Targeting and modelling urban energy retrofits using a city-scale energy mapping approach

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City authorities, community groups and retrofit installers need to identify suitable local areas and dwellings for installing energy retrofit measures. This paper presents a localised Geographical Information System (GIS) based approach that utilises publicly-available national and local datasets on housing and energy to provide targeted low carbon measures across UK cities. The study uses a rapid city-level energy assessment approach to spatially identify suitable neighbourhoods for particular retrofit measures, based on relative energy use and fuel poverty ratings. A GIS-based carbon mapping model (called DECoRuM) is then used to estimate energy use and potential for energy reduction on a house-by-house level. The improvement measures are aggregated to encourage bulk installations and drive down installation costs.

To identify an appropriate neighbourhood case study area, publicly available datasets were assessed for the town of Bicester (Oxfordshire, UK), which included Ordnance Survey Mastermap, Energy Performance Certificate data (EPC) and sub-national energy statistics available at lower layer super output area (LSOA). When the EPC data for Bicester were compared with the sub-national statistics for Bicester, the average difference was found to be ~800 kWh. This is interesting as EPCs represent dwelling specific but modelled data whereas sub-national datasets represent actual but aggregated data. Superimposing the above datasets, a neighbourhood in southwest Bicester was selected as having the highest percentage of dwellings with energy consumption >300kWh/m^2/yr (EPC), most dwellings in need of wall insulation (EPC), second highest mean total energy consumption (sub-national), and third highest percentage of fuel poor dwellings (sub-national). House-level energy assessment in the selected area using DECoRuM showed that a package based approach comprising fabric and heating system upgrade and solar PVs emerged as the most effective.

Keywords: Cities, climate change, mass retrofit, housing, energy demand, GIS

Highlights

- Local energy mapping approach rapidly identifies appropriate areas for energy retrofits
- Community engagement through Facebook is found to be highly effective in gathering data albeit from those with digital access.
- Spatial visualisation is effective in providing energy feedback to local authorities.
- Proposed approach can be used to aggregate installation of measures to drive down costs.

1 Introduction

Cities are responsible for three quarters of global energy consumption and subsequent greenhouse gas (GHG) emissions (Gouldson et al., 2016). As of the 2011 census, 82% of the population in England and Wales lived in urban areas (ONS, 2013). Building related energy consumption in the residential sector alone is responsible for 23% of total UK carbon emissions (Bonfield, 2016). In addition, over three quarters of the 28 million dwellings in the UK were built before 1980; resulting in a majority of the domestic stock pre-dating energy efficiency standards. Based on construction and demolition rates, over two thirds of the homes that will exist in the UK in 2050 have already been built (Boardman, 2007). In addition to having one of the most inefficient housing stocks in Europe (Guertler et al., 2015), the UK also has one of the highest number of households classified as fuel poor in Europe (11% in 2014). It is the poor state of the housing condition which is the lead cause for inefficiency and fuel poverty (Bonfield, 2016; Guertler et al., 2015).

As is set out above, there is a clear need for domestic retrofit in the UK (Dowson et al., 2012) and policy in the UK has shown that it is a priority for the UK Government. Furthermore, the essential aims of retrofit for registered social housing providers are consistent throughout the country: tackle fuel poverty, create healthier environments for tenants and to reduce fuel bills (Smith and Abbott, 2017). Specifically, the UK approach to energy efficient retrofit involves improving thermal efficiency through better insulation and improved airtightness, improving heating efficiency through installation of advanced systems and reduced electricity consumption through energy management (DECC, 2014).

The 2011 UK Carbon Plan states that “By 2050, all buildings will need to have an emissions footprint close to zero” (HM Government, 2011, p.5). In response to this, the UK developed a number of retrofit policies including Carbon Emissions Reduction Target (CERT), Community Energy Savings Programme (CESP), Warm Front, and the Green Deal (Dowson et al., 2012). In 2013 the Energy Company Obligation (ECO) replaced CERT, CESP and Warm Front as a single policy covering supplier obligation to improve domestic efficiency and is the largest domestic energy efficiency programme in Great Britain (DECC, 2014). The ECO is due to be upgraded in spring 2017 to sharpen its focus more on fuel poverty. Whereas the ECO is largely focused on solving the hard-to-treat and fuel poverty issues, the Green Deal was a retrofit scheme for able-to-pay domestic customers. In 2015 the Green Deal was abandoned due to the lower than expected uptake; however, a replacement programme is expected to be resolved in 2017 to cover the able-to-pay and private renter portion of the domestic sector (Pratt, 2016).

1.1 Urban modelling for large-scale energy retrofit

Most of the innovation in energy retrofit work to date has been focused on individual house demonstrators (Gupta et al., 2015). However, in order to meet the UK’s legal target of 80% emission reductions by 2050, against 1990 levels (CCC, 2015), scaling up in the form of mass energy retrofit is necessary. Mass-retrofit is the process of improving the energy performance of multiple dwellings at a community or city scale. Due to economies of scale, mass-retrofit is considered to reduce capital costs, although there can be significant barriers, such as not all private dwellings agreeing to participate (Cityfied project, 2015). It is also recognized that large-scale energy retrofit schemes can help alleviate fuel poverty (Webber, Gouldson, and Kerr, 2015), meet national carbon targets and improve the local economy (DECC, 2014), but they need to be better targeted, more cost-effective and result in a higher uptake. Retrofit providers offering energy solutions also find it difficult to identify their target customers due to lack of household-level data.

Following the shift of involvement and action to reduce emissions from the central government to local government and community based groups (Wade et al., 2013); local government and community groups now require the tools to assess their local housing stock in order to improve it. Building stock models are a useful tool to meet this need. According to Kavgic et al. (2010) ideal building stock models should at a minimum estimate baseline energy consumption disaggregated to building level, explore impact of reduction strategies, and not be confined to energy alone.

There are a large number of models capable of evaluating local housing stock to meet this need (Kavgic et al., 2010). The modelling can take two approaches, bottom-up and top-down. Methodologies for these approaches are described in detail elsewhere (Böhringer and Rutherford, 2008; Strachan and Kannan, 2008; Swan and Ugursal, 2009; Tuladhar et al., 2009); however, in the context of residential energy use modelling they are summed up as:

- *Top-down approach*: overview of energy consumption at the scale greater than a single dwelling, e.g. medium or lower layer super output area (MSOA / LSOA) level sub-national consumption statistics (DBEIS, 2016b)
- *Bottom-up approach*: uses input data which is more detailed than the sector as a whole (Swan and Ugursal, 2009)

A large number of residential energy models are reviewed in Swan and Ugursal (2009) and Kavgic et al. (2010); however, local government and community groups require a full approach to mass-retrofit which utilizes these urban energy models but also communicates the results in a user-friendly way, has the capacity to be updated based on resident input and can guide the user through the retrofit process. To serve this need in Wales, Jones et al. (2013) used a GIS based Energy and Environmental Prediction model, with an embedded sub-model (among a range of sub-models) based on the UK Standard Assessment Procedure (SAP) to estimate the house energy performance and carbon dioxide equivalent (CO_2e) emissions, and to assess the impact of carrying out energy-conservation measures. Specifically with regard to residential energy consumption, the model has the capacity to predict needed targeting of specific house types to achieve particular savings in relation to retrofit costs.

There are also strong examples of GIS-based data representation sources (with or without background models) which have been developed in the UK to visually communicate energy related data for use in the building sector. To name a few, the annual sub-national energy and fuel poverty data (DBEIS, 2017) are available at aggregated scales, providing top-down data for models, e.g. LSOA comprising 400-700 households (ONS, 2017). The National Heat Map (CSE, 2017) is freely accessible online for the planning and deployment of low carbon energy systems; to help identify locations where heat distribution is most likely to be beneficial and economic. The City of Bristol provides a house-by-house level view of the potential to install solar energy systems (BCC, 2017). Energy Saving Trust's Home Analytics (EST, 2017) provides information on the potential for energy-saving retrofit measures as a service to retrofit providers and energy companies.

Beyond the UK, energy maps have also been developed internationally to assist utilities program administrators in the USA (Crowley and GL, 2014), energy policy makers in Greece (Balta, 2014) and citizens, public administrators and government agencies to perform city wide analyses on energy performance of the building stock in Italy (Di Staso et al., 2014). Kolter and Ferreira Jr (2011) describe a methodology for the creation of energy consumption mapping in Cambridge, USA for energy companies or retrofit providers to target homes for potential retrofits. Fonseca and Schlueter (2015) describe a similar GIS based model (although visualized in three-dimensions (3D)) for the analysis of building energy consumption patterns and retrofit, with a focus on energy systems, in neighborhoods and city districts utilized in Switzerland. Also, Nouvel et al. (2015) and Wate and Coors (2015) demonstrate a model called SimStadt in Germany which presents 3D visualizations of energy demand, CO_2e emissions, savings, refurbishment scenarios and solar energy potential. The model data sources such as building registers and censuses, meteorological data, gross volume, surface type (roof, wall, and ground) and sun-wind exposed surface area mathematically derived from the building geometry encoded in a CityGML model and building physics attributes are the default benchmark data for given building archetypes. Most of these methods provide aggregated results for targeting areas for energy improvements; and are generally created for local authorities, retrofit providers, or utilities, i.e. energy savvy stakeholders. In contrast, the proposed method is formulated to communicate dwelling level energy performance to householders and to allow local groups like low carbon community groups and neighborhood organizations to take control of the information that is needed to promote, guide and monitor retrofit activity in their local areas. These beneficiaries may not be aware of the opportunity and may have a high barrier to participation, e.g. through lack of awareness, distrust or poor digital literacy. To this end, the paper describes the methodology and application of a new localised and data-driven energy mapping approach for targeting and modelling energy interventions in urban areas.

This study was undertaken as part of a 15-month UK Government (Innovate UK) funded research project (LEMUR – *Local Energy Mapping for Urban Retrofit*) to develop and deliver a service for local authorities, housing associations and community groups, using data to better plan and deliver area-based energy efficiency programmes. The overall approach of the LEMUR project (figure 1) is to rapidly identify the local areas most in need of energy improvements using publicly available data along with local authority's own data; assess the dwellings where maximum and cost-effective energy savings would be made; and then record delivery of the energy improvements. Currently, as evident by the failure of the UK Green Deal policy, the retrofit delivery process is disjointed, lacking sufficient information / poorly communicated to the public, and lacking incentive (Rickaby, 2016). The proposed process intends to streamline retrofit by allowing local groups to arrive at conclusions based on publically available data and effectively communicate and track retrofit need through visualizations.

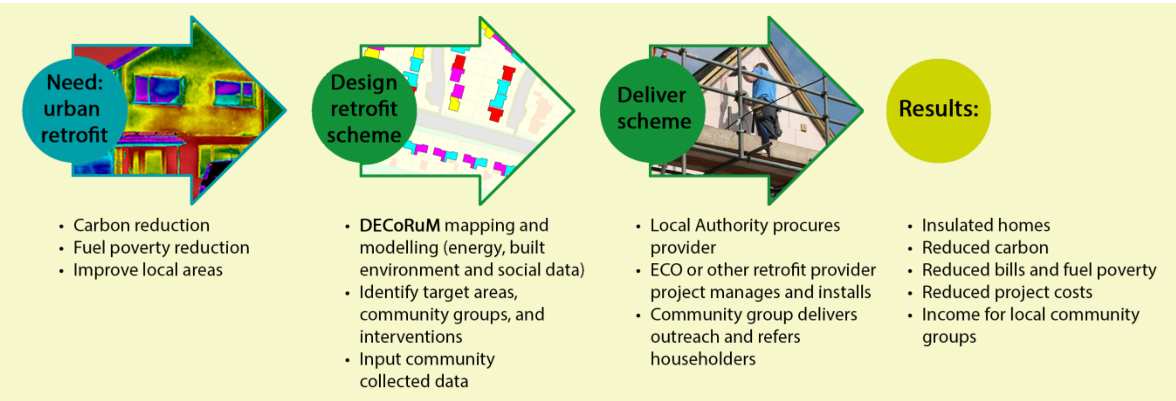

Figure 1. Overall approach of the LEMUR research project

The paper is organized as follows: section two details the methodology and is split into three sub-sections which outline the approach; section three describes the results of the rapid energy assessment and the detailed modelling; section four is the discussion which explores the effectiveness of different outreach methods and three ways to utilize the findings to approach retrofit in local areas; finally section five concludes the paper.

2 Methodology

The retrofit approach was tested in Bicester (a town in Oxfordshire, UK) and involves the following steps:

1. Rapid energy assessment to identify the local area to be targeted

2. House-level data collection for enhanced modelling to build the baseline model of the targeted area
3. Options appraisal to identify what measures are suitable for the targeted area on a house-by-house level (includes stand-alone measures or packaged measures)

Following the installation of the measures, the actual household energy use can be fed back into the neighborhood model to keep an up-to-date energy assessment of the area.

2.1 Rapid energy assessment

The rapid assessment approach involves spatial mapping (using GIS) and superimposing a variety of publicly-available top-down (aggregated) and bottom-up (house level) datasets to identify the local area having dwellings with high energy consumption, and/or high fuel poverty, and dwellings in need of energy improvements. The datasets/data sources used in rapid energy assessment include:

- *Ordnance Survey (OS) MasterMap Topography layer* and *OS Address-Point*: OS MasterMap Topography layer and Address-Point are needed to identify dwelling location and characteristics (e.g. building form).
- *Energy Performance Certificate (EPC) dataset*, over 6000 dwelling EPCs in a single spreadsheet, obtained from the Department for Communities and Local Government (DCLG, 2017) via Cherwell Council. This dataset includes dwelling energy related information (e.g. wall type, insulation, heating system, annual energy use) compiled through domestic energy assessments at address level by trained individuals. The data collection process began in 2008 and is ongoing.
- *Sub-national energy consumption statistics* (DBEIS, 2017) and sub-national fuel poverty statistics (DBEIS, 2016a), obtained from the Department for Business, Energy & Industrial Strategy: Sub-national datasets are free to use publically available datasets of metered consumption collected from fuel transporters (DBEIS, 2016b). The data are aligned with LSOA covering approximately 400-700 dwellings.

The topography layer forms the base map, EPCs and sub-national datasets were then geo-linked to the base map to be visualized: EPCs were connected via the OS Address-Point at each individual address point and LSOAs were manually outlined, then linked to sub-national data. The findings, energy consumption, fuel poverty rate, retrofit need, e.g., cavity wall insulation, are then identified for clusters of LSOAs and at LSOA level. This process is illustrated in figure 2. The arrow at the bottom of the figure, overtaking the mapping phase, indicates that calculations can be done without mapping; however, mapping is useful for communicating results.

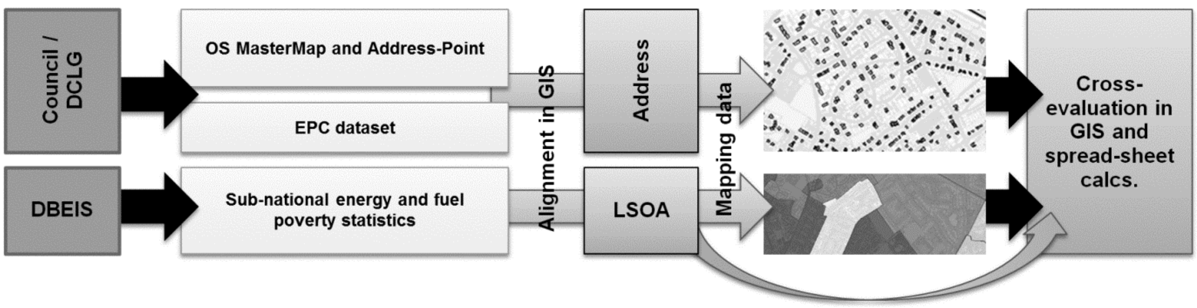

Figure 2. *Rapid energy assessment method*

After a rapid assessment is performed, a local area for detailed focus is selected based on specific retrofit goals which may be energy reduction, fuel poverty elimination or deployment of renewables. For this study, an LSOA with high energy consumption and fuel poverty was selected for detailed focus. In summary, a combination of energy consumption and fuel poverty data from EPCs and Sub-national datasets were mapped in GIS, overlaid, and isolated in order to make a selection.

2.2 Further house-level data collection for enhanced modelling

To prepare for retrofit options appraisal of the selected area, a detailed bottom-up energy analysis is helpful to 1) fill in the dwelling characteristics data gaps (i.e. where EPCs do not exist) and 2) provide estimated energy consumption data for every household. To undertake this detailed energy analysis of the selected area accurately, more primary data are collected for modelling. This data collection involves both desktop research and home energy surveys gathered through various techniques of community engagement.

2.2.1 Desktop research

The DECoRuM[1] model is used for assessing dwelling level energy use and CO_2e emissions (Gupta, 2009). DECoRuM is a GIS-based energy model with the capability to estimate current energy-related CO_2e emissions and test the effectiveness of a number of best practice energy efficiency measures and low/zero carbon technologies in homes. The model aggregates the results to a street, district or city level. The background calculations of DECoRuM are performed by BREDEM-12 (Building Research Establishment's Domestic Energy Model) and SAP 2009 both of which are dynamically linked to create the model. For context, there are more inputs than that required for EPCs; however, the data are collected based on dwelling statistics, external observations, and ideally where possible, occupant-completed home energy surveys. To inform the DECoRuM model and satisfy BREDEM-12 and SAP calculations, actual house characteristics are gathered from the following in table 1.

Table 1. Data sources

Method	Source	Example data collected
Historic and current maps	Historic Digimap, Ordnance survey, Google maps	Dwellings age, dwelling form, floor area, roof area, roof orientation, existing solar energy systems, window size and type, etc.
On-site assessment		
Home energy surveys		Number of occupants, insulation details, boiler type, secondary systems, heating set-point, solar energy systems, etc.
Dwelling statistics	Literature describing home characteristics based on age and typology (e.g. English House Condition Survey, BREDEM-12 reference tables (Anderson et al., 2002), UK Housing Energy Fact File (Palmer and Cooper, 2013)	

To simplify data collection, assumptions are made where data is not generally available. Examples of assumptions made in the model include:

- heating set-point, unless known, is assumed to be 21°C (as default in the BREDEM-12 model and SAP);
- occupancy, unless known, is calculated from floor area using the BREDEM-12 method;
- street-facing windows and frames are directly observed but all other unseen windows are assumed to be the same; wall construction and U-values (unless known, e.g.

[1] Domestic Energy, Carbon counting and carbon Reduction Model. Refer to Gupta (2009) for more background on the DECoRuM methodology and detailed modelling aspects.

reported in EPCs) are based on the age of the home where construction methods are well documented (e.g. BREDEM reference tables);

- if the home has double glazing which is easily observed, then the home has at least 100mm of loft insulation (this is to reflect the large amount of homes which have up to 100mm of loft insulation installed (over 90%) (Palmer and Cooper, 2013). EPC information or survey data on loft insulation supersedes this assumption;
- if the home has a solar hot water system, then the domestic hot water tank (assumed) has foam insulation (at least 35mm).

Calibration of the energy model is done by aligning the mean CO_2e emissions of all dwellings calculated using DECoRuM with the mean of the total CO_2e emissions as calculated from the sub-national energy consumption data at LSOA level. Where heating set-point is not known (gathered only through survey), the assumed heating set-point is reduced to align the CO_2e emissions results.

2.2.2 Home energy surveys and community engagement to collect data

Home energy surveys are helpful in gathering real data about home characteristics that cannot be gathered from observation of the dwellings and are helpful in minimizing assumptions. Some points of data and results collected from the home energy surveys for the dwellings, which were included in the mapped study area, are listed below in aggregation.

- Built form: 39% semi-detached, 34% detached, and 27% terraced
- Built age: 15% 1920-45, 79% 1946-79, 4% 1980-95, and 2% 1996-2005
- Construction: 94% brick construction, 6% timber; 92% full double glazing
- Mean occupants: 2.7 occupants
- Mean annual energy bills cost: £968
- Mean heating set-point: 19.3ºC (As can be seen here the mean heating set-point is lower than the assumed modelling set-point; validating the process of lowing the set-point to calibrate the model.)

As part of the study, a range of community engagement activities were used by the local authority, to promote the study locally and to maximize the number of home energy surveys completed. These methods included:

1. *Door-stepping*: project team members approached residents at their homes to explain the study and get the surveys filled. The completed surveys were manually entered into the LEMUR platform.
2. *School engagement:* three primary schools in the neighbourhood were asked to promote the project by sending home letters (with link to online survey) with children.
3. *Day centre (activity space for elderly)*: two representatives from the local authority attended a day centre in the neighbourhood to explain the study to the visitors (local residents) and complete the energy surveys.
4. *Church group meeting*: two representatives from the local authority attended a group meeting for middle-aged generation at a local church to have surveys filled.
5. *Local library:* a member of the local authority approached the library visitors (mainly local residents) to have surveys filled on a single day in August.
6. *Community action group:* The research team also collaborated with the local low carbon community group - worked to promote the project to the local residents and get energy surveys completed.
7. *Facebook campaign:* The local authority team also created a Facebook post to promote the project and get local residents to complete the energy surveys.

2.3 Modelling and options appraisal

The DECoRuM baseline energy model generates a large number of results including annual CO_2e emissions, annual energy consumption, and annual running costs. In addition, any number of inputs or assumptions can be mapped, e.g., which dwellings have or need cavity wall insulation, loft insulation, photovoltaics (PV), etc. The results for each household are displayed on a map using GIS; in this instance, MapInfo and ArcGIS.

Single retrofit measures and or retrofit packages are recommended via maps showing the impact of the retrofits on the dwellings. The initial success of measures, i.e., reduction of CO_2e emissions, is evaluated by creating model variants which run scenarios for each dwelling. As examples, insulation levels are set to current building regulation levels, double and triple glazing, boilers are upgraded to 88% efficiency, alternative heating systems are tested, and solar energy systems are tested. To formulate packages, best performing measures are selected and combined. To establish whether a measure is valid the following 'reduction assessment method' steps are taken in the model:

1. A simple payback (c) is calculated based on a static reduction in annual running costs (b) and current cost to install a measure (a).

$$a / b = c. \quad (1)$$

2. Install potential (yes / no) must fulfil the following:
   - Is there a reduction in energy use?
   - Is there a reduction in running costs? (includes Feed-in Tariff (FiT) and Renewable Heat Incentive (RHI) payments)
   - Is the simple payback period (c) less than the life of the measure?

3 Results

3.1 Rapid energy assessment

For the rapid energy assessment, sub-national energy data and EPCs were mapped for the town of Bicester. Figure 3 shows the sub-national energy and fuel poverty results. The different sections represent LSOAs. The data show that the southwest quadrant 'quad-SW' (in the bold outline) contains some of the LSOAs with the greatest energy consumption and the greatest fuel poverty. It is interesting to note also that the LSOAs with the lowest percentage of fuel poor dwellings are on the perimeter of the town.

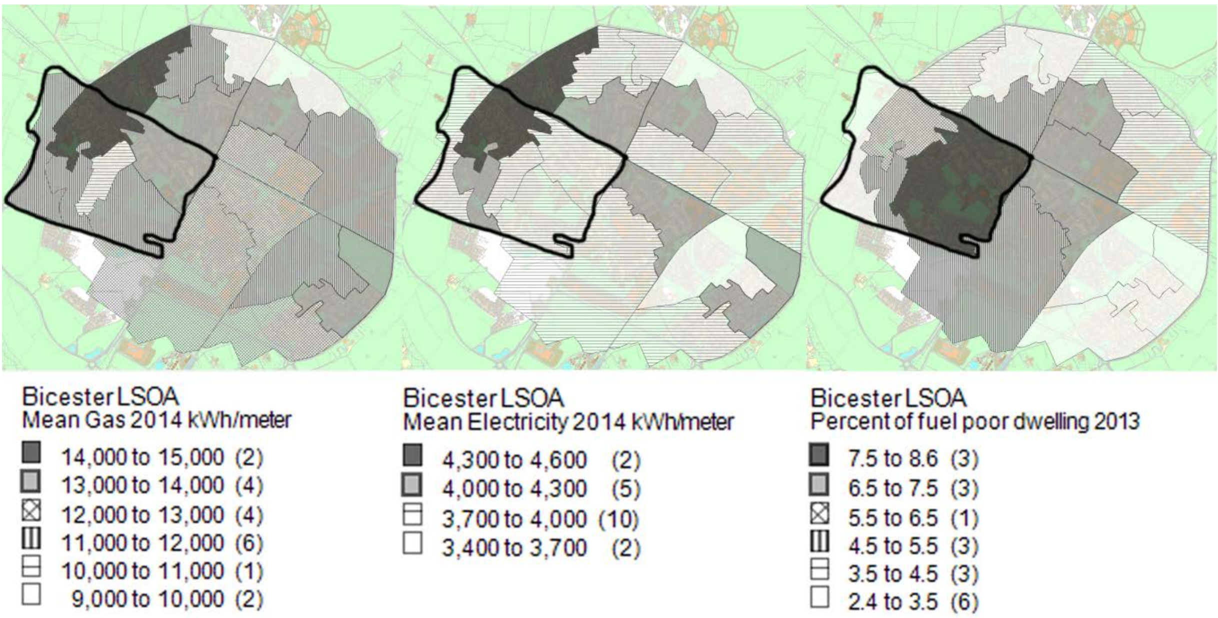

Figure 3. *Maps of mean gas consumption 2014 (left); mean electricity consumption (centre); percent of fuel poor dwellings 2013 (right). Note: the black lines indicate LSOA divisions. Background maps© Crown Copyright and Database Right 2016. Ordnance Survey (Digimap Licence).*

Figure 4 shows examples of EPCs mapped. For the town of Bicester; there were a total of 5,453 dwellings with valid EPC data. The EPC data revealed that:

- Only about 1% of dwellings in the entire EPC dataset for Bicester lack double glazing.
- There are around 500 uninsulated cavity wall dwellings and 250 uninsulated solid wall dwellings in the entire EPC dataset for Bicester; i.e. about 14% of dwellings need wall insulation.
- The south west quadrant of Bicester (outlined in figures 3 and 4) contains the most dwellings in need of wall insulation: 198 cavity wall houses with no insulation (40% of total uninsulated cavity wall) / 47 solid wall houses with no insulation (21% of total uninsulated solid wall).
- Over 50% of the dwellings with known roof insulation levels in the EPC dataset for Bicester have less than or equal to 150mm of roof insulation; these dwellings could possibly double their insulation levels.
- Over 85% of the Bicester EPC dataset is heated by gas boiler system with radiators.

Figure 5 indicates that in the south west quadrant, LSOAs 014B, 014C and 014D have the greatest energy consumption per dwelling area. Particularly, LSOA Cherwell 014C has the greatest percentage of dwellings with annual energy consumption above 300 kWh/m^2.

Figure 4. *Map of dwellings with EPCs and close-up of total energy consumption (kWh/m²) figures from EPCs for dwellings. Note: the black lines indicate LSOA divisions. Background maps© Crown Copyright and Database Right 2016. Ordnance Survey (Digimap Licence).*

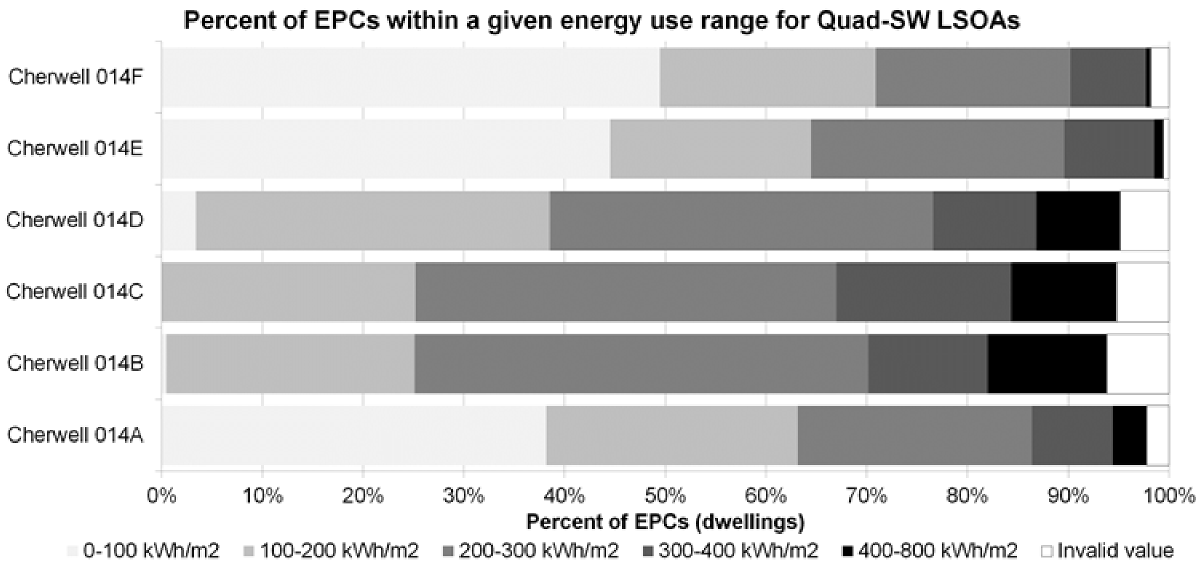

Figure 5. Per cent of total energy consumption for each Quad-SW LSOA

Table 2 shows the sub-national and EPC statistics for the three LSOAs with the greatest energy consumption. When the entire EPC dataset for Bicester was compared to the entire town of Bicester's sub-national figure, the values were only off by ~800 kWh. On the other hand, according to the comparison of EPCs in the LSOAs with the sub-national data per matching LSOAs, there appears to be an over-estimate of between 3,000-4,000 kWh/yr (16%) in the mean energy figure for the EPCs. The potential older age of EPCs versus the single year sub-national data and the modelled EPCs versus actual metered sub-national data may be some of the reasons for the discrepancy between sub-national energy data and EPCs. Other EPC limitations include:

- EPCs are valid for up to ten years (BRE, 2012), i.e. some EPCs can be out of date regarding some changes.
- Because a full SAP for EPC ratings is too complex, the Reduced Data SAP (RdSAP) was developed to rate existing dwellings for this purpose. RdSAP reduces data collection and deduces a large amount of missing data. However, EPCs are required

to be within +/-5 SAP points (assessed through quality monitoring) (BRE, 2012). Examples of calculations for data reduction:

  - The model assumes that occupants heat their houses to 21°C (living rooms) and 18°C (other rooms). However, many households are likely to heat their homes to different temperatures (Bridgeman, 2015).
  - Appliance and hot water requirements are made using simplified equations relating to the number of people in a household (Bridgeman, 2015).

- EPCs represent only the dwelling; occupant behaviour, living patterns and economic status can greatly affect real consumption (Sunikka-Blank et al., 2012).

Table 2, Three LSOAs compared with EPC data

	Cherwell 014B	Cherwell 014C	Cherwell 014D
No. of meters (electricity)	636	691	489
No. of EPCs	212	231	206
% of area covered by EPC	33%	33%	42%
	kWh	**kWh**	**kWh**
Mean Total energy consumption (sub-national)*	19,452	17,301	14,761
Mean Total energy consumption (EPC)*	22,645	21,208	17,556
EPC overestimate (kWh) & (%)	+ ~3,100 (+14%)	+ ~3,900 (+18%)	+ ~2,800 (+16%)
No. of EPCs with mean total energy consumption over mean sub-national energy consumption value	**140** (66% of EPCs in LSOA)	**153** (66% of EPCs in LSOA)	**143** (69% of EPCs in LSOA)
Bicester mean 2014 (sub-national)*	16,181		
Bicester mean EPCs*	16,929		
Total mean EPC for the three LSOAs*	20,470		
Average UK consumption* (DECC, 2015c)	**2012**	**2013**	**2014**
	19,841	19,581	16,406

* Consumption figures include both gas and electricity.

3.2 Modelling results

Superimposing the two datasets, considering highest fuel poverty, relatively high energy consumption, and highest percentage of annual energy consumption in the EPCs, an area called Highfield in Bicester was selected for building the house level energy model. The neighbourhood of Highfield covers LSOA Cherwell 014C (Figures 4). Following the selection of the Highfield area from the rapid assessment, an overlay of completed surveys in the area, and limiting the map to roughly 550 – 650 dwellings, a boundary for mapping baseline consumption was selected (figure 6). The selected boundary in figure 6 includes LSOA 014C and a little of surrounding LSOAs. The form is a little more organic as it was drawn to include as many completed home energy surveys as possible. The final modelled area included 58 completed surveys and 222 valid EPCs. *Note: though 'Highfield' is the name for a much larger community in Bicester, the modelled case study area is referred to as Highfield throughout the remainder of the study.*

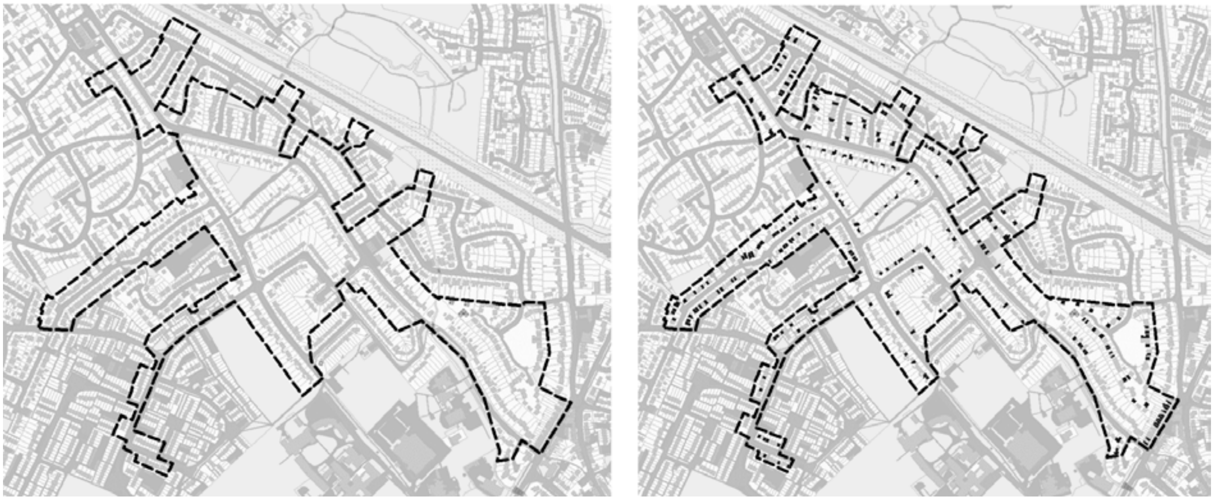

Figure 6. *Selected boundary of modelled area (left); selected boundary with dwellings with EPCs marked (right). Background maps© Crown Copyright and Database Right 2016. Ordnance Survey (Digimap Licence).*

The modelled area as compared to the town of Bicester has a greater representation of semi-detached dwellings (59%) and is mostly made up of dwellings built from the 1930s to the mid-70s, though dwellings range in age from 1920 - 2010 (figure 7).

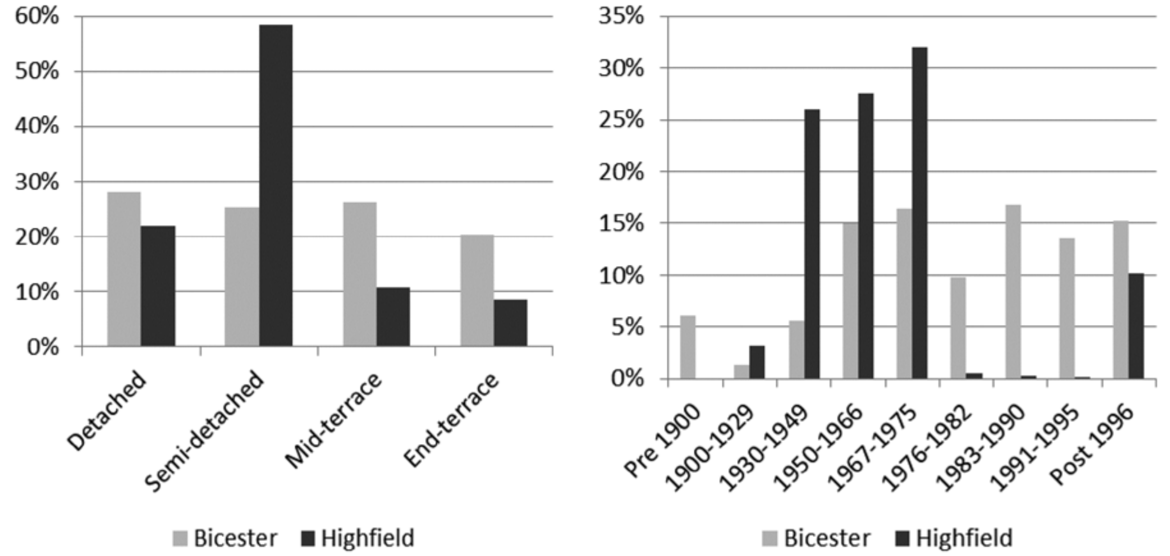

Figure 7. *Dwelling form make-up of the modelled area as compared to the entire town of Bicester (left); age-band make-up of the modelled area as compared to entire town of Bicester (right).*

3.2.1 Baseline maps

The annual energy consumption in Highfield varied between 6,000kWh to 42,000kWh with 110 dwellings consuming between 21,000–26,000kWh per year (CO_2e emissions of 5.4-6.8 tonnes/year). Energy use and CO_2e emissions by most common dwelling types in the selected neighbourhood are listed in table 3. Figure 8 shows a baseline map of dwelling annual energy use in the selected neighbourhood. Note that only a close-up of a section of the map is shown for greater clarity. Figure 6 also shows the solar potential of the dwellings by assessing the available roof area, orientation of the roof and hot water to indicate the potential for deploying solar thermal and/or solar PV systems.

Table 3. Most common dwelling types

Type designation	Dwelling type	Percent of dwellings in Highfield	Percent of dwellings with uninsulated walls	Energy use ($kWh/m^2/yr$)	CO_2e emissions ($kgCO_2e/m^2/yr$)
A	1930-1949 semi-detached	23%	72%	279	59
B	1950-1965 semi-detached	19%	64%	197	54
C	1966-1976 semi-detached	15%	57%	196	55
D	1966-1976 detached	9%	61%	210	58

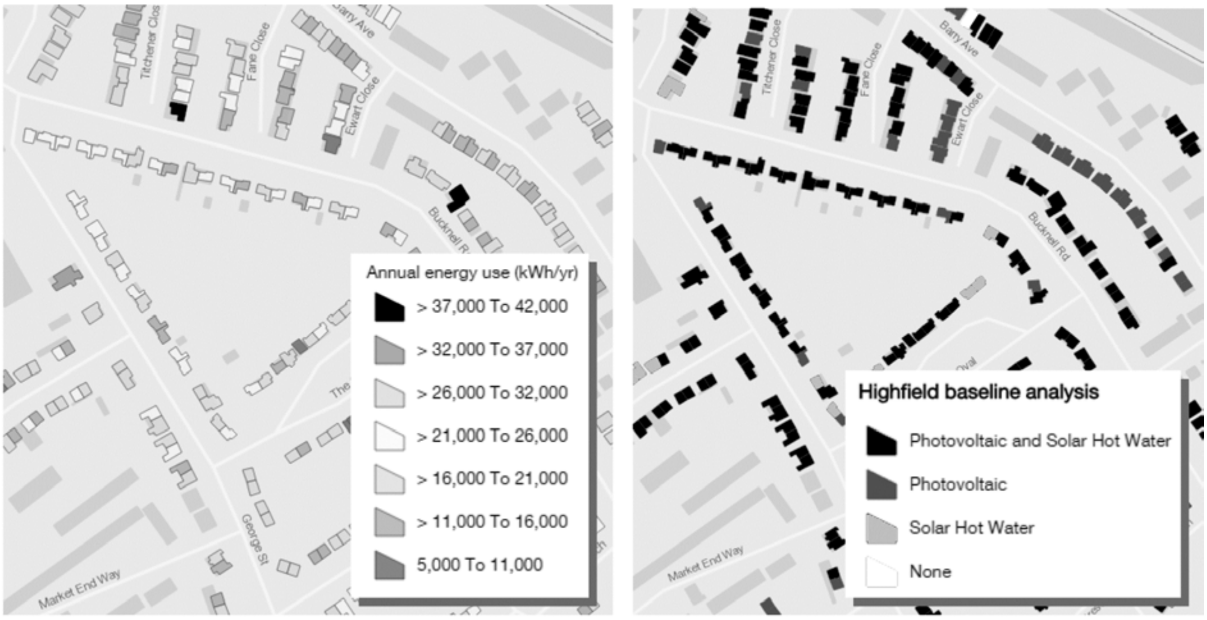

Figure 8 *Total annual energy consumption (left); solar energy system installation potential (right). Maps contain OS data© Crown Copyright and Database Right 2016.*

3.2.2 Options appraisal

The final step is to create recommendations for energy retrofit in the form of improvement packages. Solid wall insulation and cavity wall insulation produced the greatest mean reduction in carbon emissions (30% and 25% respectively). Loft and floor insulation, new condensing boiler, heat pumps and PV panels resulted in mid-range reductions with means ranging from 12-17%. Three hundred and sixty three dwellings could potentially install cavity wall insulation and 542 homes could potentially install ground floor insulation. Only about 4% of the dwellings could pass the reduction assessment method to install heat pumps. This is mostly due to the gas dominance of the area and the seven year limit on the RHI. Finally, though 577 dwellings could install photovoltaic panels, only six dwellings could justify the installation of solar hot water (SHW) systems. SHW is also subject to the seven-year maximum collection period for the RHI, which limits the return on investment for the systems. Photovoltaic panels still appear to be an effective measure even considering a significantly reduced Feed-in Tariff (FiT), (generation tariff in 2016 was about 90% less than when FiT began in 2010 (CE, 2017; Ofgem, 2017)).

The recommended measures tested were therefore grouped into the following packages:

1. *Fabric package:* wall, loft, and floor insulation, double glazing and draught proofing

2. *Fabric and heating package:* fabric package + new condensing boiler or heat pump, hot water cylinder insulation and thermostat, and pipework insulation
3. *Fabric, heating and solar package:* fabric and heating package + solar PV and solar hot water systems

The reduction assessment method revealed that eight dwellings in total could install the complete fabric package and six of these dwellings are 1930s–1960s semi-detached. Four hundred and ninety two dwellings could potentially install a condensing boiler but only nine dwellings could pass the reduction assessment for air source heat pump (ASHP) and 20 for the ground source heat pump (GSHP). The reduction assessment method revealed that six dwellings in total could install the complete fabric, heating, and solar package. Four of these dwellings are 1930s–1960s semi-detached (types A & B). Older dwellings, e.g. 1930-1949 semi-detached (most common type in the area), have shorter payback periods due to greater need for improvement, and are therefore more likely to benefit. Overall, a full fabric, heating and solar package emerged as the most effective with regard to CO_2e emissions reduction on an induvial dwelling basis (figure 9); however, as stated above, only six dwellings meet the installation approval of the reduction assessment method. This emphasizes the need to resolve the up-front cost issue of materials and systems. Table 4 shows the results of the packages on energy consumption and simple payback period.

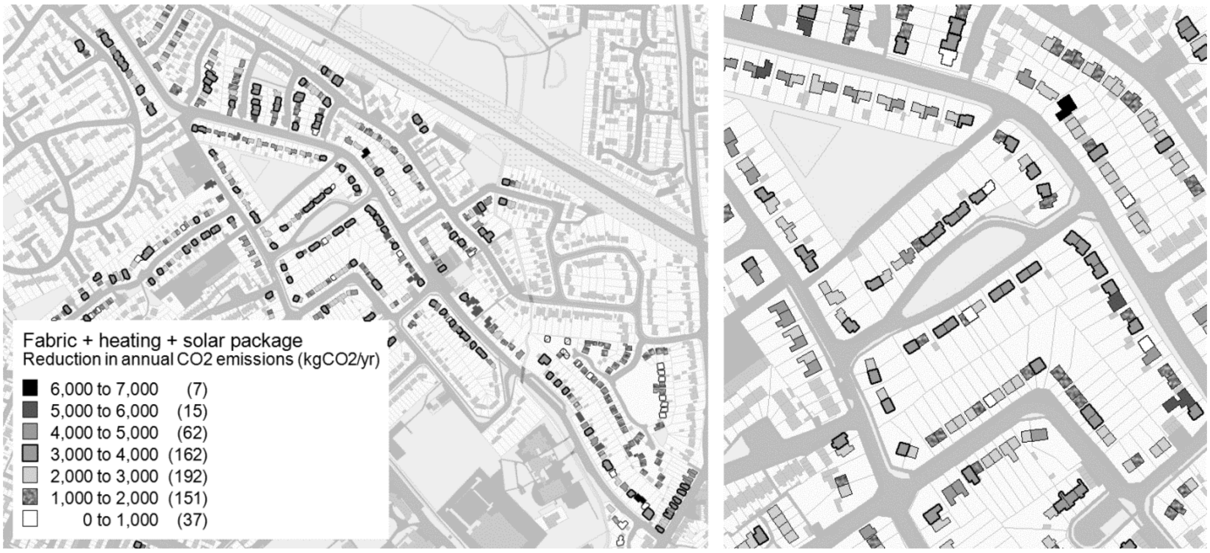

Figure 9. *Fabric, heating and solar package reduction in annual CO_2e emissions: entire map of Highfield (left); close-up of centre (right). Background maps© Crown Copyright and Database Right 2016. Ordnance Survey (Digimap Licence).*

Table 4 Retrofit package results

	Fabric package	**Fabric & heating package**	**Fabric, heating & solar package**
Number of partial or full retrofit packages	543	453	412
Mean % of energy use reduction	29%	41%	46%
Mean simple payback period	10 years	9 years	12 years

4 Discussion

4.1 Community engagement method

The most effective engagement was found to be a combination of church group, community action group and Facebook campaign. The research team worked with the low carbon community group to promote the project to their members. The strength behind the success for the community group was in the way the message and request held more legitimacy by being communicated by a familiar or known individual. The Facebook post reached over 8,000 people, with almost 400 clicks to the survey, resulting in 109 survey completions. The Facebook method was found to be highly successful in terms of effort and cost for return. The total budget was £100 (not including the prize incentives) which resulted in £0.26 per click. The Facebook method required little staff time, is easy to monitor results, and allows for targeting of specific demographics and locations. It is expected that an ideal approach would combine Facebook with other local group engagement to reach particular demographics that do not use social media, whereas, the church group and community group allowed the older demographic to be represented. Table 5 indicates the demographic findings of the community engagement/outreach efforts. It also shows the relative success and the number of surveys filled.

Table 5. Outreach results

	Survey format	Incentive	Demographic	Success*	Surveys filled (total = 234)
Door-stepping	Printed survey	None	Mixed	Very low	55 (24% of total)
Schools (x3)	Promotional letter with link sent home with children	For school	Younger generation with children	Low	40 (17% of total)
Day centre	Printed survey	For day centre	Older generation	Moderate	5 (2% of total)
Church	Printed survey	For church	Middle age	High	12 (5% of total)
Library	Printed survey	None	Younger generation with children	Low	1 (0.4% of total)
Facebook	Link to survey online	Drawing for ten vouchers of £25	Expected to exclude older generation	Very high	109 (47% of total)
Grassroots Bicester	Printed survey	For group	Mix	High	12 (5% of total)

*Success qualitatively measured as effort and cost versus rate of survey return

In contrast, door-stepping is considered the least effective approach considering the effort for return. The approach is labour intensive, requires several members of staff or volunteers knowledgeable about the project, and involves the uncomfortable cold-call scenario. It is recommended that door-stepping be conducted by community or neighbourhood groups so that residents are familiar with the visitors. The library was also unsuccessful considering the large amount of time invested. The general feeling was that residents were too busy to stop and had no interest in completing a survey. They were often with children and were focussed on their purpose for being at the library. The school approach was more effective and less intensive than the door-stepping campaign but overall not successful considering the considerable printing, sorting and packing of letters to be sent home with the children. The schools were provided with an incentive for participation regardless of surveys returned. One question that remains is whether rate of return would have been increased if the incentive was dependent on the rate of survey return. Also, it is possible that sending printed surveys with the busy parents would have improved the return. The day centre approach was considered a worthwhile approach to reach an older demographic; however, there were a few limitations, such as the need to sit, explain and assist the resident with the survey, a large number of residents for which the surveys were difficult to answer or inapplicable (individuals with early signs of dementia or sheltered housing residents). The exercise in reaching the older demographic was ultimately, however, considered worthwhile to educate and raise awareness for measures to achieve affordable warmth and energy savings. It is suggested that pre-screening individuals for applicability be done in these cases. Overall, as engagement efforts took place during the late spring and summer, it is theorised that warmth and energy concerns are not at the forefront of people's minds as they would be in the winter, thereby potentially limiting the response rate.

4.2 Modelling method and results

Outputs from DECoRuM, maps of estimated energy use and CO_2e emission reduction potential of individual households, can provide useful feedback on retrofit need and progress to community groups, residents, and local authorities. Whereas it is traditionally up to the householder to seek out energy retrofit or accept offers for retrofit from salespersons or grants from local authorities on an individual house-by-house basis which could require serving randomly spread dwellings throughout a town or city, the proposed approach provides community groups and local authorities with the information needed to rapidly pin-point local areas of high energy use and to identify potential grouped areas for retrofit. Provided this is used in multiple local authorities, the process would be helpful in building a database of emissions inventories which would help guide other areas in organizing mitigation and adaptation priorities.

After the local area is energy mapped, a number of approaches can be adopted to decide where to focus retrofit, including:

- Focus on common dwelling types which are likely to require the same type of retrofit package; maps can be used to pin-point specific dwelling types,
- Focus on common measures required; maps can pin-point dwellings that need a particular measure or combination of measures,
- Focus on clusters, e.g. hot-spots of high energy consumption.

The first most common dwelling type incidentally also has the greatest mean energy consumption (279kWh/m^2/year); this positions dwelling type A as a worthwhile starting point for retrofit in the area. In addition, common dwelling types are often grouped together making mass retrofit using this method easy to achieve. Table 5 shows the impact of the fabric, heating and solar retrofit package on the common dwellings types. Clearly retrofitting beginning with type A will benefit the area most, where the most dwellings will have a high reduction in energy consumption and running costs. In contrast, baseline energy consumption data can be assessed for areas of high-energy consumption. Alternatively, hot spots of fuel poverty or effectiveness for measures can also be mapped, e.g. mapping dwellings where cavity wall insulation is most effective in reducing energy consumption.

Table 5: Fabric, heating and solar package results

	Type A	Type B	Type C	Type D
Mean reduction in energy use (kWh)	12,493	11,025	9,921	12,572
Mean reduction in running costs	£795	£763	£669	£839

Mean simple payback	11 years	13 years	12 years	12 years
No.of dwellings install full or partial package	2 full 128 part	2 full 73 part	0 full 67 part	0 full 42 part

The maps make energy use visible by highlighting areas of heat loss and potential areas for energy improvements. Other benefits include: use as a communication tool for planning change and funding, visual source for tracking retrofit progress and change. Such a local energy mapping approach would also be beneficial for implementing any national energy retrofit programme and the ECO upgrade planned for 2017 (Pratt, 2016). This would be done by enabling retrofit providers and community groups (acting as mediators between householders and retrofit providers) to communicate and evaluate the need for energy improvements and track any improvements made. The method assists in prioritizing action by providing ECO providers or energy assessors with an overview of homes most in need, estimated consumption and a complete tool for testing potential success of measures or packages.

Because the method is intended to simplify the process and aggregate data, some expected limitations exist (to overcome these, dynamic simulation would be recommended):

- Desktop data collection and entry (e.g. entries from façade observations) can be time intensive.
- Behaviour assessment is limited: occupancy times, heating schedules, window opening schedules, etc. cannot be modelled; however, temperature set point can be modelled and collected via survey.
- Different scenarios must be calculated separately and cannot vary within a given timeframe; calculations are static.
- The model does not calculate where specifically a homeowner should insulate walls and whether internal or external insulation is ideal (insulation is simply either solid wall or cavity).

5 Conclusion

This paper has shown how the challenge of enabling mass energy retrofit in towns and cities, can be tackled by local authorities and community groups, using a systematic assessment of publicly available and spatially based data. This local energy mapping approach has the capability to facilitate wider roll out of energy improvement measures by rapidly identifying appropriate local areas and targeting suitable dwellings for energy retrofits. Mapping helps to aggregate the demand for improvement measures, which can in turn aggregate installation of measures to encourage bulk installations and drive down costs of installation.

Though the data sources shown in this study were specific to the UK, the proposed approach of spatially analysing housing, energy and fuel poverty data has wider potential for application. Many EU countries, for example, have an EPC registry (Commission, 2017) and there are many GIS base-map options available throughout the world (University, 2016). The study has also demonstrated that while spatial analysis can help target neighbourhoods, the outreach activities can increase the detail and potentially improve the modelling of domestic carbon reductions. The proposed approach is therefore potentially applicable to other countries, particularly in the EU.

The key findings from the detailed assessment of Bicester and the modelled area are:

- The final mapped area, selected based on EPCs, sub-national data and availability of filled questionnaires, had the greatest energy consumption in an area with high percentage of fuel poor households, and greater than city average need for wall insulation and roof insulation.

- Engaging the community through Facebook networks to complete homeowner questionnaires provided two-times the response rate as the next best option (door-stepping) and was significantly more effective considering effort, time and cost.
- The most common dwelling type, 1930-49 semi-detached have the greatest mean energy consumption of 279 $kWh/m^2/yr$.
- Among individual retrofit measures, solid wall and cavity wall insulation produced the greatest mean reduction in CO_2e emissions.
- Loft and floor insulation, new condensing boiler, heat pumps and PV panels resulted in mid-range reductions.
- Though heat pumps and solar hot water systems provide decent reductions, the current payback rate on the RHI is not sufficient to justify installation from a cost perspective.
- Despite drastic reduction in the generation tariff of the FiT, thereby increasing the payback period, the modelling has shown that PV panels still provide a good return on investment.
- Overall, a full fabric, heating and solar package emerged as the most effective with regard to CO_2e emissions reduction on an individual dwelling basis.

The proposed approach to spatially identify suitable local areas and aggregate the demand for energy improvements in cities is also found to be visually effective in providing energy feedback to householders and community groups, so as to gain their support for installing measures. The local energy maps can also be used by community groups and city authorities for managing the installation of energy retrofit measures. Future research could link local energy mapping with high frequency energy data from smart meters (given the expected smart meter roll-out in UK by 2020). This would enable evaluation of local energy demand profiles which can be useful for introducing local time-varying energy tariffs, heat networks or community energy systems for local management of demand and supply of energy. A potential limitation to this approach can be data protection, privacy and security; however, where local authorities or energy companies are teamed-up with active community groups or retrofit providers to incentivise participation of the homeowners, this issue can be tackled.

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References

Anderson, B.R., Chapman, P.F., Cutland, N.G., Dickson, C.M., Henderson, G., Henderson, J.H., Iles, P.J., Kosmina, L., Shorrock, L.D., 2002. BREDEM-12 Model description: 2001 Update. Building Reseach Institute, Watford, p. 94.
Balta, C., 2014. GIS-based energy consumption mapping.
BCC, 2017. Solar panels. Bristol City Council.
Boardman, B., 2007. Examining the carbon agenda via the 40% House scenario. Building Research & Information 35, 363-378.

Böhringer, C., Rutherford, T.F., 2008. Combining bottom-up and top-down. Energy Economics 30, 574-596.
Bonfield, P., 2016. Each Home Counts: An Independent Review of Consumer Advice, Protection, Standards and Enforcement for Energy Efficiency and Renewable Energy. DBEIS & DCLG, London.
BRE, 2012. Energy Performance Certificates for existing dwellings: RdSAP manual, Version 8.0. Building Research Establishment, p. 156.
Bridgeman, T., 2015. Mapping Energy Performance Certificate data by parliamentary constituency Feasibility report to Citizens Advice. Centre for Sustainable Energy, Bristol, p. 68.
CE, 2017. History of the UK Feed-in Tariff, in: Ltd., C.E. (Ed.). Contemporary Energy Ltd.
Commission, E., 2017. EU Buildings Database. European Commission, European Commission.
Crowley, R., GL, D., 2014. “Watts” Where, and Why? Using GIS to Identify Energy Efficiency Opportunities.
CSE, 2017. National heat map: New web-based tool to support low-carbon energy projects, Poilcy Analysis. Centre for Sustainable Energy.
DBEIS, 2016a. Fuel poverty sub-regional statistics. Department for Business, Energy & Industrial Strategy, London.
DBEIS, 2016b. Sub-national Consumption Statistics: Methodology and guidance booklet in: Department for Business, E.a.I.S. (Ed.). Department for Business, Energy and Industrial Strategy, London, p. 86.
DBEIS, 2017. Sub-national consumption statistics. Department for Business, Energy & Industrial Strategy, London.
DCLG, 2017. Energy Performance of Buildings Data: England and Wales. DCLG, London.
DECC, 2014. UK National Energy Efficiency Action Plan, in: Change, D.o.E.C. (Ed.). Department of Energy & Climate Change, London, p. 146.
Di Staso, U., Giovannini, L., Berti, M., Prandi, F., Cipriano, P., De Amicis, R., 2014. Large-Scale Residential Energy Maps: Estimation, Validation and Visualization Project SUNSHINE-Smart Urban Services for Higher Energy Efficiency, International Conference on Data Management Technologies and Applications. Springer, pp. 28-44.
Dowson, M., Poole, A., Harrison, D., Susman, G., 2012. Domestic UK retrofit challenge: Barriers, incentives and current performance leading into the Green Deal. Energy Policy 50, 294-305.
EST, 2017. Housing data analysis. Energy Saving Trust.
Fonseca, J.A., Schlueter, A., 2015. Integrated model for characterization of spatiotemporal building energy consumption patterns in neighborhoods and city districts. Applied Energy 142, 247-265.
Gouldson, A., Colenbrander, S., Sudmant, A., Papargyropoulou, E., Kerr, N., McAnulla, F., Hall, S., 2016. Cities and climate change mitigation: Economic opportunities and governance challenges in Asia. Cities 54, 11-19.
Guertler, P., Carrington, J., Jansz, A., 2015. The cold man of Europe - 2015. Association for the Conservation of Energy, London, p. 22.
Gupta, R., 2009. A new geographical information system-based approach to map and reduce energy-related CO2 emissions from UK dwellings, Eleventh International IBPSA Conference, pp. 2114-2121.
Jones, P., Lannon, S., Patterson, J., 2013. Retrofitting existing housing: how far, how much? Building Research & Information 41, 532-550.
Kavgic, M., Mavrogianni, A., Mumovic, D., Summerfield, A., Stevanovic, Z., Djurovic-Petrovic, M., 2010. A review of bottom-up building stock models for energy consumption in the residential sector. Building and environment 45, 1683-1697.
Kolter, J.Z., Ferreira Jr, J., 2011. A large-scale study on predicting and contextualizing building energy usage.
Nouvel, R., Brassel, K.-H., Bruse, M., Duminil, E., Coors, V., Eicker, U., Robinson, D., 2015. SimStadt, a new workflow-driven urban energy simulation platform for CityGML city models,

Proceedings of International Conference CISBAT 2015 Future Buildings and Districts Sustainability from Nano to Urban Scale. LESO-PB, EPFL, pp. 889-894.
Ofgem, 2017. Feed-in Tariff (FIT): Generation & Export Payment Rate Table 01 October- 31 December 2016.
ONS, 2013. Census Analysis-Comparing Rural and Urban Areas of England and Wales. Office for National Statistics, London, p. 43.
ONS, 2017. Super Output Area (SOA).
Palmer, J., Cooper, I., 2013. United Kingdom housing energy fact file, in: DECC (Ed.), London, p. 171.
Pratt, D., 2016. Green Deal replacement scheme pushed to 2017. Clean Energy News.
Rickaby, P., 2016. UK Retrofit Experience Rickaby Thompson Associates, Milton Keynes, UK.
Smith, L., Abbott, J., 2017. State of the Nation Survey: Low Energy Retrofit in Social Housing. National Energy Foundation, Capita, University of Salford Manchester.
Strachan, N., Kannan, R., 2008. Hybrid modelling of long-term carbon reduction scenarios for the UK. Energy Economics 30, 2947-2963.
Sunikka-Blank, M., Chen, J., Britnell, J., Dantsiou, D., 2012. Improving energy efficiency of social housing areas: A case study of a retrofit achieving an “A” energy performance rating in the UK. European Planning Studies 20, 131-145.
Swan, L.G., Ugursal, V.I., 2009. Modeling of end-use energy consumption in the residential sector: A review of modeling techniques. Renewable and sustainable energy reviews 13, 1819-1835.
Tuladhar, S.D., Yuan, M., Bernstein, P., Montgomery, W.D., Smith, A., 2009. A top–down bottom–up modeling approach to climate change policy analysis. Energy Economics 31, S223-S234.
University, C., 2016. Links to GIS data & maps. Cornell University.
Wate, P., Coors, V., 2015. 3D Data Models for Urban Energy Simulation. Energy Procedia 78, 3372-3377.