energy Security Bill factsheet: Low-carbon heat scheme*. Department for Business, Energy and Industrial Strategy (BEIS) & Department for Energy Security & Net Zero (DESNZ). https://www.gov.uk/government/publications/energy-security-bill-factsheets/energy-security-bill-factsheet-low-carbon-heat-scheme

Burnett, N., Hinson, S., & **Stewart, I.** (2024). *The UK's plans and progress to reach net zero by 2050*. UK Government https://researchbriefings.files.parliament.uk/documents/CBP-9888/CBP-9888.pdf

Bush, R. E., & **Bale, C. S.** (2019). Energy planning tools for low carbon transitions: An example of a multicriteria spatial planning tool for district heating. *Journal of Environmental Planning and Management*, 62(12), 2186–2209. https://doi.org/10.1080/09640568.2018.1536605

Carbon Action Alliance. (2025). *Colorado decision support tool*. https://storymaps.arcgis.com/stories/df8fa9215ccc4d61b75bb30a18266229

CEE. (2022). *National community energy map*. Community Energy England (CEE). https://communityenergyengland.org/pages/nationalmap

Chiu, L. F., & **Lowe, R.** (2020). Ecology of heat pump performance: A socio-technical analysis. In Sustainability in Energy and Buildings: Proceedings of SEB 2019, Budapest, Hungary. https://doi.org/10.1007/978-981-32-9868-2_60

CSE. (2018). *National heat map: New web-based tool to support low-carbon energy projects*. Centre for Sustainable Energy (CSE). https://www.cse.org.uk/projects/view/1183

Davila, C. C., Reinhart, C. F., & **Bemis, J. L.** (2016). Modeling Boston: A workflow for the efficient generation and maintenance of urban building energy models from existing geospatial datasets. *Energy*, 117, 237–250. https://doi.org/10.1016/j.energy.2016.10.057

DLUHC. (2023). *Chapters for English Housing Survey 2022 to 2023 headline report*. Department for Levelling Up, Housing and Communities (DLUHC). https://www.gov.uk/government/statistics/chapters-for-english-housing-survey-2022-to-2023-headline-report/chapter-5-energy-efficiency

Energy Systems Catapult. (2025). *Which places have a LAEP?* https://es.catapult.org.uk/tools-and-labs/local-area-energy-plans/

EST. (2025). *Boiler upgrade scheme*. Energy Saving Trust (EST). https://energysavingtrust.org.uk/grants-and-loans/boiler-upgrade-scheme/

EUA. (2021). *Energy and Utilities Alliance—The upfront cost of decarbonising your home*. Energy and Utilities Alliance (EUA). https://eua.org.uk/uploads/618D178EE4B42.pdf

Fremouw, M., Bagaini, A., & **De Pascali, P.** (2020). Energy potential mapping: Open data in support of urban transition planning. *Energies*, 13(5), 1264. https://doi.org/10.3390/en13051264

Galvin, R., Sunikka-Blank, M., & **Croon, T.** (2024). Juggling the basics: How much does an income increase affect energy spending of low-income households in England? *Energy Research & Social Science*, 118, 103766. https://doi.org/10.1016/j.erss.2024.103766

Gartland, D. (2023). *GIS techniques applied to energy mapping for local authority energy spatial planning*. Codema. https://www.ipi.ie/sites/default/files/accordion-files/module_9_gis_techniques_applied_to_energy_mapping_for_local_authority_energy_spatial_planning.pdf

George, S. (2024). *Heat pump installations soar across UK, buoyed by government grants*. edie. https://www.edie.net/heat-pump-installations-soar-across-uk-buoyed-by-government-grants/

Gupta, R., & **Gregg, M.** (2023). *Mapping technical and social capabilities in a smart and fair neighbourhood (Rose Hill)*. EnergyREV. https://www.energyrev.org.uk/media/2125/energyrev-mapping-techniques-v2.pdf

Gupta, R., Jimenez-Moreno, P., Sosa, A. D., & **Devine-Wright, P.** (2021). *Spatio-temporal mapping of local areas for engaging communities in the planning of smart local energy initiatives*. In Proceedings of ECEEE 2021 Digital Summer Study. https://project-leo.co.uk/wp-content/uploads/2021/06/ECEEE-Spatio-temporal-local-area-energy-mapping.pdf

Hamilton, J., & **Devine-Wright, P.** (2023). *Evaluation of a local area energy mapping tool (LEMAP) in a smart and fair neighbourhood*. https://www.energyrev.org.uk/media/2132/energyrev-lemap-evaluation.pdf

Hong, T., Chen, Y., Lee, S. H., & **Piette, M. A.** (2016). CityBES: A web-based platform to support city-scale building energy efficiency. *Urban Computing*, 14, 2016. https://userpages.umbc.edu/~nroy/courses/fall2018/cmisr/papers/CityBES.pdf

Jankowski, P. (2009). Towards participatory geographic information systems for community-based environmental decision making. *Journal of Environmental Management*, 90(6), 1966–1971. https://doi.org/10.1016/j.jenvman.2007.08.028

Lingard, J. (2021). Residential retrofit in the UK: The optimum retrofit measures necessary for effective heat pump use. *Building Services Engineering Research and Technology*, 42(3), 279–292. https://doi.org/10.1177/0143624420975707

Loomans, N., & **Alkemade, F.** (2024). Exploring trade-offs: A decision-support tool for local energy system planning. *Applied Energy*, 369, 123527. https://doi.org/10.1016/j.apenergy.2024.123527

Merchant, H., & **Wentworth, J.** (2025). *Net zero and the UK's historic building stock*. UK Government https://post.parliament.uk/net-zero-and-the-uk-historic-building-stock/#_edn7

Middlemiss, L., Davis, M., Brown, D., Bookbinder, R., Cairns, I., Mininni, G. M., Brisbois, M. C., Hannon, M., Owen, A., & **Hall, S.** (2024). Developing a relational approach to energy demand: A methodological and conceptual guide. *Energy Research & Social Science*, 110, 103441. https://doi.org/10.1016/j.erss.2024.103441

Middlemiss, L., Snell, C., Morrison, E., Chzhen, Y., Owen, A., Kennedy, K., Theminimulle, S., & **Carregha, T.** (2023). Conceptualising socially inclusive environmental policy: A just transition to net zero. *Social Policy and Society*, 22(4), 763–783. https://doi.org/10.1017/S1474746423000180

Moore, N., Haines, V., & **Lilley, D.** (2015). Improving the installation of renewable heating technology in UK social housing properties through user centred design. *Indoor and Built Environment*, 24(7), 970–985. https://doi.org/10.1177/1420326X1559881

Moral, G. H., González, V. S., Massa, G., & **Tranque, C. V.** (2019). ENERGIS: Decision-support tool for the implementation of energy policies at urban and regional level. *IOP Conference Series: Earth and Environmental Science*, 290, 012165. https://doi.org/10.1088/1755-1315/290/1/012165

Nicol, S., Roys, M., Ormandy, D., & **Ezratty, V.** (2021). *The cost of poor housing in the European Union*. https://files.bregroup.com/bre-co-uk-file-library-copy/filelibrary/Briefing%20papers/92993_BRE_Poor-Housing_in_-Europe.pdf

ONS. (2023). *Energy efficiency of housing in England and Wales: 2023*. Office of National Statistics (ONS). https://www.ons.gov.uk/peoplepopulationandcommunity/housing/articles/energyefficiencyofhousinginenglandandwales/2023

Open Data Bristol. (2020). *Solar potential*. https://opendata.bristol.gov.uk/explore/dataset/solar-potential/map/?location=17,51.45737,-2.59491&basemap=jawg.streets

Parrish, B., Hielscher, S., & **Foxon, T. J.** (2021). Consumers or users? The impact of user learning about smart hybrid heat pumps on policy trajectories for heat decarbonisation. *Energy Policy*, 148, 112006. https://doi.org/10.1016/j.enpol.2020.112006

Peñaloza, D., Mata, É., Fransson, N., Fridén, H., Samperio, Á., Quijano, A., & **Cuneo, A.** (2022). Social and market acceptance of photovoltaic panels and heat pumps in Europe: A literature review and survey. *Renewable and Sustainable Energy Reviews*, 155, 111867. https://doi.org/10.1016/j.rser.2021.111867

Roberts, S., Bridgeman, T., Broman, D., Hodges, N., & **Sage, C.** (2020). *Smart and fair? Exploring social justice in the future energy system: Phase one report and recommendations*. https://centreforsustainableenergy.ams3.digitaloceanspaces.com/wp-content/uploads/2023/03/18215611/smart-and-fair-phase-1-report-september-2020.pdf

Rowe, G., & **Rankl, F.** (2024). *Housing and net zero* (CBP 8830). UK Government https://researchbriefings.files.parliament.uk/documents/CBP-8830/CBP-8830.pdf

Sweetnam, T., Fell, M., Oikonomou, E., & **Oreszczyn, T.** (2019). Domestic demand-side response with heat pumps: Controls and tariffs. *Building Research & Information*, 47(4), 344–361. https://doi.org/10.1080/09613218.2018.1442775

Tewari, S., & **Rajagopalan, P.** (2025). Integration of heat pumps in social housing—Role of user behaviour and user satisfaction. *Buildings*, 15(6), 898. https://doi.org/10.3390/buildings15060898

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. *Nature Energy*, 9(5), 570–579. https://www.nature.com/articles/s41560-024-01506-w

UrbanFootprint. (2024). *UrbanFootprint*. https://urbanfootprint.com/

Voet, S., & **Dethier, S.** (2024). *Bridging the EU consumer enforcement pathways in mass harm situations*. https://www.beuc.eu/sites/default/files/publications/BEUC-X-2024-005_Bridging_the_EU_consumer_enforcement_pathways_in_mass_harm_situations.pdf

Williams, A., & **Thomson, M.** (2023). Significance of insulation and heat pumps in decarbonising the UK. *Journal of Energy and Power Technology*, 5(1), 1–12. https://doi.org/10.21926/jept.2301003

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