A New GIS Based Decision Support Tool For Enabling Local Energy Retrofits

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Abstract

This paper describes the application of a data-driven localised Geographical Information System based decision support tool to spatially identify (model and map) suitable households accurately and cost-effectively, using a case study in Oxford (UK). Drawing on publicly available datasets on housing and energy, and combining it with local datasets and energy modelling, optimal neighbourhoods and dwellings are targeted for specific retrofit measures to meet the specific need of obligated energy suppliers in the context of the Energy Company Obligation. Findings show that dwellings most in need of insulation upgrade and relief from high energy bills are not necessarily the dwellings with the greatest energy consumption per area.

Introduction

The UK Government has implemented various policies aimed at encouraging energy efficiency measures, particularly in residential buildings. During this time, EU Directives have guided substantial parts of UK energy efficiency policy. These policies have resulted in an 18% reduction in energy demand between 2000 and 2014. However, since 2015, a number of UK energy efficiency policies have either been scrapped or reduced in scope (POST, 2017).

One policy that remains however, though it has evolved in name and scope over time, is the Energy Company Obligation (ECO). Under the ECO, energy suppliers (utilities) are obligated to reduce CO_2 emissions and fuel poverty[1] from households in a cost-effective manner. To do this, the obligated energy suppliers work with installers to introduce efficiency measures into homes such as insulation and heating measures (Ofgem, 2018).

The ECO has two schemes that take different routes to meeting the obligation depending on specific needs. These are the Home Heating Cost Reduction Obligation (HHCRO) and the Carbon Emissions Reduction Obligation (CERO).

- The HHCRO requires energy suppliers to promote measures that result in financial savings on energy bills such as insulation and heating measures. Eligibility depends on financial need and vulnerability.
- The CERO focuses on hard-to-treat homes[2]. The obligation also requires that a certain number of CERO funded projects be located in rural areas (Energy UK, 2018; Government Grants UK, 2018).

Regarding improvement measures, HHCRO covers a large number of insulation measures, heating measures and micro-generation, CERO only covers insulation measures and district heating connections (Ofgem, 2015).

Within the past year, the UK Government has been reducing investment in energy efficiency, as a result the ECO budget reduced by 40%. This currently represents the only opportunity for government supported energy efficiency improvement in the residential sector (Hartely, 2017). Millions of homes across the UK still need energy improvements, the process of identifying suitable homes with eligible residents can be a time-consuming task (e.g. using community events, door-knock or social media campaigns). A more targeted solution can be beneficial not only for the energy suppliers responsible for the ECO, but also for the local authorities and community groups who have an interest in energy improvement in their areas.

To meet this need, this paper describes the application of a data-driven localised Geographical Information System (GIS) based decision support tool to spatially identify (model and map) suitable households accurately and cost-effectively, using a case study in Oxford (UK). Drawing on publicly available datasets on housing and energy, and combining it with local datasets and energy modelling, optimal neighbourhoods and dwellings are targeted for specific retrofit measures.

[1] Fuel poverty is defined as a household that is not able to adequately heat their property at an affordable cost. Fuel poverty is considered to occur when more than 10% of a household's income is spent on heating the home to an adequate level. Recent increases in fuel prices has led to a sharp increase of the number of UK home owners considered to be in a state of fuel poverty (Government Grants UK, 2018).

[2] Hard-to-treat homes are defined as those with narrow cavity walls, solid wall, prefabricated or frame construction and properties with more than three storeys (TEC, 2018).

Methodology

The methodology for the study is comprised of two principal steps:

1. Identifying focal areas based on ECO requirements using publicly available datasets.
2. Rapid assessment of dwellings suitable for ECO funding based on relevant factors.

Identification of focal areas

To identify an appropriate case study focal area, publicly available datasets were assessed for Oxfordshire (UK), which included, the UK Government's sub-national energy (DBEIS, 2017b) and fuel poverty (DBEIS, 2017a) data at lower layer super output area (LSOA) (areas of approximately 400-800 dwellings), Energy Performance Certificate (EPC) data, provided open access through the Ministry of Housing, communities and Local Government (MHCLG, 2017b), and other mapped data including the 2011 census (UCL, 2015). For the purposes of this study, three variables focussing on economic, physical and social vulnerability were selected, which would align with ECO eligibility:

1. Identification of LSOAs with high levels of fuel poverty (DBEIS, 2017a) in order to accommodate the prime objective of ECO.
2. Households with individuals that are vulnerable or have disabilities and
3. Social housing renters that are 65 years old or older (UCL, 2015).

To connect data with mapping, to visualize overlap of LSOA and postcode level data, LSOA boundaries are also linked with postcode boundaries (ONS, 2017) in GIS.

Rapid assessment of suitable dwellings for ECO

Following the identification of a focal area for deeper investigation, to identify select dwellings for ECO funding and retrofit, a GIS-based carbon-mapping model called DECoRuM (Domestic Energy, Carbon counting and carbon Reduction Model) is used in this example to identify dwellings with:

1. high energy consumers,
2. poor wall and roof U-values,
3. high running costs, and
4. the greatest potential for energy reduction from wall insulation improvement.

Conceptually overall, DECoRuM was created to estimate energy use and potential for energy reduction on a house-by-house level. DECoRuM is a GIS-based toolkit for energy/CO_2e emissions reduction planning with the capability to estimate energy consumption and effectiveness of mitigation strategies in existing UK dwellings, aggregating the results to a street, district and city level. The aggregated method of calculation and map-based presentation allows the results to be scaled-up for larger application and assessment. Aggregated improvement measures, for example, hypothetically encourage bulk installations and drive down installation costs.

In the DECoRuM model, CO_2e emissions are the result of heat loss calculations from fabric and ventilation characteristics, estimated energy use from heating, domestic hot water and electricity use as calculated using the Building Research Establishment's (BRE) Domestic Energy Model (BREDEM-12) and the UK Government's Standard Assessment Procedure (SAP). Data for calculations include actual house characteristics gathered from historic (Digimap) and current maps (OS Mastermap and Google street view), EPCs, and literature describing home characteristics based on age and typology (e.g. Tabula/Episcope (BRE, 2014)).

A basic version of BREDEM-12 (2001) Excel spreadsheet was obtained from BRE and it was in the first iteration developed by the author in 2007 (Gupta, 2009) to include all equations (Anderson et al., 2002) necessary to predict annual energy use from dwellings. This involved coding the model's equations and importing its extensive reference tables as database look-up tables. One of the main enhancements of BREDEM-12 in DECoRuM was the inclusion of a function to predict CO_2e emissions and fuel costs according to end use by reference to fuel types.

BREDEM-12 requires input data for almost 95 parameters to predict dwelling energy consumption (Anderson, et al., 2002). Though all of these data are measurable, it is difficult to obtain in practice, owing to the high cost of detailed on-site surveys. This poses considerable problems for energy modelling on an urban scale. Oxford, for instance, has almost 50,000 dwellings, so a citywide energy model based on full BREDEM-12 (and SAP 2001) calculations for every property clearly would not be practicable. In response to this problem, DECoRuM's data reduction technique classifies the 95 input data parameters required by BREDEM-12 into four categories:

1. *Data common for all dwellings* (50 input parameters, e.g. degree day region, height above sea level, site wind speed) sourced from BREDEM-12 reference tables (Anderson, et al., 2002; BRE, 2015), English House Condition Survey.
2. *Data derived from built form of the dwellings* (five input parameters, e.g. zone areas, occupancy, window area) sourced from standard dwelling configurations reports.
3. *Data derived from age of the dwelling* (18 input parameters, e.g. heating system, controls, U-values) sourced from BREDEM-12 reference tables, English House Condition Survey.
4. *Data collected for individual dwellings* (22 input parameters, e.g. ground floor area) Characteristics that are collected and entered into the model include: built form, floor area, dwellings age, exposed wall area, orientation, wall, roof and window type and insulation where available, renewables, etc.

Assumptions / limitations:

- Depending on the level of precision desired, desktop data collection and entry (e.g. entries from façade observations) can be time intensive; however distributed questionnaires on dwelling characteristics (especially externally unobservable characteristics) can be helpful; however, not implemented in this instance.
- Occupancy, unless taken from questionnaires, is calculated from floor area using the BREDEM-12 method.
- Behaviour assessment is limited: occupancy times, heating schedules, window opening schedules, etc. cannot be modelled.
- Assumptions are made about occupant behaviour, e.g. temperature set-point; however, it can be modelled and collected via survey.
- Wall construction and U-values (unless known, e.g. reported in EPCs) are based on the age of the home where construction methods are well documented (e.g. BREDEM reference tables).
- 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).
- Different scenarios must be calculated separately and cannot vary within a given timeframe; calculations are static.

Verification is performed by calibrating the aggregated energy consumption results to the sub-national energy consumption data for England and Wales at postcode scale (DBEIS, 2017b). The results for each household are displayed on a map using GIS; in this instance, MapInfo. GIS allows any DECoRuM input or output variable to be mapped for visual communication, e.g. kWh/year, CO_2e emissions/m^2/year, homes in need of cavity wall insulation, PV suitability, etc.

Results

Identification of focal areas

In the first step, *identify LSOAs with high proprortion of households that are fuel poor,* figure 1 shows the LSOAs mapped over the whole of Oxfordshire.

As figure 2 zooms in to show, the city of Oxford has areas with the greatest percentage of fuel poor dwellings in all of Oxfordshire. Figure 2 shows the LSOAs with the highest proportion (25-30%) in dark red to lowest proportion (3-5%) in dark green. Oxford is an appropriate place to start as it has LSOAs with proportions of fuel poor households which excede the highest proportions in other district councils of Oxfordshire by 10%. In other words, in all other district councils in Oxfordshire the LSOAs with highest proportion of fuel poor households fall in the range of 15-20% (lighter orange colour).

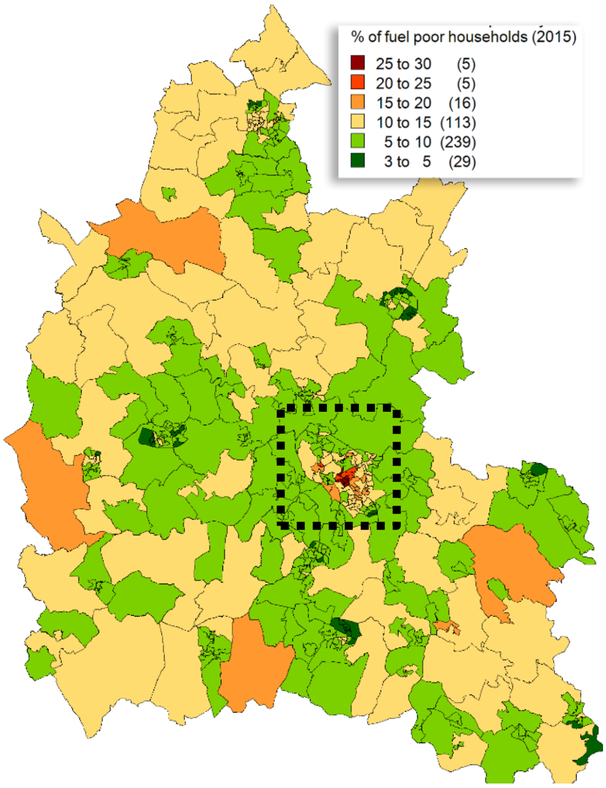

Figure 1: Fuel poverty in Oxfordshire at LSOA (DBEIS, 2017a; ONS, 2016). Contains National Statistics data © Crown copyright and database right [2018]; Contains OS data © Crown copyright and database right [2018].

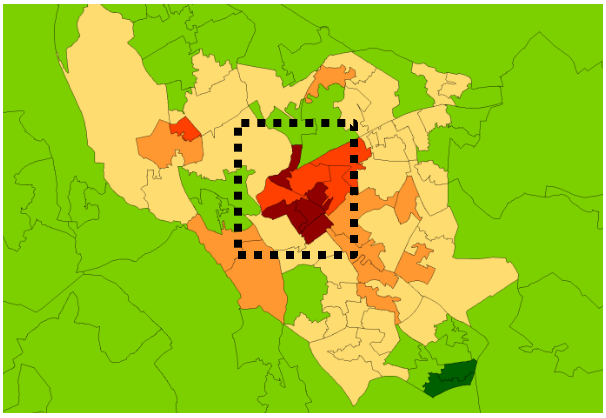

Figure 2: Fuel poverty in Oxford at LSOA (DBEIS, 2017a; ONS, 2016). Contains National Statistics data © Crown copyright and database right [2018]; Contains OS data © Crown copyright and database right [2018].

Figure 3 shows a further zoomed in view of the high fuel poverty areas with overlays of:

- postcode boundaries,
- 10% or greater of households are in the census as having residents with long-term health problems or disabilities that limit day-to-day activities (white boundary), and
- 50% or greater of households are residents 65 years or older in rented social housing (thick black boundary).

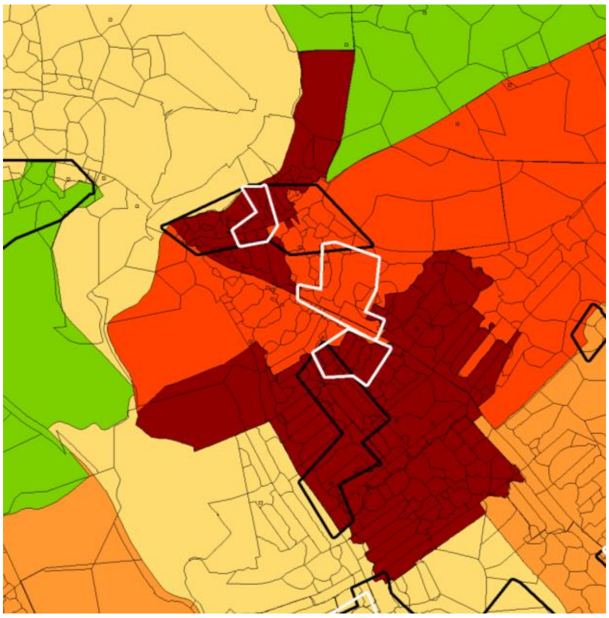

Figure 3: Fuel poverty overlap with postcodes, social renters 65 and over, and vulnerable residents (DBEIS, 2017a; ONS, 2016, 2017; UCL, 2015). Contains National Statistics data © Crown copyright and database right [2018]; Contains OS data © Crown copyright and database right [2018]; Contains Royal Mail data © Royal Mail copyright and database right [2018].

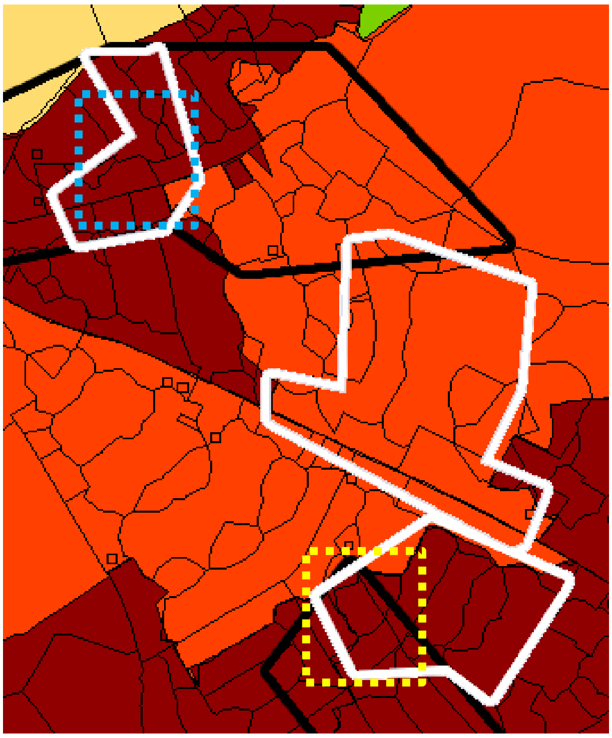

Figure 4: Two potential ECO focal areas highlighted (DBEIS, 2017a; ONS, 2016, 2017; UCL, 2015). Contains National Statistics data © Crown copyright and database right [2018]; Contains OS data © Crown copyright and database right [2018]; Contains Royal Mail data © Royal Mail copyright and database right [2018].

Figure 4 shows two prioritised focal areas based on the overlap of three HHRCO variables of fuel poverty, vulnerability due to age and or disability. The focal area in the lower centre of the image (with a yellow box) is ultimately selected over the other as it has a higher proportion (40-60% vs. 20-40%) of EPCs with ratings in the categories of E, F, and G. Under the HHCRO, suppliers can deliver measures to social housing premises where they have an EPC energy efficiency rating of E, F or G (Ofgem, 2017).

Rapid assessment

Following the DECoRuM rapid assessment, figure 5 shows the energy consumption for the dwellings in the mapped area. Flats are displayed as circles over the buildings in which they are located. Ground floor flats are represented by the circles closest to the street; top floor flats are furthest from the street. Most of the highest energy consumers per m^2 are flats.

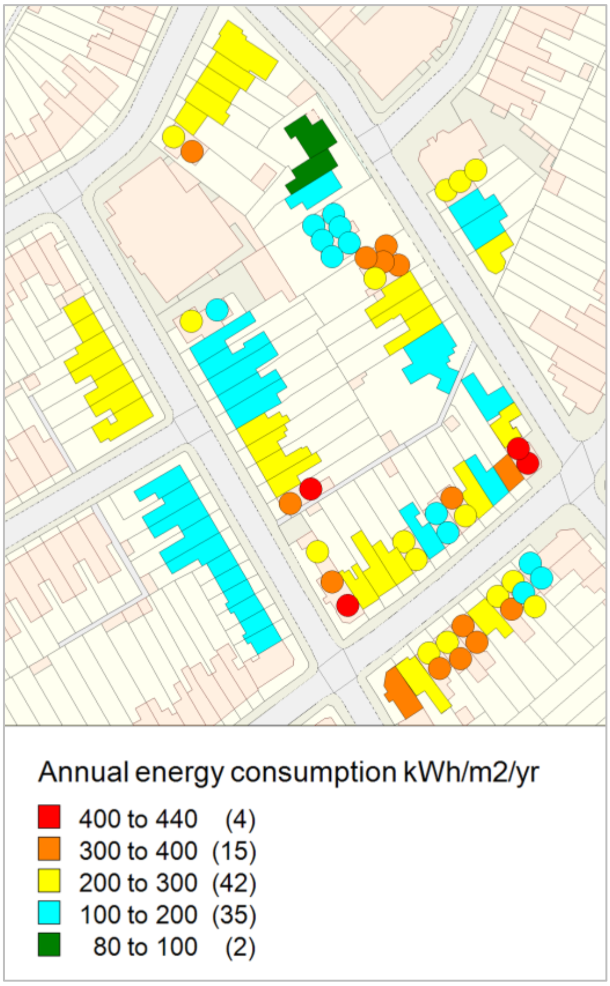

Figure 5: Dwelling level energy consumption. Contains EPC data (MHCLG, 2017b); Map© Crown Copyright and Database Right 2018. Ordnance Survey (Digimap Licence).

Figure 6 from the DECoRuM analysis shows a mean U-value for the exposed area (U_e) of the dwellings. This Overall U-value represents the walls (U_w) and roof (U_r) and is calculated using the following formula:

$$U_e = U_w \, x \, A_w / (A_w + A_r) + U_r \, x \, A_r / (A_w + A_r) \quad (1)$$

Where:

- U_e = mean exposed U-value for the dwelling
- U_w = wall U-value
- U_r = roof U-value
- A_w = area of exposed walls
- A_r = area of roof

From the figure it is obvious that most (73%) of the dwellings have U-values that are above the median (1.03 W/m²K).

Figure 6: Fabric U-value. Contains EPC data (MHCLG, 2017b); Map© Crown Copyright and Database Right 2018. Ordnance Survey (Digimap Licence).

Figure 7 shows the mean rank of dwellings calculated from the ranking of dwellings based on U-value from the previous figure and the ranking of annual running costs as calculated through DECoRuM.

This consideration shifts the focus away from simply high energy consumers (figure 5) to dwellings with occupants most likely in need of economic assistance also with greatest impact of improvement (upgrading insulation, for example). DECoRuM has the capability of mapping different measures in addition to or other than insulation, e.g. boiler upgrade, window upgrade, Solar Photovoltaic suitability.

Figure 7: Mean rank of U-value and running costs. Contains EPC data (MHCLG, 2017b); Map© Crown Copyright and Database Right 2018. Ordnance Survey (Digimap Licence).

Finally, figure 8 shows the energy reduction potential from installing insulation to meet the current building regulation for wall insulation, i.e. 0.3 W/m²K (MHCLG, 2017a). Many of the high-ranking dwellings in figure 7 correspond to the higher energy reduction potentials shown here. This final figure can be helpful in making decisions on where to focus for the greatest impact in meeting the ECO.

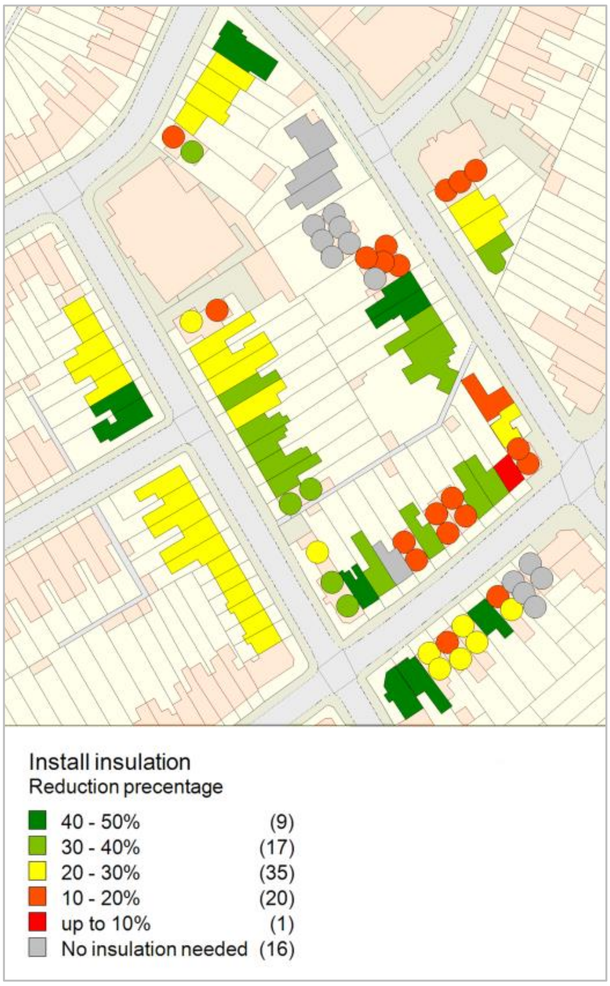

Figure 8: Energy consumption reduction potential of wall insulation improvement. Map© Crown Copyright and Database Right 2018. Ordnance Survey (Digimap Licence).

Discussion

Outputs from DECoRuM, maps of estimated energy use and energy or CO_2e emission reduction potential of individual households, can provide useful feedback on retrofit need and progress to obligated energy suppliers, local authorities, community groups, residents, and retrofit providers. Whereas it is traditionally up to the householder to seek out energy renovation or accept offers for renovation 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 the energy suppliers, local authorities and / or community groups with the information needed to rapidly pin-point local areas of high energy use or economic need and to identify potential grouped areas for renovation.

After the local area is energy mapped, several approaches can be adopted to decide where to focus renovation depending on objectives, including:

- Focus on common dwelling types which are likely to require the same type of renovation measure or package of measures; DECoRuM generated 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 or economic need.

The spatial 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 renovation progress and change. One recognized limitation in the process presented is the need to validate the results of the DECoRuM model. One approach would be through smart meter data.

Future research and development of the presented approach includes linking energy mapping with smart-meter data (given the expected smart meter roll-out in UK by 2020) (DBEIS, 2018). This would enable evaluation of area-wide trends in energy use (demand profiles) which can be useful for introducing local (time of use) energy tariffs, heat networks or community energy systems. Tracking energy consumption either before or after retrofit, coupled with detailed data on dwelling characteristics collected through the methods described, can provide a more detailed picture of retrofit requirements or progress than simply using smart meter data alone.

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 renovation providers to incentivise participation of the homeowners, this can be resolved. Future development of DECoRuM would also benefit from the integration of the entire rapid assessment process into the DECoRuM tool as currently these are two different processes.

Conclusion

The paper has demonstrated the process of isolating an appropriate area of Oxfordshire for detailed mapping and potential retrofit focus based on high energy consumption, high rate of fuel poverty and insulation need. The challenge of incomplete data on which homes could benefit from what retrofit measures is met using housing statistics and the EPC dataset through the provision of data on wall types (with or without insulation) and roof insulation thickness. Each of these dwelling characteristics can be mapped for a specific area including the entire town allowing an individual measure-based or package retrofit focus on a mass scale.

This method assists in prioritising action by providing ECO providers or energy assessors with an area based spatial analysis of homes most in need, estimated consumption and a complete tool for testing potential success of measures or packages of measures. This decision-making approach brings together energy modelling and GIS mapping with community engagement to address the barriers to mass retrofit programmes, and the business needs of both ECO obligated energy companies and technology providers seeking suitable households/customers. The above information also assists in aggregation of private sector housing retrofit activities to minimise installation costs.

Though the paper has shown how publicly available datasets on housing and energy can be used to plan mass retrofit and provide targeted low carbon measures across a city, there is the current challenge of lack of policy support for retrofit in the UK, except for the ECO programme. Nonetheless, the access to data and the process provided would allow retrofit / ECO providers to target specific areas for mass retrofit based on these datasets. As EPCs have been registered across the country and likewise sub-national data are available throughout, similar analysis could easily be performed for any city or county throughout the UK.

References

Anderson, B. R., Chapman, P. F., Cutland, N. G., Dickson, C. M., Henderson, G., Henderson, J. H., . . . Shorrock, L. D. (2002). *BREDEM-12 Model description: 2001 Update* BR 438). Watford: B. R. Institute. http://www.iea.org/media/statistics/eemanual/UK_BREDEM_model_description.pdf

BRE. (2014). *Building Typology Brochure England: September 2014* 296-024). Watford: B. R. Establishment. http://episcope.eu/fileadmin/tabula/public/docs/brochure/GB_TABULA_TypologyBrochure_BRE.pdf

BRE. (2015). *BREDEM 2012: A technical description of the BRE domestic energy model: Version 1.1*. https://www.bre.co.uk/filelibrary/bredem/BREDEM-2012-specification.pdf

DBEIS. (2017a). *Fuel poverty data measured as low income high costs (2015 data)* [Data set]. Retrieved from https://www.gov.uk/government/statistics/sub-regional-fuel-poverty-data-2017

DBEIS. (2017b). Sub-national consumption statistics. Retrieved Date Accessed, 2013 from https://www.gov.uk/government/publications/regional-energy-data-guidance-note.

DBEIS. (2018). *Smart meters: a guide*. London: GOV.UK Retrieved from https://www.gov.uk/guidance/smart-meters-how-they-work.

Energy UK. (2018). Energy Company Obligation. Retrieved Date Accessed, 2018 from https://www.energy-uk.org.uk/policy/energy-efficiency/energy-companies-obligation.html.

Government Grants UK. (2018). HHCRO Grant Funding. Retrieved Date Accessed, 2018 from http://www.government-grants.co.uk/hhcro.

Gupta, R. (2009). *A new geographical information system-based approach to map and reduce energy-related CO_2 emissions from UK dwellings.* Eleventh International IBPSA Conference.

Hartely, G. (2017). Is the Energy Company Obligation (ECO) fulfilling its obligations? Retrieved Date Accessed, 2018 from http://www.energysavingtrust.org.uk/blog/energy-company-obligation-eco-fulfilling-its-obligations.

MHCLG. (2017a). *Conservation of fuel and power: Approved Document L.* London: GOV.UK Retrieved from https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l.

MHCLG. (2017b). Energy Performance of Buildings Data: England and Wales. Retrieved Date from https://epc.opendatacommunities.org/.

Ofgem. (2015). Energy Company Obligation (ECO2): Measures Table. Retrieved Date Accessed, 2018 from https://www.ofgem.gov.uk/publications-and-updates/energy-company-obligation-eco2-measures-table.

Ofgem. (2017). ECO2t Social housing E, F and G declaration. Retrieved Date Accessed, 2018 from https://www.ofgem.gov.uk/publications-and-updates/eco2t-social-housing-e-f-and-g-declaration.

Ofgem. (2018). Support for improving your home. Retrieved Date Accessed, 2018 from https://www.ofgem.gov.uk/environmental-programmes/eco/support-improving-your-home.

ONS. (2016). *Lower Layer Super Output Areas (December 2011) Full Clipped Boundaries in England and Wales* [Data set]. Retrieved from http://geoportal.statistics.gov.uk/datasets/da831f80764346889837c72508f046fa_0

ONS. (2017). *Postcode to Output Area to Lower Layer Super Output Area to Middle Layer Super Output Area to Local Authority District (December 2011) Lookup in England and Wales* [Data set]. Retrieved from https://www.arcgis.com/home/item.html?id=ef72efd6adf64b11a2228f7b3e95deea

POST. (2017). POSTNOTE 550: Future Energy Efficiency Policy. London: Parliamentary Office of Science & Technology.

TEC. (2018). Carbon emissions reduction obligation (CERO). Retrieved Date Accessed, 2018 from http://www.environmentcentre.com/advice/energy-efficiency/grants-and-loans/green-deal-and-eco/energy-companies-obligation-grants/carbon-emission-reduction-obligaiton-cero/.

UCL. (2015). *Datashine Census* [Data set]. Retrieved from http://datashine.org.uk/