A FRAMEWORK FOR DELIVERING ENERGY EFFICIENCY AND DECENTRALISED ENERGY GENERATION PROJECTS TO TACKLE FUEL POVERTY AND CO_2 EMISSIONS IN CITIES

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ABSTRACT

UK government is providing part-funding for organisations to commission external feasibility studies. This is reflected in government strategy and funding toward a low carbon, smart, local energy system. Such studies would provide detailed advice on technical and economic feasibility and assist in developing a technical specification. Local energy system projects vary wildly in scale, from a single building to districts and the whole city. However, the building stock in a city is distributed over the territory, and some of the building types are present only at specific sites. Therefore, domestic energy and carbon models need tools to determine their spatial dimension and these may be provided by spatial components. This paper describes the development of a spatial framework for annual energy consumption, CO_2 emissions and fuel poverty estimation from individual dwellings to neighbourhoods up to districts and the whole city. We propose the integration of urban models with a spatially enabled database as a key component to establish baseline conditions to provide a starting point for measuring the value added by energy and carbon policy interventions for resilient urbanism.

INTRODUCTION

Newcastle upon Tyne, a city in North East England, UK. In the inter-census ONS (2001) – ONS (2011) period, the proportion of unshared dwellings decreased to 0.40%, but, interestingly, the proportion of detached homes rose to 7.8%. This change was accompanied by a moderate rise in flats and maisonettes, to 3.18%. In the same 2001-2011 period, the percentage of purpose-built dwellings rose to 2.4% and that of converted or shared houses, including bed-sits, to 8.18%. These rises are due to the steadily increasing numbers of students, and indeed the City Council (NCC, 2007) forecasts that this growth will continue. Alongside encouraging the development of purpose-built student accommodation, the council is seeking to discourage the conversion of family houses into flats or houses in multiple occupations (HMO) in selected areas (NCC, 2011, p. 28).

This paper focuses on a hitherto unexplored research question, for which at present there is no definitive answer, regarding the need for a systematic framework to estimate the realistic energy consumption, carbon emission and poverty of housing stock at sub-city levels, from each building to a neighbourhood until the city. This information can be used by local governments to identify areas for future intervention, and thus enhance the effectiveness of energy efficiency and carbon saving measures, especially to the poor.

A FRAMEWORK FOR ENERGY, CARBON AND POVERTY

The concept of ‘fuel poverty’, the inability to afford adequate warmth at home has become a focus for social policies (Bradshaw and Hutton, 1983). The definition was established by Dr Brenda Boardman (Boardman, 1991) as fuel poverty is the ability of a household to afford to heat its home to an adequate standard. With the introduction of the Warm Homes and Energy Conservation Act (UK Parliament, 2000), fuel poverty was formally defined within UK government legislation. This research uses government fuel poverty statistics since 2001.

Figure 1 shows that, initially, clear progress was made towards the fuel poverty targets. Fuel poverty households (shown in red), have been declining sharply prior to the introduction of the targets in 2001, continued to fall, and reached the lowest level at around 1.2 million households in 2003 and 2004. The trend then reversed markedly: fuel poverty levels among the whole population peaked by 2009, before falling back in 2010 and 2011. The decrease in fuel poverty in England between 2010 and 2011 was the result of a rise in income, and a reduction in energy use, through improvements in the energy efficiency of housing. The 2010 target for vulnerable households was missed, with 2.8 million vulnerable households classified as fuel poor in England in 2010. By 2015, nearly 11% of English households were still in fuel poverty, and by 2018 down to 10.3%. Figure 1 also shows the fuel poverty in the UK

(Department for Business Energy and Industrial Strategy, 2017).

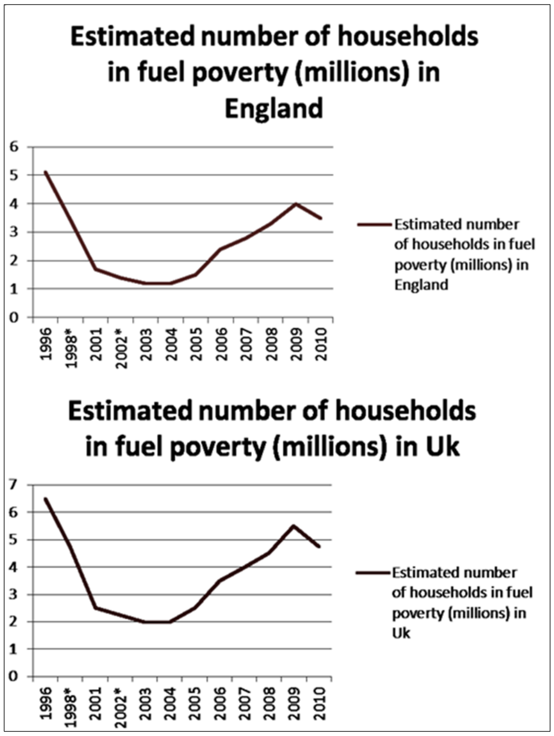

Figure 1 Estimated numbers of households in fuel poverty in England and UK. Source: Data before 2003 from DECC Fuel Poverty Monitoring Indicators 2012 (DECC, 2012).Data from 2003 onwards from DECC Trends in Fuel Poverty in England 2003 to 2011 (DECC, 2013c)

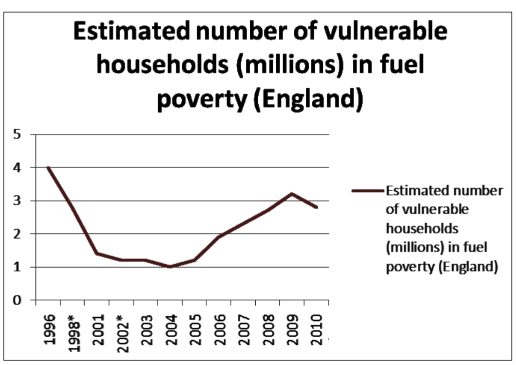

Figure 2 Vulnerable households in fuel poverty. Elaborated by the authors

Fuel poverty impacts multiple areas of policy, but perhaps the most significant impact is on health. In 2002, the Townsend Centre for International Poverty Research took a small area (electoral ward) approach to measuring fuel poverty (Gordon, 2002). The UK government announced that it would adopt a measure of fuel poverty with fuel costs equivalized according to the number of people in the household, rather than the type of household (BRE, 2013). Regarding vulnerable households in England, the fuel poverty trend is shown in Figure 2.

Low income and consumer energy costs are factored into the Office of Gas and Electricity Markets OFGEN (2013) definition of vulnerability – meaning it does include fuel poverty. Note that it is not only vulnerable households which are in fuel poverty; while attention has focussed on older people in fuel poverty, families and children have been relatively neglected, as shown in Figure 2. In small areas, fuel poverty is more visible, as seen in Figure 3.

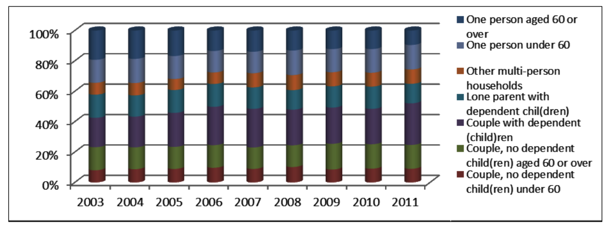

Figure 3 Vulnerable households in fuel poverty. Elaborated by the authors

Therefore, the key elements in determining whether a household is fuel poor under the Low Income High Cost (LIHC) indicator (BEIS, 2017) are: the household income, the household energy requirements, and fuel costs. The cost of energy is modelled rather than based on actual spending and is calculated by combining the fuel requirements of the household with corresponding fuel prices. These costs capture four areas of fuel consumption: space heating, water heating, lights and appliances, and cooking. Therefore, in our paper the key elements in determining whether a household is fuel poor (Middlemiss and Gillard, 2015) are: (i) income, (ii) fuel prices, and (iii) energy consumption.

Current national models use the **B**uilding **R**esearch **E**stablishment **D**omestic **E**nergy **M**odel (BREDEM) engine and English Housing Survey (EHS) data sets for estimating domestic end-use energy, carbon, and fuel poverty for social housing. EHS is a national survey of housing in England, commissioned by the Department for Communities and Local Government (DCLG). The 2009 EHS summary of tables for the key measures of stock and household data is published on government sites (UK Data Service, 2012), alongside a report (DCLG, 2010).

In local area planning, there is a need for a framework (OECD, 2001) that provides: (i) a careful design of a set of case studies with common research instruments used to explore the quantitative aspect of the area-based initiatives; (ii) the use of a detailed survey instrument for a representative sample of the population; and (iii) the establishment of an evidence-based model that can form the baseline conditions to provide a starting point for measuring the value added by energy policy interventions. More recently, fuel poverty has focussed on older people, resulting in relatively more policy instruments targeted at this group and a narrow stereotype equating fuel poverty with images of the 'old and cold'. However, retrofitting has to be analysed and delivered within the context of numerous other structural inequalities and causes of vulnerability (Gillard *et al.*, 2017). We believe that local authorities (LAs) require a spatial understanding of end-use energy demands in targeted city areas to provide evidence for meeting future challenges in planning local energy and carbon services.

This research inherited the Newcastle Carbon Route Map (NCRM), which is an early incarnation of a building level data set for Newcastle. The initial phase of this research involved substantial data management, cleaning, restructuring and additions to this initial data set. The resultant data set incorporated in a single database table a large number of building related data sets which are described in detail in next section. The Newcastle Carbon Route Map Framework (NCRF) utilises this data set and adds on the energy modelling aspect through linking with the English House Survey (EHS) as input to the Cambridge Housing Model (CHM). This provides the means to produce building level energy consumption, carbon and fuel poverty estimates which in turn can be analysed both spatially and aspatially (e.g. by building type). This building level approach through the NCRF provides the potential for energy planners and other bodies to model energy interventions with flexibility in scale and to potentially adapt plans to local area characteristics. CHM implements a BREDEM based energy model to compute energy estimates as it is the model used by DECC to underpin the 2012 Housing Energy Fact File and Energy Consumption in the UK (Hughes, 2011)

THE SPATIAL APPROACH TO MODELLING

The CHM is a bottom-up model that estimates end-use energy consumption. End-use refers to energy consumed by final end-users (after transformation) (Prime *et al.*, 2014). End-uses are space heating (SH), domestic hot water heating (DHW), electric appliances and lightning (AL), and cooking (CK) (Anderson and Chapman, 2010). However, the building stock in a city is distributed over the territory, and some of the building types are present only at specific sites. Therefore bottom-up models need tools to determine their spatial dimension and these may be provided by spatial components. Also, bottom-up models require a Geographical Information System both to process data and demonstrate local impact.

Spatial modelling is an important aspect of energy consumption, and local energy consumption patterns are important to alleviate fuel poverty and for micro-generation supply. Bahu et al. (2013) argue that energy system frameworks require a spatial representation in order to reflect the local area characteristics and the boundary conditions used in operational strategies within a decentralised decision analysis. Other authors explore energy, carbon and fuel poverty methodologies in cities (Baker *et al.*, 1989; Fahmy *et al.*, 2011; Howard *et al.*, 2012; BEIS, 2017). This paper attempts to address some of these issues - or the shortcomings of these models - and the important impact on policies in sub-city areas. In this spatial framework, the spatial distribution of aggregated buildings' end-use energy consumption can be compared with the current/future supply infrastructure or decentralized bounded low carbon generation to create a sub-city case scenario. Area-based case scenarios are used in evidence-informed energy efficiency and carbon reductions and/or fuel poverty policies/practices, which attempt to identify appropriate energy/carbon reduction targets in aggregated building stocks (Heeren *et al.*, 2013). However, there are a significant number of uncertainties which are not usually communicated and understood by LAs, policy development of national data sets, and other stakeholders such as planners, architects and engineers. To better understand, communicate and describe uncertainties, it is necessary to obtain a detailed local knowledge of the stock and non-filtered building or post code level consumption data. Further model validation to ascertain uncertainties in the CHM model, imputation algorithms, and DECC data is certainly needed (Urquizo *et al.*, 2017b). In this research, it goes even further to suggest that a re-think of underlying energy models to enable the integration of building and urban modelling challenges are necessary. Gill et al. (2010, p. 506) argue that behaviour has a significant influence on space heating and electricity and a less significant influence on water heating. However, perhaps the major difficulty of NCRF physical modelling is that internal temperature is a constant, and if all other factors are constant, variations in internal temperature are the most sensitive factor in energy demand (Hughes et al., 2013, p. 159).

Our paper explores the spatial distribution of energy, carbon and fuel poverty and offers new and interesting insights into the dimensions of fuel poverty patterns using an area-based approach. Many of these patterns only become visible when exploring the geographic characteristics of fuel poverty at Lower Layer Super Output Area (LLSOA) areas and below, i.e. a single building. The need for a greater focus upon socio-spatial vulnerabilities commonly associated with urban areas could be beneficial in terms of the effective targeting of fuel poor households (Robinson *et al.*, 2018).

INITIAL DATA SET

The sampling frame is a method of selecting members of the population within that boundary, and in this paper, the sampling frame is the Warm Zone programme in South Heaton district. The Warm Zone Project (WarmZone) data set (EST *et al.*, 2005) contains valuable survey information related to the physical characteristics of dwellings, such as heating fuel and boiler type, wall type, and insulation, etc., and the approximate age and building type classification.

The overall aim of the WarmZone programme was to facilitate efficient, integrated and appropriate delivery of practical measures to alleviate fuel poverty and improve domestic energy efficiency in defined areas (EST *et al.*, 2005). The sample is a part of the population; in the WarmZone programme, the sample was 68% of city dwellings. For those dwelling locations that were not part of the survey –or dwellings unvisited by the WarmZone programme– several techniques collectively known as spatial prediction methods were used to estimate the values of a particular targeted quantity (Calderón *et al.*, 2015; Urquizo *et al.*, 2018).

The LA provided dwelling level information about social housing through Your Home Newcastle (YHN) data. YHN is an Arm's Length Management Organization (ALMO) responsible for managing council homes on behalf of Newcastle City Council. In 2009, YHN managed 28,950 council homes on behalf of Newcastle City Council, 1,800 homes on behalf of the Byker Community Trust, and 330 homes on behalf of Leazes Homes. YHN also manage 1,500 leasehold properties on behalf of Newcastle City Council and the Byker Community Trust.

YHN council homes have an accurate build date taken from the deeds, and properties mainly consist of post-war, non-traditional buildings; however, there are also many pre-1919 terraces, semi-detached houses, and flats in YHN housing stock. Where possible, YHN dates were used in preference to other building age data as it was deemed the most reliable. The additional attributes provided by the YHN records for 28,950 properties were added to the data set as part of this study. This paper has followed the LA's criteria for selecting three suburban residential areas (Westgate, South Heaton, and Castle) which represent the city's diverse demographics and housing stock/ownership. These areas, in turn, can be considered city zones to demonstrate different technologies and types of retrofit. Urban density is a key indicator for evaluating area-based retrofit energy schemes. A building-centric retrofit programme may be suited to a low-density suburban area such as Castle, with 1.8 dwellings per hectare. A decentralized technological energy solution (e.g. district heating) may be more suited to a high-density suburban area such as South Heaton, which has 43.48 dwellings per hectare. Similarly, tenure and social demographic profiles are useful urban descriptors for discriminating between future funding options and models of retrofit programmes. The funding models for social housing and privately owned stock are likely to be very different. In the case, considered in this paper, there is a representative mixture of predominant social groups: young families (Group E) in Castle; educated young single people (i.e. university students, Group F), in South Heaton; and people living in social housing (Group B), in Westgate. Additionally, in Castle district, 52% of the YHN have the decent home standard (DCLG, 2006), while only 13% in South Heaton district and 33% in Westgate district do so. Out of the properties managed by YHN, 4,111 properties are part of a district, group, or sheltered accommodation heating scheme referred to as community heating. The Decent Homes Standard is a technical standard for public housing introduced by the United Kingdom government.

The most disaggregated level of spatial information in our paper is about a single dwelling. Every dwelling has a unique property identifier (its unique property reference number (UPRN) code) and address; both are part of the Local Land and Property Gazetteer (LLPG) and the aggregated National Land and Property Gazetteer (NLPG) data set. The LAs have statutory responsibility for the street name and property number[1] and additionally informs Royal Mail of new buildings and address changes. The NLPG data set is comprised of the constituent Local Land and Property Gazetteers (LLPGs), and also joined-up national and regional services (Nicholson, 2006). Gazetteer refers to those records in the data set where attributes have been added through the incorporation of the LLPG records. The next level of hierarchy corresponds to a building, as each one could have a number of dwellings. Every building is identified by a unique Topographic Identifier (TOID). At the building level, two additional information points were integrated: the Cities Revealed (CR) data enables us to identify all residential properties by age and structure category through the Cities Revealed building class code compatible with Ordnance Survey Mastermap^{TM} data (The GeoInformation Group, 2012). The building class provides a detailed perspective of the built environment.

The Cities Revealed building classification data set provides building classifications and ages against MasterMap^{TM} building outlines. Additionally, a further set of building classifications was incorporated to show building use classification from the SCORCHIO project,

[1]LAs are involved in all stages of the property lifecycle – planning, building, occupation, and demolition.

which identifies the number of residential and commercial properties within the building (Triantakonstantis and Barr, 2009).

Tenure correlates strongly with the heating system and in Newcastle, owner occupied, and social housing are the predominant tenures. Communal heating and E7 is localized in social housing rented properties from local authority and housing associations, whereas gas heating is mostly in owner occupied and private rented properties. There are more installations of efficient boilers in owner occupied tenures than in private rented. E7 (the off-peak electricity tariff) mostly uses electric storage heaters, although there are also warm air heating systems. If the heat and hot water in the dwelling is generated by electricity, but there are no storage heaters or hot water tanks, E7 will probably not be cost effective. If the heat in the dwelling is generated by gas, E7 may still be a good fit, provided that the bulk of the electricity use is at night. The E7 model needs two additional variables for the hot water in the energy profile: the hot water heating system, and tank insulation. E7 is used in a variety of tenures and building types. It is prevalent in owner-occupied small area properties in the Castle area, while the city-owned tower block in South Heaton uses storage heaters, and the housing association properties in Westgate use storage heaters. This potentially also has an impact on the fuel poverty policy and strategy, given the amount of E7 heating existing in social housing tenures.

Again, this is indicative of the complexity of the model and the difficulty of using national data sets and models to properly address this type of fuel tariff. These three micro energy structures (HMOs, District Heating and E7 tariff) are difficult to model from existing data and with current energy models.

Gas fuel systems are the predominant type in individual properties, i.e. our data set suggests that gas fuel is at 92% of the housing stock, and 7% is electricity heating with an Economy 7 tariff. Wood, coal, and electricity combined account for just 1% of the stock. However, E7 is important in social housing and needs to be modelled in a better way because there is an implication for fuel poverty. This study has noted that time-of-use tariff electricity heating with Economy 7 tariffs mostly use storage heaters and, surprisingly, warm air systems because this type of fuel tariff is associated with night heat storage and daytime use.

Analysis of the database shows that there is an important interaction between household composition, mobility, energy use, and interestingly fuel poverty. From the UK Census data, the number of people living in a house in Castle has decreased, and household compositions of “one person living in a household” are now important. Furthermore, this person is usually a pensioner living in “owner-occupied housing”. The household size (mostly pensioners) suggests that the increased heating regime associated with pensioners does not fit with the heating regime of standard occupancy.

The council also provided information on Registered Social Landlords (RSL), which is the technical name for social landlords (Housing Associations). In England, these were formerly registered with the Housing Corporation, and from 2010 to 2012 associations were termed “Registered Providers” under the Housing and Regeneration Act (2008, p. 38) irrespective of status. Since 2012, the terms RSL and PRP (Private Registered Providers of Social Housing) are used as alternative names for Housing Associations. Providers may be private (registered as either “for profit” or “non-profit” organisations) or public local authority landlords. The RSL data were incorporated into the data set as part of this study to provide additional attribute information to 6,073 records.

This study incorporated the WarmZone data into the data set and carried out extensive data cleaning activities. In addition, some basic analysis of the survey penetration of the WarmZone data was conducted which highlighted that these data were relatively consistent in penetration across some Basic Land and Property Unit (BLPU) classification scheme codes for residential dwellings (LGIH, 2010, pp. 232-263), but that in Westgate there was limited penetration in category RD06 (residential self-included).

As the WarmZone data is the only data set that provides energy critical attributes, such as heating fuel and boiler type, added care is needed when considering energy estimate results from NCRF in Westgate flats due to the low survey penetration.

Since 2009, the City Council has been able to identify and attain evidence of where some of the most vulnerable groups within the city are located. The data are provided by Rowntree (2010) in the form of a number and percentage of households within each of the broad socio-economic classification groups and types. These numbers act as descriptors of the areas this study is attempting to analyse and are intended to be indicative of the socio-economic patterns of the districts. Experian data show that Castle has middle income younger families living in modern houses, while South Heaton has students, young couples and singles living in small, old flats, and Westgate has low-income persons living in social housing and young, educated persons living in temporary accommodation.

The final spatial database is a collation of diverse data sets concerning building structures and energy information. An explanation of the varying performance of the model within the three Middle Layer Super Output Areas case-study provides an insight into the importance of locality in modelling energy consumption, even at these scales. Westgate has a much more diverse portfolio of building types (e.g. a high proportion of tall, mixed-use buildings) and energy systems (e.g. district heating and Economy 7), whereas Heaton and Castle are much more homogenous in their structures. It may also be a factor that Westgate is a deprived area with a high proportion of social housing and there are socio-demographic issues at play. For example, Westgate has two LLSOAs areas with the highest percentage of people aged 16-74 in long-term unemployment in the case study areas: LLSOAs 8349 (4.22%) and 8399 (4.88%); these figures are not reflected in the modelling process. This suggests that building level data and comprehensive energy system data are key components of the accurate modelling of energy consumption, even in LLSOA areas.

SPATIAL RESULTS ON ENERGY CONSUMPTION CO_2 EMISSIONS AND FUEL POVERTY

In this section, the attention is on the spatial database of the sub-city domestic energy and carbon model framework and the two perceived key benefits of having a spatially enabled database: determining the precise spatial extent of the energy consumption and CO_2 in sub-city areas, and the ability to develop a reverse lookup procedure which enables the identification of building aggregated areas with spatial expression patterns (Urquizo *et al.*, 2016; Urquizo *et al.*, 2017a) most similar to a given parameter within the building energy profile. Far less complex are the interactions between urban form, climate, and buildings (fabric and heating supply systems). These interactions are not explicitly and coherently addressed in energy models, and this can lead to estimations that are based either on incorrect building aggregate responses over sub-city areas, or which ignore important behaviour and practices by different socio-economic segments in the population. However, the framework developed here could be easily adapted to integrate better models in future and, as it uses common forms (UPRN and TOID) for specifying building locations, it could easily be linked to other geospatial data sets such as socio-demographic data.

Figure 4 shows terraces along Simonside Terrace and Rothbury Terrace and Table 1 shows our estimates per Unique Property Reference Number (UPRN) of the total annual Energy (Gas) and Energy (Electricity) consumption in kWh along with the corresponding CO_2 emissions of the Simonside Terrace in tonnes of CO_2. UPRN is a unique numeric identifier for every spatial address in Great Britain. Local authorities have the statutory permission to name and number every street and property in Great Britain and allocate UPRNs.

Useful fuel poverty data below local authority level is available in the EHS data set. This paper uses a similar integration procedure for fuel poverty data.

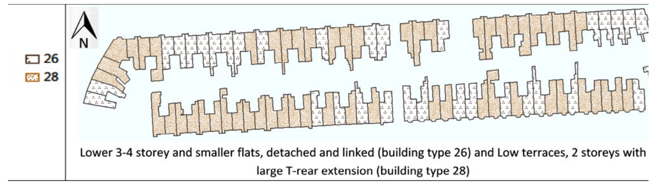

Figure 4 Linear terraces in South Heaton

Table 1 Per-dwelling energy and carbon estimation of the Simonside Terrace

Address	Area (m^2)	Energy Gas (kWh)	Energy Electricity (kWh)	CO_2 Gas (Tons)	CO_2 Electricity (Tons)
68 Simonside Terrace	86.07	19,050	3,147	3.772	1.627
62 Simonside Terrace	82.79	13,223	2,392	2.618	1.237
64 Simonside Terrace	84.49	19,050	3,174	3.772	1.627

Figure 5 shows how the income and fuel poverty index are correlated. Figure 5 also shows an interesting proxy to fuel poverty, the pre-payment meter. The main argument is that it is difficult for someone who inherits a prepayment meter to return to the credit method of securing energy supply. When a tenant inherits a prepayment meter in the property, the supplier usually refuses to remove it so that tenant can use the credit method, because of the property's postcode. Overall, at the end of 2010, 3.2% of electricity customers and 3.2% of gas customers were in debt ('debt' refers either to customers who have a prepayment meter set to collect a debt or customers who are on a rescheduled debt repayment programme due to last longer than 91 days/13 weeks). While the overall number repaying a debt has decreased, there are signs that the recession and high energy bills are continuing to have an impact on customers who are struggling to pay (DECC, 2013a).

Another issue to consider is that more and more of the fuel poor do not use pre-payment meters, and these represent mostly older people who comprise a significant number of fuel poor. Also, pre-payment is common in local areas with large student populations due to the short tenancy characteristics of this group. It is important to understand here that those on prepayment meters usually pay more for their fuel because prepayment tariffs are more expensive than other payment methods, and therefore fuel poor households spend a much greater proportion of their income on fuel, i.e., prepayment tariffs make it harder to reduce debt, leaving less money for other essentials. Even those prepayment customers not in debt can find it difficult to switch, either because of the prohibitive cost of having a new meter installed or because they have a bad credit rating and have been turned down for credit terms.

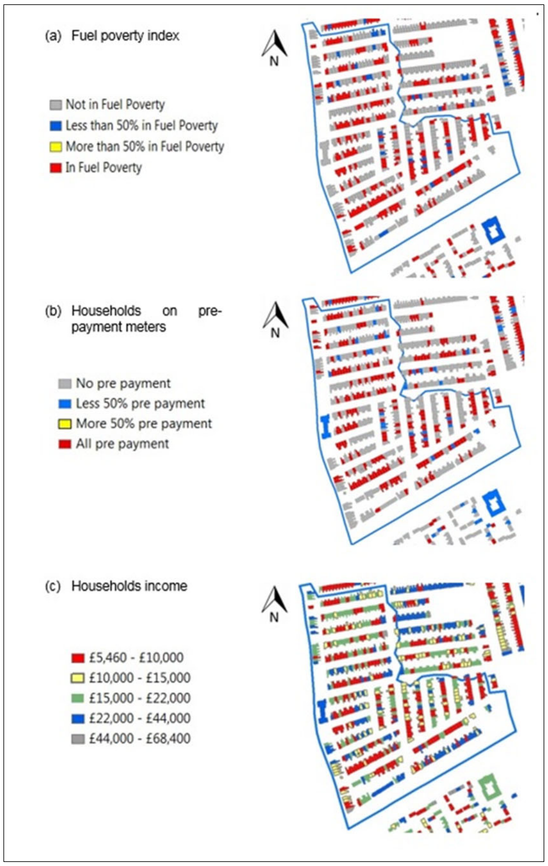

Figure 5 Fuel poverty index, households on pre-payment meters and households income. LLSOA 8362 at scale 1:3,000

Figure 5 also highlights and interesting relation between fuel poverty, building type and tenure. There are a high number of House is in Multiple Occupation (HMOs) in "lower 3-4 story mid-terraced flats and detached and linked" houses, corresponding to the "Late Victorian/Edwardian (1870-1914)" buildings in South Heaton. A House is in Multiple Occupation (HMO) if at least three tenants live there, forming more than one household and sharing a toilet, bathroom, or kitchen facility with other tenants.

The vulnerability of HMO tenants to fuel poverty can be attributed to the lower energy efficiency of such properties, or the increased presence of low-income households with above-average energy needs. This is particularly true for HMOs, where energy efficiency upgrades have often been impeded by the complexities associated with tenure arrangements (Bouzarovski and Cauvain, 2016).

DISCUSSION AND SOME REMARKS

This paper has shown that, as the scale decreases, local area characteristics are important. Our paper outlines how area-based targeting (Walker *et al.*, 2012) can identify small areas with relatively large numbers of households in fuel poverty.

Using this type of analysis, the approach to energy efficiency areas may exploit a similar concept to that used in the fuel poverty literature known as the Low Carbon Zone (LCZ) (Boardman, 2007). In this approach, all the residents within the area may be offered an Energy Company Obligation package to improve the energy efficiency of the home without considering the tenure or the income of the household.

Uncertainty arises when integrating spatial data from different scales (Urquizo *et al.*, 2017b), e.g. overlaying an LLSOA map over a Gazetteer map leaves some city parcels being part of several LLSOAs. Uncertainties from on-site data are those obtained through domestic energy efficiency campaigns (WarmZone) to alleviate fuel poverty. WarmZone's approach is a door-to-door assessment using teams who systematically contact households, mainly face-to-face on the doorstep, to acquire (through secondary information) a measure of the fuel poverty status of the household. This information is then used to target the provision of an appropriate energy efficiency measure.

CONCLUSION

Progress against the government target for fuel poverty reduction, as set out in the UK Fuel Poverty Strategy, is monitored using defined, detailed calculations (DECC, 2013b). It is not realistic to replicate this level of data collection through a door-to-door assessment. Examples of uncertainty arising from the WarmZone data are: (i) WarmZone is restricted to a set of (inaccurate) data, as it is largely related to the assessment of fuel poverty, both before and after intervention, and therefore is an approximate measure; (ii) the WarmZone data collection was focused on areas where there was existing evidence of spatially clustered concentrations of fuel poverty within a locality which could benefit from high impact approach zones.

The figures in this paper re-iterate three key messages of this research: local area characteristics are important to the understanding of the energy consumption and carbon estimates in sub-city areas; energy efficiency measures are area specific and the application has to be area-based, and these areas may not align with UK official aggregation areas.

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