A new area-based mapping approach to examine the heat pump suitability and readiness of UK dwellings

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Abstract

Heat pumps are critical for meeting the UK's legally binding commitment to achieve net zero by 2050. An area-based approach that can target appropriate homes is necessary for the rapid deployment of heat pumps at scale. This paper describes the application of an online and interactive local area energy mapping tool (LEMAP) to assess air source heat pump (ASHP) suitability for 865 dwellings in a suburban area of Oxford, UK. The tool brings together GIS based spatial data on energy, buildings, socio-demographics, tenure, fuel poverty and electricity networks to (1) identify the baseline current energy demand, (2) target dwellings that are heat pump suitable but require adequate insulation and support (3) target dwellings that are heat pump ready.

The suitability and readiness elements of the 'targeting' approach required versatile data that included building footprints from the Ordnance Survey, Energy Performance Certificates (EPC) and socio-demographics (Experian Mosaic). Heat Pump Suitable dwellings were regarded as dwellings that required current levels of insulation to be improved adequately, while Heat Pump Ready dwellings had current good levels of insulation (>EPC rating D). About 483 of the total 865 dwellings were considered suitable (56 % of the target area), of which 432 were considered Heat Pump Ready. Ten dwellings were targeted as 'priority' among the Heat Pump Suitable dwellings since they used electricity for heating. The suitable dwellings comprised owner occupied and social housing. They were located in two secondary substation areas with grid loading of 40–60 %. Fuel poverty was prevalent and digital capability was low, raising concerns about the rollout of smart energy technologies without adequate education and training. The findings helped to customise the offering and financial incentives for heat pump deployment, combining fabric improvements for Heat Pump Suitable and rapid deployment for Heat Pump Ready dwellings along with resident engagement.

Introduction

Decarbonisation in the building sector is a significant component to achieving the UK government's carbon emissions targets of 78 % reduction by 2035 and net zero by 2050 (DESNZ, 2022). As a result, many local authorities across the country have been determined to promote and accelerate the low carbon process in their local areas. In the UK, natural gas is the main energy source for space heating in buildings, however, this traditional heating method hinders decarbonisation progress despite exceptional advancements made in gas boilers' efficiency over the past few decades. Heat pumps, using electricity, are comparatively more energy efficient and less carbon intensive method for heating buildings.

Research conducted by Eggimann, Hall and Eyre (2019) demonstrated through simulations of a 50 % heat pump uptake scenario in the UK by 2050, that a peak reduction of up to 5.8 GW (19 % reduction from 31.2 GW peak increase) could be achieved with managed load profiles. Likewise, simulations by Feldhofer and Healy (2021), estimated a peak reduction of 20–25 % (among three international locations) due to heat pump demand flexibility compared with the base case in which the same system is operated at fixed temperature set points. In many British homes to date, existing heat pumps installations decisions have been largely voluntary, and consideration of the physical suitability of the dwelling may not have been included in their decision making. There are many factors that influence the operational efficiency of heat pumps and building insulation level is one of the most important factors. The BEUC (Bureau Européen des Unions de Consommateurs: the European Consumer Organisation) estimates that for Northern European climates, after switching the heating off, the temperature drop is around 1.6 °C/hour in non-retrofitted buildings and 0.7 °C/hour in retrofitted and better insulted buildings (improved U-values for walls, windows, floors, and roofs) (BEUC 2023).

Though these findings indicate that better insulation is needed regardless of heating system, for heat pumps to be most efficiently utilised with less peak demand, a key issue to resolve is how to target dwellings that are suitable for heat pump installation at scale. These homes should have good physical capability and other relevant abilities to allow efficient operations of the system so that a significant reduction in carbon emissions could be achieved. GIS-based energy mapping tools have been used and are an ideal tool for assisting local authorities in making decisions on local energy planning. They have the analytical ability to promote low carbon technologies such as heat pumps on a large scale (Camporeale & Mercader-Moyano, 2021). However, many existing tools, are regarded negatively for focusing only on analytics and unidirectional dashboards and having information-deficit assumptions about users (Owens & Driffill, 2008). Instead, increasing attention is being given to the integration of energy mapping and community engagement as the two-way interaction with local communities and involvement in the energy planning process is now realised as an important and necessary way to promote the low carbon transition (Buchanan *et al.,* 2018).

This paper describes the application of an online and interactive local area energy mapping tool (LEMAP) to assess air source heat pump (ASHP) suitability for 865 dwellings in a suburban area of Oxford, UK. The LEMAP tool brings together GIS based spatial data on energy, buildings, socio-demographics, tenure, fuel poverty and electricity networks to (1) identify the baseline current energy demand, (2) target dwellings that are heat pump suitable but require adequate insulation and support, and (3) target dwellings that are heat pump ready. In addition, the social and economic characterises of the dwellings and the difference between the dwellings that are suitable and ready for heat pumps are also analysed via the LEMAP tool.

Literature review

Decarbonising residential heating is one of the main challenges that must be tackled to achieve the government's net zero carbon emission reduction by 2050 goal because this sector is responsible for about 21 % of the UK's CO_2 emissions (BEIS 2018). Today, about 80 % of dwellings in the UK use gas boiler systems for heating (Office for National Statistics, 2023). The transition to low carbon residential heating is not considered straightforward as it will require fundamental changes to domestic heating methods (Lowe, 2020). Replacing traditional gas boilers with high efficiency heat pumps at scale is considered a solution for this fundamental transition.

Local area energy mapping tools are considered to have potential for promoting low carbon transition at local authority scales. However, because smart energy mapping tools are a relatively new concept for local area decarbonisation, there are questions about their nature, the way they work, and their outcomes. In this regard, Ford et al. (2021) provide insights into these tools, namely that they should be developed based on local requirements and inputs as well as wider impacts and pressures: social, technical, financial, and environmental. Moreover, these tools should implement interaction between "smart", "local" and "energy systems". This study also conducted a deep review on the existing mapping tools to explore their advantages and improvements that can be achieved. A selection of the reviewed tools is listed in Table 1 and the tools are described below.

The London Heat Map developed by CSE (Centre for Sustainable Energy) is a tool that aims to enable local energy projects to identify the districts that have high heat demand and are suitable for district heating (CSE, 2018). This tool combines address-level modelling and analysis of demand data, map layers also involve area-based average heating fuel consumption weighted and disaggregated by address-level data sources. Detailed building-related map layers such as built form, age and tenure are included in this tool. The RCEF (Rural Community Energy Funded) live project map aims to deliver solutions to improve resource efficiency and support carbon reduction targets by helping rural communities set up renewable energy projects. Users can identify the location of projects and obtain related offers or key information via the live project map (WRAPNI, 2020). The Energy Spatial Planning tool was developed by Dublin's Energy Agency and aimed to analyse local energy demand and production within a spatial context. This tool combined district level maps that are made with residential and commercial sector-related information (Gartland, 2015b).

The Leeds Heat Planning Tool which was developed by the local authority of Leeds and energy companies, aims to link commercial opportunities with community needs for meeting wider social objectives of the town or city, such as alleviating fuel poverty. The tool mainly covers three categories of data, which are techno-economic, governance and social categories (Bush and Bale, 2019). The Bristol City Council also developed a spatial mapping tool via the Bristol Community Energy scheme, for supporting users to be involved in local energy projects in the area of energy efficiency, environmental and sustainability matters and benefiting the city in carbon emission reduction by improving participation (Bristol Community Energy, 2020). This is a Google Map-based tool that allows users to obtain information and benefits regarding the local energy projects with which they want to be involved. The Community Energy Hub, which was created by CEE (Community Energy England), also used Google Maps to allow users to identify information about community and local energy projects to get involved. The projects could be identified based on the type, theme and region, and users can also use the Hub to create spots on the map for additional projects and their information (Community Energy Hub, 2020). Finally, a spatial mapping tool developed under the Keep Scotland Beautiful scheme aims to help users identify the support that their local energy projects offer (Keep Scotland Beautiful, 2020). This tool is powered by OS maps (Ordnance Survey), the user can find a summary for each involved project, links to further information and contacts via the website and social media. There is also an option to select preferred local authorities and a theme (e.g. energy efficiency advice, transport or building energy efficiency) to find relevant information.

In general, the reviewed spatial mapping tools are powered by either GIS or Google Maps. The GIS-based tools tend to have more geographic area classifications, and the ability to demonstrate data and analysis related to energy demand, fuel poverty, vulnerability, and energy capacity. The Google Maps based tools have simple interfaces and functions. Furthermore, only a few of the reviewed tools considered socio-economic characteristics for the areas the tools aim to deal with. Furthermore, the tools that had this consideration, such as the Energy Spatial Planning tool for Dublin, only provide maps at the district level. These findings reveal that existing mapping tools lack socio-economic data that can help community energy project developers understand better the interplay between building, social and economic characteristics of local areas for designing appropriate offerings for local climate action.

Methods

CASE STUDY

The Rose Hill and Iffley neighbourhood (Figure 1) located in south of Oxford was selected as the case study of this research. The neighbourhood includes 36 postcode zones, 19 streets and 865 dwellings which are mainly serviced by two electricity substations, the Courtland and Fiennes substations. The neighbourhood was selected for heat pump installation because the dwellings within these two substation areas have a significant difference in their social and economic patterns, but the secondary substations are both considered capable for heat pumps installation as they were not overloaded (with load levels between 40 and 60 %) (Gupta and Gregg, 2023). The Rose Hill and Iffley neighbourhood dwellings were mostly built around the Second World War between 1920 and 1945. The primary built forms were semi-detached and terraced, 42 % and 38 % of the total 865 dwellings respectively. In the Courtland substation area, 72 % of the total 368 dwellings were owner-occupied, while only 27 % of the total 497 dwellings in the Fiennes substation area were owner-occupied. Social housing made up 57 % of the Fiennes substation area. Rented properties in the two substation areas were close in proportion, with 22 % in the Courtland area and 17 % in the Fiennes area.

DATA RESOURCES AND MAPPING TOOL

LEMAP was created to spatially and temporally visualise local energy flows and energy profiles in an intuitive manner to help with the planning of heat pump installation at scale in the Rose Hill and Iffley neighbourhood. The development process of the tool was discussed comprehensively in a previous study (Gupta *et al.*, 2021). The tool gathered relevant energy, building, and socio-economic data that allowed the residents, policy makers and related parties to easily understand the context of a select neighbourhood. The tool includes four technical elements, (1) 'baselining' element that includes map layers for local area energy flows in relation to socio-economic characteristics; (2) 'targeting' element which targeted technically suitable properties for ASHP installations; (3) 'forecasting' element that demonstrates energy demand profiles and (4) 'capability' element that shows the different types of capabilities of the case study dwellings. LEMAP was constructed on the ESRI ArcGIS platform using spatial data resources explained below.

Publicly available data

Publicly available data were gathered from government websites including the Department for Business, Energy and Industrial Strategy (BEIS) and DHULC (Department for Levelling Up, Housing and Communities).

- **OS AddressBase** – AddressBase data from the Ordnance Survey were utilised to gather detailed address information including spatial coordinate data for the dwellings on the eligible streets for the project.

Table 1. Review of existing local area energy mapping tools.

Tools	Developer	Purpose	Resolution scale
London Heat Map	CSE	Identify districts that have high heat demand and are suitable for district heating.	Building
RCEF live project map (wrapni, 2020)	WRAP	Improve resource efficiency and support government carbon reduction targets by helping rural communities set up renewable energy projects.	Rural community
Energy Spatial Planning tool	Dublin's Energy Agency	Provide essential information and analysis to local energy projects in Dublin.	District
Leeds Heat Planning Tool	Local authority	For the district heating project in Leeds to tackle fuel poverty.	District
Bristol Community Energy tool	Bristol City Council	To support local energy projects for energy efficiency, environmental and sustainability matters.	Projects point
Community Energy Hub	CEE	To identify information about community and local energy projects.	Projects point
Spatial mapping tool	Keep Scotland Beautiful/ Climate Challenge Fund	For Climate challenge projects in Scotland to tackle climate change	Projects point

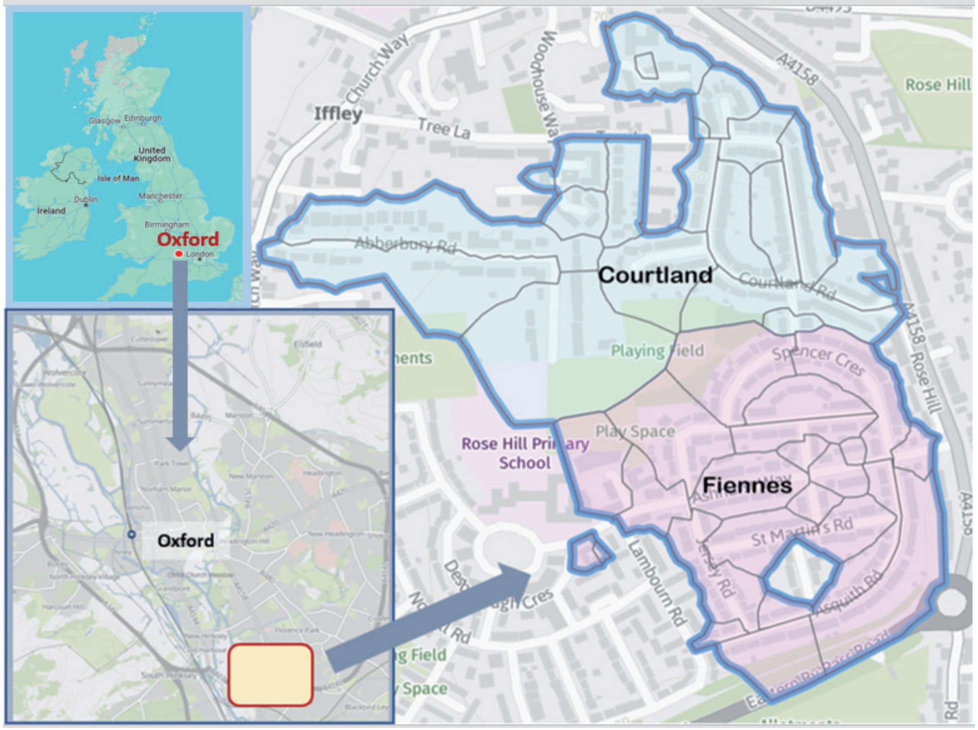

Figure 1. The Rose Hill and Iffley neighbourhood.

- **EPC Open Data** – EPC data for England and Wales; provides a large range of household-level data variables (n=87), including built form, roof insulation, wall insulation, etc.
- **Energy consumption data** – Postcode level electricity and gas consumption data for domestic buildings.

Privately available data

The private data refer to the datasets accessible through special permissions or purchase, the datasets listed below were included in this research.

- **Mosaic dataset** – Experian's Mosaic dataset segments individuals and dwellings based on their demographic, behaviour, and lifestyle characteristics. The Mosaic dataset provides census-based information. It includes 47 data variables such as household composition, tenure, length of residency, etc.
- **Geomni dataset** – Geomni building dataset is a unique database for understanding the age, structure, characteristics and use of commercial, public and residential buildings across the whole UK.
- **Acorn dataset** – Consolidated Analysis Centers, Inc. (CACI)'s Acorn household dataset is a segmentation of the UK's population at the household level. The segment is based on day-to-day life such as financial circumstances, health and happiness.
- **SSEN dataset –** A dataset covering grid and substation data for the area provided by research partner, SSEN (Scottish and Southern Electricity Networks).

Crowd-sourced data

The crowd-sourced data refer to data acquired from residents through an online survey on dwelling attributes (such as built form and envelope insulation), household characteristics (such as the number of occupants and presence of elderly or young persons) and energy use (such as heating type, age of central heating system). Crowd-sourced data helped to enhance community participation by enabling the addition of contextual detail and provision of customised results to residents about their dwelling energy profiles. Crowd-sourced data were displayed with the consent of the user to maintain data privacy.

SUITABILITY ANALYSIS

Three categories were developed to define a dwelling' status with respect to heat pump readiness as follows:

- **Heat Pump Suitable** – Includes dwellings that are suitable for heat pump installation based on their *current* insulation levels as well as dwellings with the potential for improvement of insulation to a sufficient level according to their EPC certificate. In other words, dwellings with either *current* or *potential* EPC level D (or better) were considered to be heat pump suitable.
- **Heat Pump Ready** – Refers to those Heat Pump Suitable dwellings in which the current insulation levels are sufficient, in other words, only dwellings with *current* EPC level D or above were considered heat pump ready.
- **Heat Pump Priority** – Refers to the Heat Pump Suitable dwellings wherein electricity is their main energy source for space heating and hot water. The premise is that such dwellings can easily switch to electrical heat pumps since the existing electricity driven heating systems are likely to be inefficient and need replacement.

This research aimed to target dwellings that were suitable for ASHP deployment within the case study boundary. Limitations were: first, only residential buildings were considered eligible for ASHP installation as the project was focused on residential buildings only. Second, historic listed buildings were excluded as it can be more difficult to address their energy efficiency needs due to their special architectural or historic importance and restrictions. Third, flats were not considered suitable for ASHP installation due to possible space issues for the heat pump unit location.

CAPABILITY ANALYSIS

For the targeted dwellings, a set of four capability assessments were evaluated to establish their ability to efficiently utilise, adopt, afford, comprehend, and accept low carbon technologies (LCT) including heat pumps. The capability approach is also helpful in classifying existing, anticipated and potential opportunities for the targeted dwellings to participate in future smart and flexible energy systems and to identify and classify each household's capabilities and attributes to participate in that opportunity (Banks & Darby, 2021). The capability profile was defined into four categories: technical, digital, financial and social capabilities. In addition, each capability category was graded into four levels to evaluate the grade in which each household relates to the capability profile. The following bullet points explain the capability assessments and the four grades for each capability assessment and their explanations are given in Table 2.

- *Technical capability* – The technical capability evaluates the overall physical ability of dwellings in terms of adopting sustainable LCTs. The LCT considered in this analysis included solar PV, battery storage, electric vehicle (EV) charger, ground source heat pump (GSHP) and ASHP. Potential synergies among these technologies were also considered. The evaluation criteria for each type of LCT were illustrated in a previous research (Gupta et al., 2021). The more LCTs that were technically suitable for installation in the dwelling, the higher the grade.
- *Digital capability* – Digital capability evaluates the engagement of a household in a dwelling with digital technology, including the use of smartphones, computers, broadband, and the level of digital engagement. The digital capability grade was calculated based on Experian's Mosaic digital group classification of dwellings. The Mosaic digital group has 11 types ranging from 'Capital connections' to 'Tentative elders. The connection between the digital capability grades and the Mosaic classifications are also identified in Table 3. The digital capability assessment gives a general overview of the eligible dwellings' abilities to manage the flexible operation of a heat pump and the digital training that may be required.
- *Financial capability* – The financial capability assessment evaluates a household's ability to invest, take some level of financial risk or access capital or funding to deploy LCTs. The grade for measuring a household's financial capability is an average of Mosaic's affluence rating and equivalised household income band grouping. Mosaic's affluence uses several variables such as income, property value, council tax, outstanding mortgage, etc., to arrive at 20 bands. In addition, there are nine equivalised household income bands ranging from >£65,000 to <£10,000. These income bands are Mosaic's adjusted net household income at an address, taking into account income tax, national insurance, council tax and the household size and composition in bands. Table 3 lists the alignment of Mosaic's digital groups and digital capability grades and the explanations of the four financial grades.
- *Social capability* – Social capability assessment is aimed at evaluating the household's motivation towards LCTs, including the knowledge base, skills, and social awareness to understand and value what these could bring to their lifestyle and the environment. The social capability grades are measured based on a combined consideration of EPC and Mosaic data, including the existing LCTs as indicated by EPC assessments and Mosaic's consumer behaviour types labelled Financial Strategy Segments. Table 3 lists the alignment of EPC's LCT data and Mosaic's financial strategy segment groups and the social capability grades and the explanations of the four social capabilities.

Results

According to the suitability analysis, 483 (56 %) dwellings were identified as Heat Pump Suitable, 432 (50 %) dwellings were identified as Heat Pump Ready and 10 dwellings were identified as Heat Pump Priority (1 %). The socio-economic characteristics of these three categories as well as their analysed capability results are explained in detail in the following sections.

HEAT PUMP SUITABLE DWELLINGS

Of the 483 Heat Pump Suitable dwellings, the Courtland substation area included 265 dwellings (55 % of the total suitable dwellings), and the Fiennes substation area included 218 dwellings (45 % of the total suitable dwellings). Within the substation areas, 72 % of all dwellings in the Courtland area were Heat Pump Suitable whereas, only 44 % of all dwellings in the Fiennes area were Heat Pump Suitable. Figure 2 shows the map view of the suitability analysis results for the dwellings that are targeted as Heat Pump Suitable within the project boundary. The map only shows the Heat Pump Suitable dwellings, the dwellings that were not suitable for heat pump installation are filtered out in this map.

A summary of the social economic characteristics of the Heat Pump Suitable dwellings is provided in Table 3. Semi-detached built form is clearly the dominant type for Heat Pump Suitable dwellings at 50 % (n=240). The second is terraced at 39 % (n=190). The age distribution of buildings suitable for heat pumps is largely concentrated in the 1920–1945 age range at 81 % (n=390). Owner-occupied tenure makes up 70 % (n=340) and council housing/housing associations makes up the remaining 30 % (n=143). The family sizes were evenly balanced between families of 1–2 persons, 3–4 persons and over 5 persons (n~160) for each category. The majority of households (45 %) had a relatively high affluence level according to the Mosaic data and as would correspond with this only 37 % (n=178) were considered fuel poor. Experian defines fuel pov-

Table 2. Alignment of datasets variables and capability grades.

Technical capability	
Grades	Grade explanations
Full potential	Fully capable of adopting multiple LCTs
Partial potential	Capable of adopting some LCTs
Need improvement	Capable of adopting technologies if relevant improvements are made to the dwellings.
Unsuitable	Dwellings unsuitable for LCTs, such as listed buildings

Digital capability		
Grades	Grade explanations	Mosaic Digital Groups
Hi-tech users	Dwellings with cutting-edge hardware immersed in digital technology	Capital Connections, Digital Frontier, Mobile City
Tech Savvy	Dwellings composed of avid users of social media and smartphones that aspire to obtain cutting-edge hardware	First-gen Parents, Aspirant Frontier, Online Escapists
Training required	Dwellings that only use digital technology for entertainment, shopping or practical purposes	Upmarket Browsers, Savvy Switchers, Cyber Commuters
Other priorities	Dwellings with limited, little or no interest in digital technology, preference given to non-digital approaches.	Beyond broadband, Tentative elders

Financial capability			
Grades	Grade explanations	Mosaic Affluences	Household incomes
Happy investor	Dwellings with the ability to invest in LCTs without looking for a financial return	Bands 17–20	>£50,000
Venturers	Dwellings with access capital or funding to acquire LCTs and expect some economic payback or delay of payments	Band 16	£30,000–49,999
Penny savers	Dwellings that depend on loans, grants, or programmes to implement LCTs or change life patterns toward energy flexibility	Bands 5–15	£20,000–29,999
Deprived	Socially or economically deprived dwellings with priorities beyond LCTs	Bands 1–4	<£20,000

Social capability			
Grades	Grade explanations	EPC LCTs	Mosaic Financial segment
Fully convinced	Dwellings that prioritise activities towards the environment.	At least one preexisting LCT	Money makers, Established investors
Motivated	Dwellings with some interest and knowledge on the effect of flexible and LCTs on the environment.	No preexisting LCT	Earning potential, Growth phase, Deal seekers, Career experience, Mutual resources, Respectable reserves, Golden age
Sceptical	Dwellings that need to be trained or guided to understand the benefits of implementing LCTs or making changes in their lifestyle to flexible energy patterns	No preexisting LCT	Family pressures, Small-scale savers, Single earners, Home-equity elders, Declining years
Not interested	Dwellings with lifestyles that do not align with using LCTs	No preexisting LCT	Cash economy

erty in Mosaic data as households spending greater than 10 % of their income on fuel. This is different from the Department for Energy Security and Net Zero (DESNZ)'s calculation which involves a fuel poverty energy efficiency rating method, energy cost modelling and housing cost consideration (DESNZ, 2021). Therefore, the fuel poverty proportion examined with the Mosaic data is relatively higher than the proportions indicated by the DESNZ, which ranged between 7–18 % for the area (DESNZ, 2022). Not shown in the table, the majority (72 %) of residents were working age between 26–65; the elderly (66+) accounted for the remaining 28 %.

HEAT PUMP READY DWELLINGS

Of the 483 Heat Pump Suitable dwellings, 432 dwellings (89 %) were identified as Heat Pump Ready. The Courtland substation area included 231 dwellings (53 % of the total ready dwellings), and the Fiennes substation area included 201 dwellings (47 % of the total ready dwellings). Within the substation areas, 63 % of all dwellings in the Courtland area were Heat Pump Suitable whereas, only 40 % of all dwellings in the Fiennes area were Heat Pump Ready. Figure 3 shows the map view of the readiness analysis results for the dwellings that are targeted as Heat Pump Ready within the project boundary. The map only shows the Heat Pump Ready dwellings, the dwellings that were not ready for heat pump installation are filtered out in this map.

A summary of the social and economic characteristics of the Heat Pump Ready dwellings is provided in Table 4. It was found that the characteristics of the Heat Pump Ready dwellings are very close to those of the Heat Pump Suitable dwelling due to the Ready category being a subset of the Suitable category. Note: not shown in the table, the majority (72 %) of residents were working age between 26–65; elderly (66+) accounted for the remaining 28 %. Within the working age group, the mature age group between 46–65 dominated.

HEAT PUMP PRIORITY DWELLINGS

Among the 865 dwellings, about 10 dwellings (1 %) were identified as Heat Pump Priority. Among these, five needed insulation improvements and the other five were ready for heat pump installation. Figure 4 identifies the distribution of these Priority dwellings. Most (n=8) were in the Courtland substation area and the other two were in the Fiennes substation area. Among

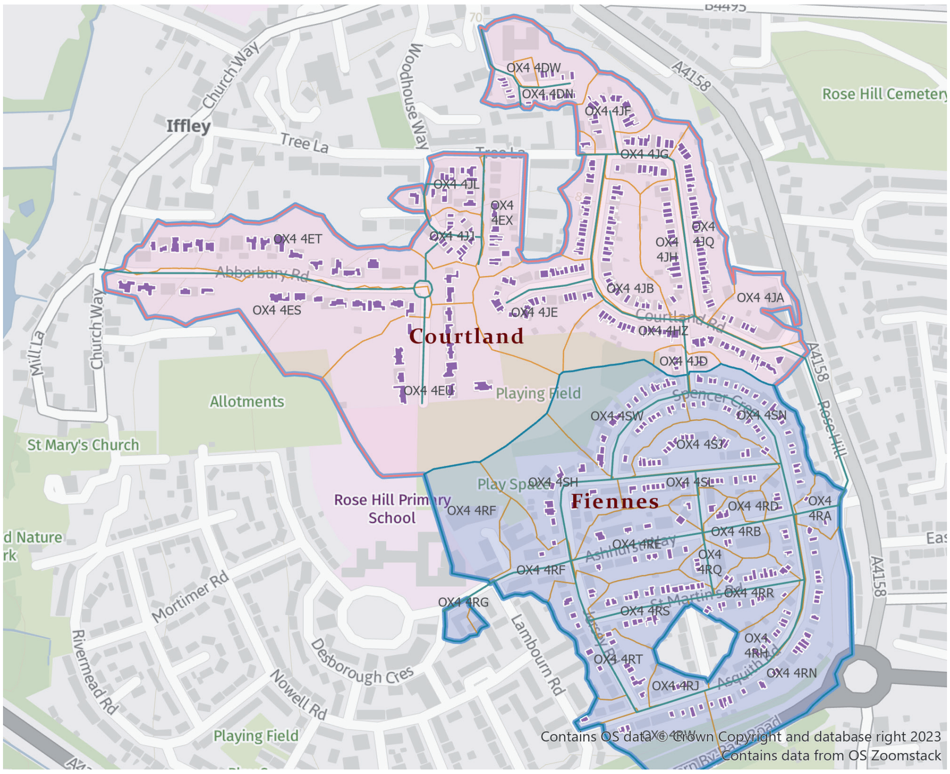

Figure 2. Map view of dwellings that are heat pump suitable within the project and electricity substation boundaries, pink refers to the Courtland substation and blue refers to the Fiennes substation.

Table 3. Social and economic characterises of the Heat Pump Suitable dwellings.

Tenure	Owner-occupied	Privately rented	Council/housing association					
	70 %	0 %	30 %					
Built Form	Detached	Semi-detached	Terraced	Bungalow				
	10 %	50 %	39 %	1 %				
Building age	Pre-1870	1871–1919	1920–1945	1946–1954	1955–1979	1980–1999	2000–2009	Post-2010
	0 %	2 %	81 %	2 %	2 %	11 %	0 %	1 %
No. of residents	1–2 person	3–4 person	5+ person					
	33 %	33 %	34 %					
Bedroom number	1 bedroom	2 bedrooms	3 bedrooms	4 bedrooms	5 bedrooms			
	1 %	16 %	59 %	17 %	6 %			
Affluence	0–4	5–9	10–14	15–19				
	15 %	23 %	17 %	45 %				
Fuel poverty	Yes	No						
	37 %	63 %						

the Priority dwellings, semi-detached and terraced built forms counted a five each. Most (n=7) were built between 1920–1945 and owner-occupied (n=7). Seven dwellings were occupied by working age residents (between ages 26–65) and three by elderly occupants (aged 66+). Nine Priority dwellings had three bedrooms, and one dwelling had four bedrooms. Six of the dwellings were occupied by small families (1–2 persons) and four of the dwellings were occupied but mid-size families (3–4 persons). Finally, seven dwellings had Mosaic's affluence index of 15–19 while three of the dwellings were considered to be fuel poor.

CAPABILITY ASSESSMENT

The following section describes the capability assessment of the three heat pump categories. Figure 5 shows the capability assessment results. The technical capability of the three

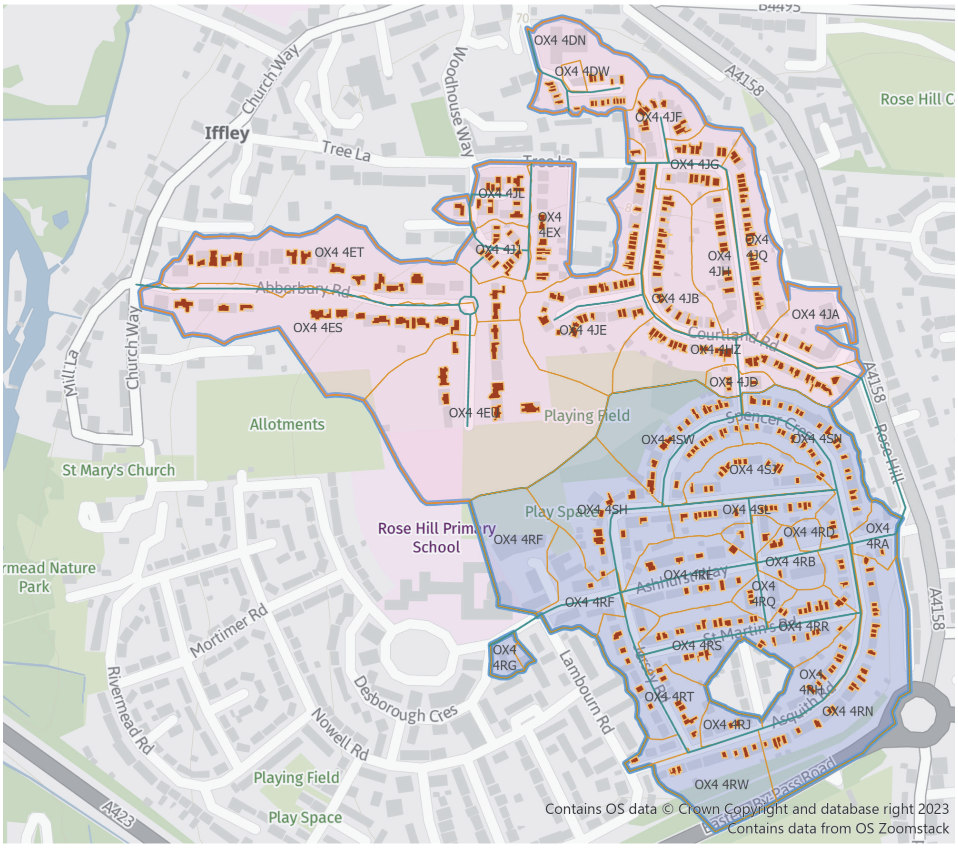

Figure 3. Map view of dwellings that are Heat Pump Ready within the project boundary.

Table 4. Social and economic characterises of the Heat Pump Ready dwellings.

Tenure	Owner-occupied			Privately rented		Council/housing association		
	68 %			0 %		32 %		
Built Form	Detached		Semi-detached		Terraced		Bungalow	
	10 %		50 %		39 %		1 %	
Building age	Pre-1870	1871–1919	1920–1945	1946–1954	1955–1979	1980–1999	2000–2009	Post-2010
	0 %	2 %	80 %	2 %	3 %	12 %	0 %	1 %
No. of residents	1–2 person			3–4 person		5+ person		
	35 %			30 %		34 %		
Bedroom number	1 bedroom	2 bedrooms		3 bedrooms		4 bedrooms		5 bedrooms
	2 %	17 %		59 %		17 %		6 %
Affluence	0–4		5–9		10–14		15–19	
	16 %		23 %		17 %		44 %	
Fuel poverty	Yes				No			
	38 %				62 %			

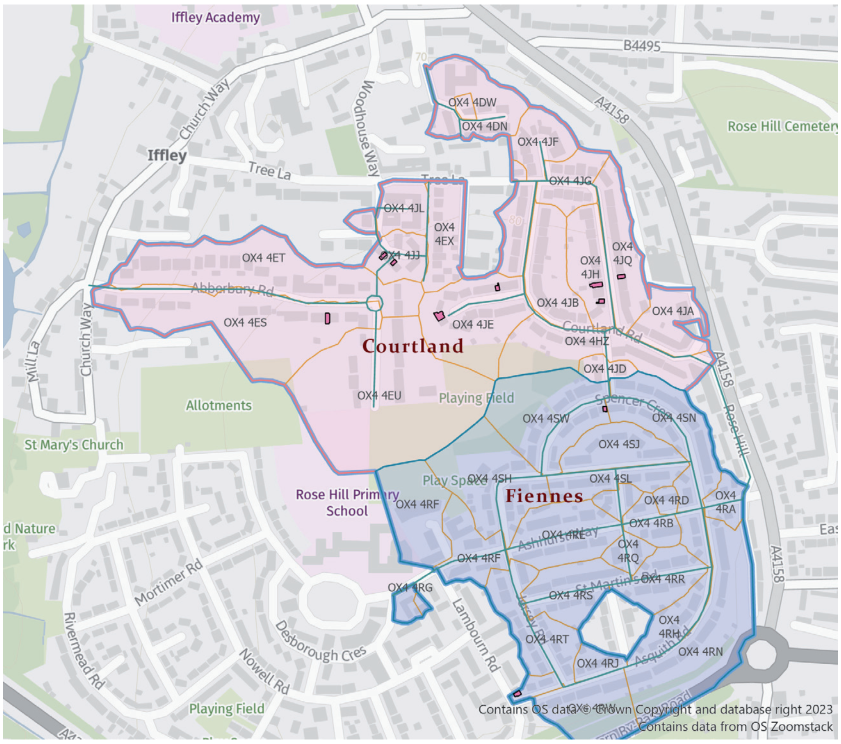

Figure 4. Map view of dwellings that are Heat Pump Priority within the project boundary.

Heat Pump categories indicates a positive result as a majority of Suitable and Ready dwellings had "Full potential". For the relatively low technical capability grades of "need improvement" and "unsuitable", the properties only counted 10 %–1 % respectively. As Heat Pump Readiness requires at least "Partial potential" these account for 0 % in the low range. Again, 50 % of the Heat Pump Priority dwellings need insulation improvements. The result indicates that many of the targeted dwellings have a relatively good level of technical capabilities and are suitable for multiple LCT adoptions, in which the targeted dwellings are all suitable for ASHP adoption currently or pending an insulation level improvement. Though most dwellings are technically suitable for LCTs installation, they would also require training (43–50 %) according to the digital capability assessment. This finding could be significant to the LCT product providers as they are responsible for developing and providing relevant technical training and use skills about their products. Though this is the case, there are several households that can be considered high-tech users (10–20 %) and technically savvy (34–40 %). Households with "Other priorities" are of little concern (1–2 %). Overall, the households were well distributed financially among "happy investors" (24–30 %), "venturers" (30–40 %) and "penny savers" (20–34 %). There was, however, a notable segment of the households that were considered "deprived" (10–13 %). These households will likely need financial support to install heat pumps. Finally, considering social capability, most dwellings range between "motivated" and "skeptical". "Fully convinced" (18–30 %) make up a notable proportion of the dwellings which may help provide social capital when attempting to influence others to take up heat pumps.

Discussion

Local authorities are key players in the UK's decarbonisation process because they connect the micro-scale small group actions and macro-scale states and markets (Tingey & Webb, 2020). However, local authorities need appropriate tools for local area energy planning. The LEMAP tool has provided local intelligence for a neighbourhood area in Oxford to support local area energy transition by replacing traditional gas boilers at scale with energy efficient ASHPs. The LEMAP tool provided an accessible interactive online platform for local authorities, community groups and LCT suppliers by visually integrating socio-economic and technical data to identify dwellings that are suitable for heat pump installation.

The suitability analysis also revealed which types of dwellings were not suitable for the initial deployment of heat pumps. These included mainly privately-rented properties and flats. The split incentive between private landlords and tenants for rented properties needs to be addressed for the take-up of heat pumps. Most of the flats were owned by social housing providers for whom appropriate funding schemes through the Local Authority or energy utility need to be addressed.

The socio-economic assessment of the Heat Pump Suitable, Ready and Priority dwellings provided a comprehensive assessment of the dwellings. It was found that the targeted dwellings had similar social and economic features, they are mostly semi-detached or terraced dwellings that had been built around the period of 1920–1945. In those dwellings, most of them had a suitable living space in terms of the number of residents and bedrooms, however, there is still a small segment of them that are over-occupied and under-occupied. This matters to both occupants and the LCT suppliers because this can influence the sizing of equipment and the heating and hot water demand.

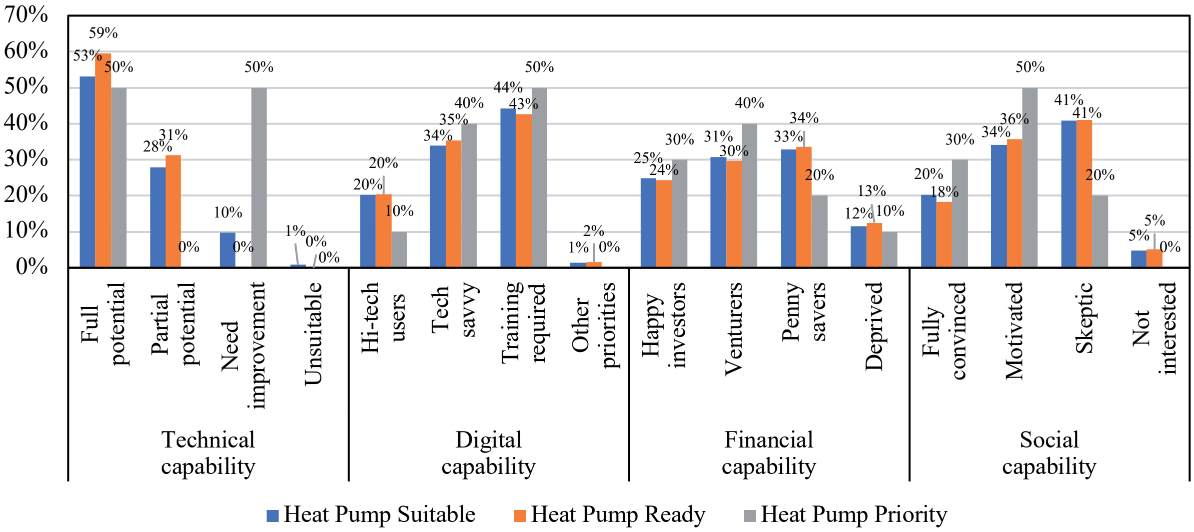

Figure 5. Capability assessment results of the Heat Pump Suitable, Ready and Priority dwellings. Note: the proportions for each capability grade may not sum up to 100 %, this is due to data lockage for a small number of dwellings resulting in unknown results for their capabilities.

Among the targeted dwellings that are suitable for heat pump installations, property tenure, affluence level and fuel poverty conditions between the two main categories of Heat Pump Suitable and Heat Pump Ready were relatively similar. More specifically, the targeted dwellings which were owner-occupied homes should have a comparatively better economic capability. Moreover, the percentage of the targeted dwellings which were council housing (about 30 %) was found to be proportionally close to the percentage of dwellings that were experiencing fuel poverty (about 37 %) and had low Mosaic affluence levels between 0–9 (about 38 %). therefore, this part of dwellings is highly likely to face economic difficulties in adopting LCTs. These data and findings are important for local authorities in order to investigate further and develop fair incentive policies.

The capability analysis results showed detailed technical, digital, financial and social capabilities for each of the targeted dwellings for heat pump installation. Despite a significant number of dwellings being evaluated with high levels of individual capabilities, only a few of them had high levels for all four types of capabilities. In many cases, dwellings with high technical capabilities, financial capabilities and social capabilities tended to have low digital capabilities. This suggested the need for training of these householders for the operation of heat pumps and smart controls. Capability assessment also showed that the majority of dwellings had at least one type of good level of capability, which is a positive finding towards decarbonisation. Regarding social capability, those "fully convinced" made up a notable proportion of the dwellings which may help provide social capital when attempting to influence others to take up heat pumps. Together with other findings provided in this research, the local authorities are encouraged to tailor plans and offers that facilitate the swift deployment of heat pumps coupled with resident engagement.

Conclusion

This paper has demonstrated, based on versatile spatial datasets, the application of LEMAP, a new local area energy planning tool to identify dwellings for large-scale rapid and accurate deployment of heat pumps in a suburban area of Oxford (UK). The LEMAP tool combined technical suitability analysis with capability assessment to identify three categories of dwellings for heat pump installations. The tool also evaluated the likelihood of these dwellings to be digitally, socially and financially capable of moving to low carbon heating. The suitability and readiness elements of the 'targeting' approach required data that included building footprints from the Ordnance Survey, Energy Performance Certificates (EPC) and socio-demographics (Experian Mosaic). The electricity grid loading in this suburban area is under 60 % and therefore can support high-density installation of heat pumps. This approach showed that about 483 of the total 865 dwellings in the analysed neighbourhood were considered Heat Pump Suitable (56 % of the target area), of which 432 were considered Heat Pump Ready and 10 dwellings were regarded as Heat Pump Priority.

This spatial approach to local area energy planning not only enhances the precision of planning but also promotes collaboration among key stakeholders, such as local authorities, electricity network operators, and local communities. The findings from this research are utilised by the collaboration between local council and research partners to quickly identify dwellings that may be willing to participate in the UK Government funded Clean Heat Streets project. Building surveys for heat pump installation could be carried out with greater efficiency in the dwellings identified. There are currently more than 50 homes involved in the project, with more than 10 heat pumps installed so far, with this number expected to increase to 100 as the project progresses through to 2025.

Such type of visual and data rich mapping tool can enable the widespread adoption of low-carbon technologies, ultimately contributing to achievement of local Net Zero. Future research could involve comparing socio-economic data obtained from the actual adoption or rejection of heat pumps in the area with modelled assumptions to improve the accuracy of targeting in local are energy mapping. Deployment of heat pumps could also be combined with building retrofit measures (insulation upgrade, triple-glazed windows) and other LCTs technologies such as solar panels and batteries, to gain a holistic idea of local decarbonisation and the implication for additional load to the community grids. This type of data rich spatial intelligence will help local electricity network operators to rapidly approve installation of LCTs in areas with minimal network constraints and encourage flexible operation of heat pumps in areas of network constraints. Such collaborative working is becoming increasingly necessary for achieving place-based decarbonisation.

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