Title

Underrepresenting neighbourhood vulnerabilities? The measurement of fuel poverty in England

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Abstract

The vulnerabilities that enhance the likelihood of a household falling into fuel poverty are increasingly recognised as highly multidimensional and geographical. However, the most established indicators used to measure fuel poverty are primarily based upon expenditure. This paper seeks to understand to what extent expenditure-based indicators succeed in representing wider socio-spatial vulnerabilities that manifest in particular locales. Our analysis focuses upon England, where a policy review in 2012 led to the replacement of a 10% indicator with a Low Income High Cost indicator. Fuel poverty estimates are scrutinized at a neighbourhood scale, considering their relationship with a range of socio-economic, demographic and socio-technical characteristics. Place-based effects upon these relationships that arise from the wider context within which each neighbourhood sits are also accounted for using Geographically Weighted Regression. The findings suggest that a 'one-size fits all' expenditure-based indicator is unlikely to capture the heterogeneous socio-spatial vulnerabilities that enhance the likelihood of fuel poverty experienced between different demographics and geographical contexts.

Key words

Fuel poverty, socio-spatial vulnerability, indicators, Geographically Weighted Regression, place-based effects

Introduction

Fuel (or energy) poverty can be defined as the condition in which a household is unable to access sufficient domestic energy services to allow it to participate meaningfully in society (Buzar 2007). The definition builds upon the significant contribution to understanding of the phenomenon made over several decades by Boardman (1991, 2010). This lack of access to sufficient energy services can manifest as a range of negative outcomes upon health and wellbeing (Liddell and Morris 2010). In industrialised nations, fuel poverty is traditionally recognised as the result of the interaction between three drivers: high energy prices, low incomes and domestic energy inefficiency (Boardman 1991, 2010, Hills 2012) but more recent understandings have challenged this conceptualisation. Fuel poverty is recognised as a unique form of deprivation and disadvantage (Boardman 2010, Buzar 2007), given its association with particular arrangements of socio-technical and networked infrastructures that lead to a 'poverty of connections' (Graham and Marvin 2001: 288). A large proportion of evidence underpinning this understanding has focused upon the United Kingdom (UK) where fuel poverty has featured within policy agendas since the 1990's. Here, energy price increases have exceeded increases in household incomes and there is a legacy of hard-to-treat buildings (Boardman 1991, Rudge 2012). However, the issue is not confined to the UK, with an inability to access sufficient domestic energy services documented across industrialised nations in Europe (Thomson and Snell 2013) and beyond (Harrison and Popke 2011).

Increasingly, research has sought to highlight the multi-dimensional and spatially-constituted nature of fuel poverty. One way in which this has been achieved is using the concept of vulnerability that draws attention to the uneven social (Hall et al. 2013, Middlemiss and Gillard 2015) and socio-spatial distribution (Bouzarovski and Petrova 2015, Bouzarovski et al. 2017) of factors that enhance the likelihood of a household falling into fuel poverty. These socio-spatial vulnerability factors may include, but are not limited to: age, health, financial capacity, availability of state support, energy inefficiency in the built environment, high energy prices and the existence of social networks. However, this approach has often not been reflected in the measurement of fuel poverty in policy. In England, where measurement approaches have undergone considerable revision, both the former 10% indicator and the new Low Income High Cost (LIHC) indicator are expenditure focused. Analysis of the spatial distribution of the indicators suggests that each fuel poverty indicator captures 'different notions of what it means to be fuel poor, representing particular socio-spatial vulnerabilities, potential injustices and geographies of fuel poverty' (Robinson *et al.* 2017: 13). Neither

indicator succeeds in representing the diverse range of geographies apparent within wider research.

The objectives of this paper are threefold: to provide *i)* insight into the socio-spatial vulnerabilities that each indicator prioritises or underrepresents, and in which neighbourhoods, *ii)* further knowledge of the geographic characteristics of vulnerability to fuel poverty, and *iiii)* a means of challenging the indicators and associated policy to question why certain socio-spatial vulnerabilities are underrepresented within a particular neighbourhood. As debates concerned with place-based vulnerability to fuel poverty are relatively embryonic, to achieve this aim we draw upon the established literature concerned with deprivation more broadly in which the important contribution of place is better articulated. Our analysis is carried out at a neighbourhood scale, considering the relationship between fuel poverty as understood by each indicator and a range of socio-economic, demographic and socio-technical characteristics. We specifically focus upon those vulnerabilities associated with disability and illness, older age, families with young children, lone parent families, private renters and households without gas central heating. An Ordinary Least Squares (OLS) linear regression technique is carried out. Place-based effects and the influence of surrounding neighbourhoods upon these relationships are also considered using Geographically Weighted Regression (GWR) to account for local variability in regression statistics (Fotheringham et al. 2003). Whilst the analysis focuses upon England, our findings have wider significance for those interested in the use of indicator-based methods to measure and monitor fuel poverty (whether in research, policy or practice), and more broadly in the geography of fuel poverty.

A place-based understanding of deprivation

The importance of geography and place is well established within research concerned with poverty, deprivation and disadvantage. The general consensus is that where you live matters in addition to who you are (e.g. Dorling 2001, Galster 2001, Lupton 2003, Macintyre et al. 2002). Place has an important role in 'determining, shaping, and sometimes reinforcing deprivation' (RTPI 2016: 2), contributing to what inspires and conditions us.

Neighbourhoods are described by Galster as a 'bundling of spatially-based attributes' (2001: 2111). This bundling can be understood as 'socio-spatial' as attributes including the physical

and built environment, infrastructure, demographics, class, local services, political characteristics and social networks converge in a particular place, as a result of geographical processes (Lindley et al. 2011). The socio-spatial characteristics of a neighbourhood have a role to play in the socioeconomic outcome of, as well as the opportunities available to, a household or individual (Dietz 2002). There are several important characteristics that determine the interactions between a neighbourhood and the households that they are composed of, and with the wider regional and national context within which they operate. Some characteristics are well-established and difficult to alter, for example, the housing stock or economic base underpinning an area (Lupton 2003). Neighbourhoods also have a distinct composition and individuals with shared characteristics concentrate in particular places, lending their collective attribute to the space, for example, income or life stage (Galster 2001). Despite these relatively established characteristics, neighbourhoods are not fixed within rigid boundaries (Massey 1994), as is often necessary to assume in analyses of this scale given the limitations of administrative datasets. Rather the neighbourhood is influenced by the wider context within which it sits, engaging with the regional and national mechanisms that control wider socio-economic resources or capacities that contribute towards localised deprivation, in what Crossley (2017) terms 'Westminster effects' in the UK context. Relationships also exist between one neighbourhood and the next.

Spatially variable vulnerability to fuel poverty

In contrast to research concerned with deprivation more broadly, the important contribution of place towards a household's inability to access sufficient energy services has only recently begun to be articulated. Several embryonic agendas have emerged that seek to understand in greater depth how fuel poverty, and associated negative outcomes for wellbeing, manifest in certain households. Systematic injustices are explored that arise throughout the system of energy provision in relation to the distribution of appropriate, affordable energy, the recognition of specific household's energy needs and the procedures that lead to adequate domestic provision of energy (Walker and Day 2012). A capabilities framing is mobilised by Day et al. (2016) to understand the freedoms and opportunities people have to achieve wellbeing in relation to domestic energy services. The concept of vulnerability is also used to identify those factors that increase the likelihood of a household falling into fuel poverty (Middlemiss and Gillard 2015, Bouzarovski and Petrova 2015, Bouzarovski et al. 2017).

Each framing better articulates the multi-dimensional nature of fuel poverty. In addition, to differing extents, the framings recognise the importance of geography and place in understanding the uneven distribution of fuel poverty (Bouzarovski and Petrova 2015, Bouzarovski and Simcock 2017). These debates are especially pertinent in the context of new challenges of inequality and poverty as a result of the Global Financial Crisis and austerity policies (Hall et al. 2013).

In this analysis we draw primarily upon the concept of vulnerability which draws attention to the spatially variable nature of factors that enhance the likelihood of a household experiencing fuel poverty. Vulnerability is understood as the:

> 'degree of susceptibility to... stresses, which is not sufficiently counterbalanced by capacities to resist negative impacts in the medium to long term, and to maintain levels of overall wellbeing' (Allen 2003: 170).

This degree of susceptibility to a stress, in this instance a lack of appropriate energy services, is determined by a range of personal, social, economic, socio-technical and institutional factors, as evidenced by Cutter (2003) and Adger (2006). These factors can be combined with aspects of place to identify socio-spatial vulnerability, the geographical expression of the losses of wellbeing that can result from a particular stress (Lindley et al. 2011). Drawing upon this concept of vulnerability, Bouzarovski et al. theorise fuel poverty as a 'socio-spatial phenomenon' (2017: 35).

Bouzarovski and Petrova (2015) identify six vulnerability dimensions that can inhibit the effective operation of socio-technical pathways that allow for sufficient energy services in the home. Two dimensions relate to the traditional drivers of fuel poverty: affordability and energy efficiency. Four additional dimensions are also documented: access, flexibility, needs and practices. Access refers to a lack of appropriate fuel types given a households required energy services; flexibility is concerned with the ability of a household to switch to energy services that meet their specific needs; needs recognises the disparity between a households requirement for energy services socially, culturally and economically, and the energy services available to them; practices identifies the ways in which a household may use energy inefficiently. Some vulnerability dimensions are the result of aspects of place directly coupled with geography, including material and infrastructural features of a locale (Lupton 2003). For example, energy efficiency is determined by the legacy of the built environment (Rudge 2012) whilst access is influenced by the role of place in facilitating networked energy

infrastructures that make available affordable fuel types (Graham and Marvin 2001). Galster (2001) highlights how other dimensions are not directly coupled with physical and material geography, instead lending their collective attribute to the space as a result of aggregation, due to social and historical processes. For example, older or disabled residents with a greater need for energy concentrate in particular neighbourhoods. Additionally, some vulnerability dimensions are associated with the relative position of a neighbourhood. These include structural factors associated with the regional context in which the neighbourhood sits, for example, energy or housing markets (Middlemiss 2016), and factors associated with surrounding neighbourhoods, for example, the existence of social networks (Middlemiss and Gillard 2015).

Fuel poverty indicators in England

Vulnerability thinking draws attention to the effect that place has upon this unique form of deprivation; however, there is little recognition of the importance of place in fuel poverty policy and attempts by policymakers to measure the phenomenon. In England, where measurement of fuel poverty is perhaps most developed, owing to the Hills Review in 2012 (Hills 2012), the approach of the Department for Energy and Climate Change (DECC) (now the Department for Business, Energy and Industrial Strategy), has consistently been expenditure-focused, previously employing a 10% indicator and more recently a LIHC indicator. Described in Table 1, the 10% indicator places considerable emphasis upon energy price and is an absolute fuel poverty threshold, making it possible for any number of households to be fuel poor. Meanwhile, the LIHC indicator prioritises a relative understanding of the income a household has available to spend on fuel. Considerable attention has been paid to the merits of each indicator questioning both the technicalities of the indicator design (Boardman 2012, Moore 2012) and the political motivation for the change in measurement approach, particularly given the significant reduction in fuel poor households that has resulted (Hall *et al.* 2013, Middlemiss 2016). The number of households classified as fuel poor in 2012 decreased from 13.8% of households using the 10% indicator to 10.5% of households using the LIHC indicator (DECC 2014).

Whilst sub-regional fuel poverty statistics are produced by DECC at the Lower Super Output Area (LSOA) scale, the design of the 10% and LIHC indicators of fuel poverty has tended to treat fuel poverty as a household issue, operating in isolation from the neighbourhood and regional context. Middlemiss (2016) highlights how subsequently the LIHC indicator

underplays the role of structural energy markets in enhancing fuel poverty. The restriction of fuel poverty to a household issue can also be challenged given the socio-spatially variable nature of fuel poverty outlined previously and research that subsequently highlights the neighbourhood embeddedness of the phenomenon (e.g. Liddell et al. 2011, Walker et al. 2012).

In analysing the geography of fuel poverty using each indicator, Robinson et al. (2017a.) demonstrate how the move from a 10% indicator to a LIHC indicator in England has resulted in a relative transfer of fuel poor households towards regions with higher housing costs and towards urban areas, whilst the fuel poor using the indicator are also more spatially heterogeneous. For example, in rural areas, there was a 8.1% decrease in fuel poor households in 2012 using the LIHC indicator rather than the 10% indicator, whilst in areas classified as urban there was on average no decrease (DECC 2014). These substantial differences in the geographical distribution of fuel poverty using each indicator suggest that those socio-spatial vulnerabilities that manifest in locations which (by its design) an indicator overlooks, are likely to be underrepresented. Building upon this knowledge, this paper offers a new perspective on the measurement of fuel poverty, providing understanding of the socio-spatial vulnerabilities that each expenditure-based indicator reveals and underrepresents, and in which locales. In doing this, further insights into the geography of fuel poverty in England are provided with implications for alternative national contexts.

Table 1. Indicators used to calculate percentage of fuel poor households in England.

Indicator	Definition	Date	Type	Calculation
LIHC	'A household is considered fuel poor is they have required fuel costs above the average (national median level) and if they were to spend that amount, they would be left with a residual income below the poverty line' (DECC 2016: 3)	2015	Relative	The LIHC indicator uses an energy threshold and an income threshold. Households that exceed both are fuel poor. The energy threshold is modelled by combining fuel requirements of household and corresponding fuel prices. Fuel requirements account for property size, household size, energy efficiency and fuel mix. The income threshold is calculated using 60% of the weighted median income After Housing Costs and is equivalised. This is combined with equivalised fuel costs.
10%	'A household is considered to be fuel poor if they are required to spend more than 10% of their income on fuel, to maintain an adequate standard of warmth' (DECC 2016: 6)	2000	Absolute	The 10% indicator uses a ratio of modelled fuel costs (consumption and energy price) and income (Before Housing Costs). Households exceeding a ratio of 0.1 are fuel poor.

Source: DECC (2016)

Methodological approach

To investigate where and to what extent existing fuel poverty indicators reflect the socio-spatial distribution of vulnerabilities associated with a lack sufficient domestic energy services, sub-regional fuel poverty estimates are scrutinised at a neighbourhood scale, considering their relationship with a range of socio-economic, demographic and socio-technical variables. Place-based effects upon these relationships are accounted for using GWR.

Scale of analysis

The analysis is carried out at the LSOA scale, neighbourhood units designed for reporting of small area statistics that represent between 400 and 1200 households (ONS 2011a.). Whilst issues exist pertaining to the ability of LSOA to represent the complexity of the neighbourhood, as LSOA can conceal considerable diversity between the households they represent as socially homogenous, they are the most appropriate analysis scale given the use of administrative data. Each LSOA is represented in the analysis by a population-weighted centroid, a single reference point derived from the spatial distribution of the population within the LSOA.

Geographically weighted regression

Regression techniques indicate the type and strength of the relationship between the dependent and independent variables; in this instance fuel poverty estimates for each indicator and socio-spatial vulnerability variables. When these relationships vary across space a GWR model accounts for the effect that surrounding areas have upon the relationships in a particular neighbourhood (Fotheringham et al. 2003). For each indicator a 'global' OLS regression model (described in Robinson et al. 2017b.) and a 'local' GWR model allow for comparisons between national (global) associations and more geographically refined (local) associations.

In contrast to the OLS regression, which uses a single regression equation for the entire dataset, the GWR fits a regression equation to every LSOA, weighted by a function of the distance from neighbouring LSOA, allowing relationships to vary across space. This can be articulated using the equation:

$$y_i = a_0(u_i, v_i) + \sum_k a_k(u_i, v_i)x_{ik} + \varepsilon_i$$

where (u_i, v_i) represents the coordinates of the ith point in space (each LSOA population-weighted centroid in this instance) and $a_k(u_i, v_i)$ is the continuous function $a_k(u, v)$ realised at each point i (Fotheringham et al. 2003).

To account for variation in LSOA size an adaptive bandwidth determines its weighting, allowing for a smaller bandwidth around population centroids where the data is denser (Fotheringham et al. 2003). A corrected Akaike Information Criterion (AICc) method is used to predict the bandwidth yielding a parameter of 799 (2.4% of LSOA).

Sub-regional fuel poverty estimates and socio-spatial vulnerability variables

Sub-regional estimates of fuel poverty for both the 10% indicator and the LIHC indicator are the dependent variables. Estimates are derived from modelling based upon the English Housing Survey and provide a percentage of fuel poor households for the year 2012 (DECC 2014).

A range of socio-spatial vulnerability variables representative of demographic, socio-economic or socio-technical characteristics are selected as independent variables. An extensive literature review followed by a process of step-wise regression and backward elimination using the OLS model identified six vulnerability variables: households with a disability or limiting long-term illness, all pensioner households, households with young children, lone-parent households, private renters and households without gas central heating. Table 2 explores further the vulnerability factors and pathways that are likely to characterise households represented by each variable. Several additional variables were identified but excluded during the analysis: social renters, single person households and households with a pre-payment meter. This was due to problems of multicollinearity (where two variables are highly correlated) or a lack of suitable data.[1] For a more extensive review of literature concerned with the geographical variance of the vulnerability factors and pathways detailed in Table 2, see Robinson et al. (2017a.). Household scale data is obtained from the most recent Census (Table 3) (ONS 2011a.).

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[1] Although these variables were excluded due to the results of the OLS models, it is recognised that this does not preclude them from having an effect on the GWR models. Although outside the scope of this analysis, readers should bear this in mind when interpreting the results of the GWR models.

Table 2. Possible vulnerability pathways for socio-spatial vulnerability variables.

[1]Vulnerability dimension	Example vulnerability factor	Disability[2]	Pensioner[3]	Young child[4]	Lone parent[5]	Private rent[6]	Non-gas[7]
Access	Inability to access cheaper fuels		x			x	x
Affordability	Low income	x		x	x		
	State pension		x				
	State security benefits	x			x		
	Unemployment	x			x		
	Part-time or precarious employment	x			x		
	Ineligible for financial support for heating			x	x	x	
	High energy use per capita	x	x				
	Income from state support reduced	x	x		x		
Efficiency	Lack of capital to invest in efficiency	x	x	x	x	x	
	Inefficient energy conversion by appliances		x			x	
	Energy inefficient property		x			x	x
	Limited eligibility for efficiency measures			x		x	x
Flexibility	Inability to switch to cheaper tariff		x		x	x	x
	Under-occupancy		x				
	Reduced autonomy over energy service	x	x				x
	Lack of control or choice over daily lives	x	x	x	x	x	
	Precarious living arrangements					x	
	Lack of housing rights					x	
	Unaffordability of owner-occupancy					x	
Needs and practices	Large proportion of time spent at home	x	x	x	x		
	Physiological need for energy services	x	x	x	x		
	Under-representation in fuel poverty policy	x		x	x	x	
	Lack of awareness of support	x	x	x	x		
	Lack of social relations in/outside the home	x	x	x	x	x	
	Unhealthy warm-related practices		x				

Source:

[1]Bouzarvoski and Petrova (2015)

[2]Gillard et al. (2017), Snell et al. (2015)

[3]Chard and Walker (2016), Healy and Clinch (2002)

[4]Gillard et al. (2017), Liddell and Morris (2010)

[5]Gingerbread (2013)

[6]Ambrose (2015)

[7]Graham and Marvin (1994), Roberts (2008).

Table 3. Socio-spatial vulnerability variables datasets and descriptive statistics

Descriptor	Census dataset	Mean	Min.	Lower Quar.	Med.	Upper quar.	Max.	IQ* range
DISABILITY	Household with disability or limiting illness	25.64	3.00	21.60	25.5	29.60	60.10	8.00
PENSIONER	All pensioner household (aged over 65 years)	20.72	0.00	14.54	20.47	26.32	65.95	11.78
YOUNG CHILD	Household with young child(ren) (0-4 years)	12.11	0.69	8.25	11.15	14.84	59.60	6.56
LONE PARENT	Lone parent household	7.11	0.00	4.06	6.09	9.21	39.87	5.15
PRIVATE RENT	Privately rented household	16.24	1.30	8.20	12.40	20.70	90.30	12.50
NON GAS	Household with non-gas central heating	20.55	1.59	9.96	14.69	22.99	98.68	13.03

*Inter quartile

Source: ONS (2011a.).

National and local scale relationships between fuel poverty estimates and socio-spatial vulnerability variables

The national-scale results of the OLS regression demonstrate that there has been a shift in the type of household likely to be detected as fuel poor, from a 10% indicator that pinpoints fuel poverty amongst pensioner and off-the-grid households towards a LIHC indicator that highlights fuel poverty amongst low income families (Robinson et al. 2017b.) (Table 4). However, Adjusted R^2 values for each of the OLS models show that the LIHC indicator model explains only 23% of the variance in the relationships whilst the 10% indicator model explains 32% of the variance. In contrast, the Adjusted R^2 values for the GWR models suggest that they explain considerably more of the variance in fuel poor households using each indicator (65% and 72% respectively) by accounting for the changing effect of predictor values across space.

Table 5 displays the summary results for the GWR model for each fuel poverty indicator. Once mapped, the coefficient estimates highlight locales where the influence of a socio-spatial vulnerability variable upon fuel poverty using each indicator is particularly strong, either negatively or positively (Figures 1-4). The following sections discuss these spatial patterns further, comparing the different extents to which socio-spatial vulnerabilities are represented by each indicator, considering which vulnerabilities are overlooked by the indicators, and reflecting upon the limitations of the analysis approach. How representative an indicator is of a particular socio-spatial vulnerability is determined by i) the strength of the positive correlation between the two indicators and ii) how closely aligned the spatial distribution of the coefficient estimates is to the spatial distribution of the vulnerability variable.

Table 4. OLS regression models.

Descriptor	LIHC indicator				10% indicator			
	Coefficient est.	StdError	t-Statistic	VIF	Coefficient est.	StdError	t-Statistic	VIF
Intercept	0.094472	0.337705	0.279747	---	0.340571	0.370015	0.920423*	---
DISABILITY	0.3355458	0.005931	56.557118*	1.534838	0.294818	0.006499	45.364943*	1.534838
PENSIONER	-0.086398	0.006744	-12.811075*	2.442525	0.060302	0.007389	8.160738*	2.442525
YOUNG CHILD	0.069810	0.007155	9.756461*	1.651629	-0.031796	0.007840	-4.055711*	1.651629
LONE PARENT	0.056805	0.007185	7.906306*	2.121714	-0.014179	0.007872	-1.81188*	2.121714
PRIVATE RENT	0.253467	0.004794	52.867880*	1.511060	0.163514	0.005253	31.127402*	1.511060
NON GAS	0.064383	0.002879	22.361189*	1.102838	0.312323	0.003155	99.002216*	1.102838

Note: LIHC model, N= 32,844, adjusted R2 = 0.231839, AIC = 239888.120711. 10% model, N=32,844, Adjusted R2 = 0.322807, AICc = 245890.215314.

*Significant at 0.001 level

Source: Robinson et al. (2018).

Table 5. GWR models.

Descriptor	LIHC indicator (coefficient estimates)						
	Mean est.	Min. est.	Lower quar.	Median	Upper quar.	Max. est.	IQ* range
Intercept	2.755653	-8.81328	0.905857	2.954928	6.911875	16.789417	6.006018
DISABILITY	0.118834	-0.035428	0.04898	0.088958	0.16366	0.453623	0.114680
PENSIONER	-0.045553	-0.418038	-0.091877	-0.024724	0.026485	0.234505	0.118362
YOUND CHILD	0.007392	-0.22	-0.026488	0.079237	0.261626	0.561141	0.288114
LONE PARENT	0.061056	-0.28	-0.066617	0.053004	0.163524	0.359083	0.230141
PRIVATE RENTER	0.176777	-0.06	0.101401	0.187608	0.289015	0.474736	0.187614
NON GAS	-0.012492	-0.31	-0.143219	-0.043999	0.037649	0.200534	0.180868

Descriptor	10% indicator (coefficient estimates)						
	Mean est.	Min. est.	Lower quar.	Median	Upper quar.	Max. est.	IQ* range
Intercept	6.653573	-6.097825	3.095929	6.51299	9.858161	17.331789	6.762232
DISABILITY	0.045701	-0.134653	0.001136	0.032948	0.070789	0.347365	0.069653
PENSIONER	0.010080	-0.335684	-0.043683	0.019489	0.069725	0.284755	0.113408
YOUNG CHILD	-0.003815	-0.208673	-0.046900	-0.016020	0.032997	0.357279	0.079897
LONE PARENT	0.012427	-0.239007	-0.036295	0.013344	0.064664	0.202016	0.100959
PRIVATE RENT	0.140429	-0.133425	0.061893	0.126297	0.218129	0.404626	0.156236
NON GAS	0.098217	-0.227701	-0.004793	0.119317	0.228607	0.452340	0.233400

Note: LIHC model, N= 32,844, adjusted R2 = 0.646709, AIC = 170791.103775.10% model, N=32,844, Adjusted R2 = 0.768967, AICc = 71694.524498.

*Inter quartile

Comparing the socio-spatial vulnerabilities and neighbourhoods represented by fuel poverty indicators

The private renter vulnerability variable is the only variable that is represented well by the spatial distribution of fuel poor households using both indicators, exhibiting a positive relationship in each 'global' OLS model when controlling for other variables. For the 10% indicator 'local' GWR model, the 25% of LSOA with the highest positive coefficients exceed +0.21 and are concentrated in urban areas in the Midlands and Northern regions, in particular the North East. This concurs with the spatial distribution of privately rented properties in which low concentrations are found in the suburbs of urban areas where home ownership is high (ONS 2011a.). The strength of these positive relationships is greater using the LIHC GWR model in which 25% of LSOA have a coefficient of over +0.29. With the exception of two clusters of negative coefficients in London's commuter belt, all LSOA have a positive coefficient using the LIHC indicator. This positive relationship is strongest in major cities, with the exception of London, and in remote rural areas that also have a high percentage of private renters (Houston and Sisson 2012).

In representing the socio-spatial vulnerabilities associated with private renting, the LIHC indicator might be anticipated to be most effective. By including housing costs in the calculation of income, the 10% indicator favours households that own their property outright (Moore 2012). In contrast, the calculation of income *After Housing Costs* in the LIHC indicator favours households with higher housing costs, including mortgage or rent payments (Hills 2012). In fact, using the GWR model, the private renter variable is that which exhibits some of the strongest positive relationships with fuel poor households using both indicators. This suggests that vulnerability amongst private renters is determined to an extent by the different facets of vulnerability that the design of each indictor prioritises, high energy prices concerning the 10% indicator and relatively low incomes in the case of the LIHC indicator. Private renters tend to be disproportionately reliant upon high cost pre-payment meters and live in energy inefficient properties, increasing the price of energy (Ambrose 2015). It also suggests that the vulnerability variable begins to explain the manifestation of the phenomenon in diverse urban and rural settings. Whilst the positive relationship is less strong in parts of London, despite the region having the highest percentage of privately rented households, this can be partially attributed to high concentrations of private renters living in more affluent neighbourhoods (GLA, 2015).

In contrast, the LIHC indicator better represents socio-spatial vulnerabilities associated with disability and illness that manifest in large city regions. Using the OLS models, disability and long-term illness has a positive effect on fuel poverty using both indicators. Investigating further the spatial variation in these relationships, for the 10% indicator GWR model 25% of LSOA have a coefficient of above +0.07 whilst for the LIHC indicator GWR model 25% of LSOA have a coefficient of over +0.16. Geographically, households with a member with a disability or long-term illness tend to concentrate in urban areas in the Midlands and North, or in coastal communities (ONS 2011a.), areas with structural forms of deprivation related to income and employment. Concurring in part with this spatial distribution, Figure 1 highlights a positive relationship using the 10% indicator in large cities across the North and the Midlands. For the LIHC indicator this positive relationship is stronger and additionally manifests in some southern cities including London, Luton and Southampton. Greater recognition of the concentration of the variable in city regions by the LIHC indicator can be partially attributed to its design prioritising vulnerabilities typically associated with urban areas, including rates of home ownership and high housing costs. It can also be related to the spatial distribution of relative income deprivation, an element prioritised by the LIHC indicator, as households with a disabled member are more likely to experience relative poverty (Snell et al. 2015).
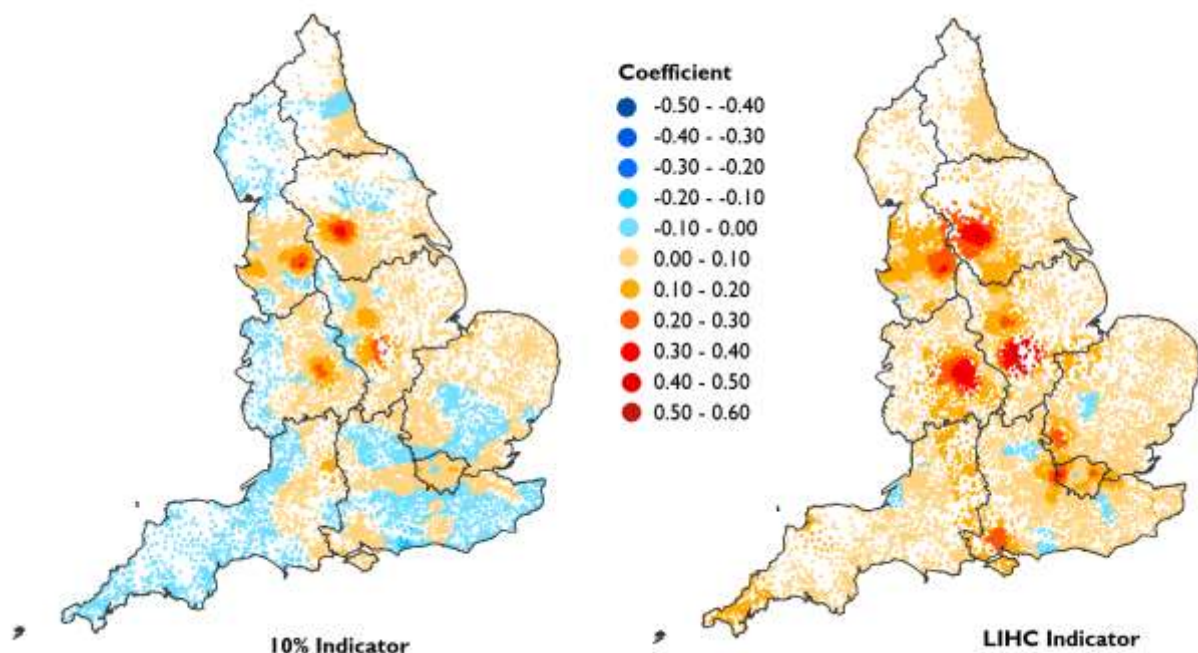

Figure 1. GWR coefficient estimates for disability and illness variable. Source: ONS (2011b.).

Unlike the disability variable, socio-spatial vulnerabilities associated with non-gas central heating are best represented by the 10% indicator. Non-gas central heating has a relatively high positive effect on fuel poverty using the 10% indicator OLS model (+0.31), compared to the LIHC indicator (+0.06). Geographically, households without gas central heating cluster in rural areas and in pockets of inner city areas within major conurbations (ONS 2011a.). Concurring to some extent, the negative coefficient estimates from the GWR models of both indicators are concentrated in urban conurbations. However, compared to the 10% indicator, the LIHC indicator has a less strong positive relationship with the non-gas central heating variable in rural areas. Abandonment of universal tariff structures during the privatisation of energy companies has resulted in social fragmentation, with fewer cross subsidies between urban areas that are cheaper to supply and more expensive rural areas (Graham and Marvin 1994). As such, the non-gas central heating variable is the variable to which high energy prices make the greatest contribution, a significant component in the 10% indicator design.
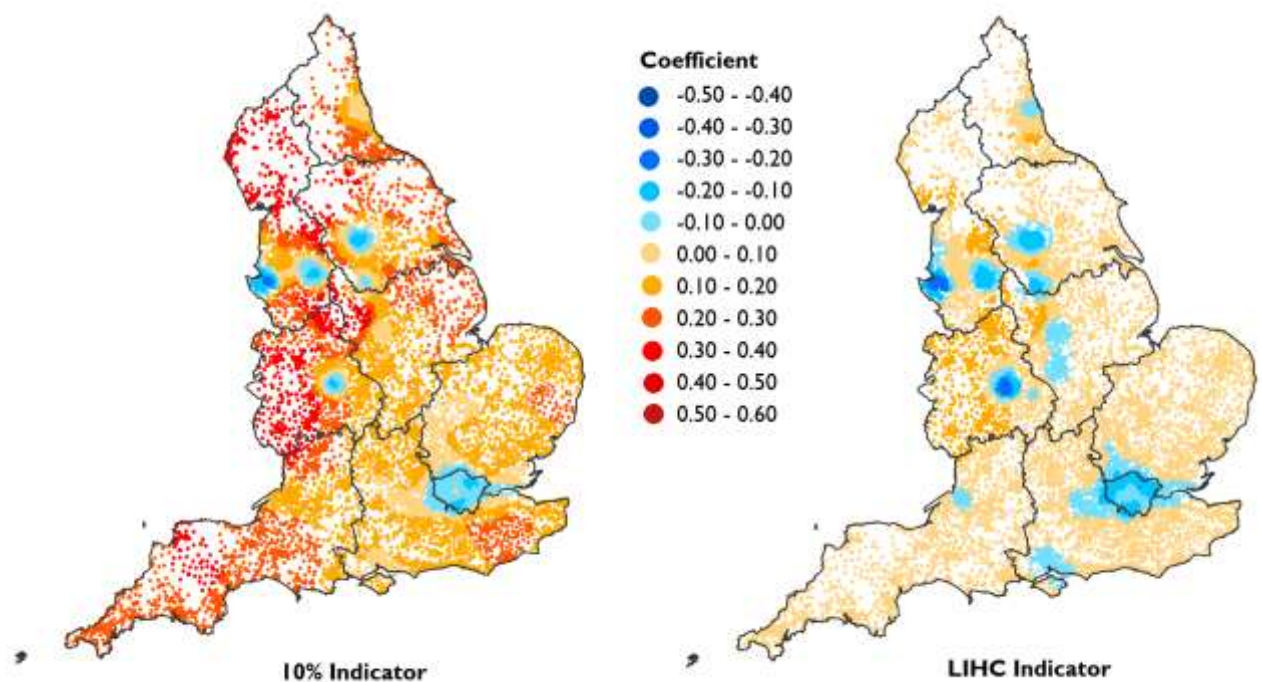

Figure 2. GWR coefficients for non-gas central heating variable.Source: ONS (2011b.).

The spatial distribution of the all pensioner household variable is also best represented by the 10% indicator. In the OLS model the variable has a positive effect on fuel poverty using the 10% indicator (+0.06) and a negative effect using the LIHC indicator (-0.09). For the 10% indicator GWR model, 40% of LSOA have a negative coefficient, largely concentrated in urban conurbations. For the LIHC indicator approximately 60% of neighbourhoods have a negative coefficient value concentrated in large urban conurbations, but extending into swathes of rural areas across the South West, South East and North West where there is a high percentage of all pensioner households (Figure 3). Given that neighbourhoods with the highest percentage of all pensioner households are commonly found in rural and coastal areas (ONS 2011), the distribution of the 10% indicator coefficients best represents the variable. This can be explained by the considerable influence of energy price upon the 10% indicator, a factor that commonly enhances the vulnerability of older populations due to their tendency to live in rural areas off the gas network (Roberts 2008). In contrast, the LIHC indicator places more emphasis upon properties with high housing costs (using a *Before Housing Cost* measure of income) excluding pensioners who are most likely to be owner-occupiers (ONS 2011a.). The LIHC indicator is also less likely to recognise under-occupied properties, common amongst pensioners, due to the equivalisation of income according to household composition (Healy and Clinch 2002, Moore 2012).
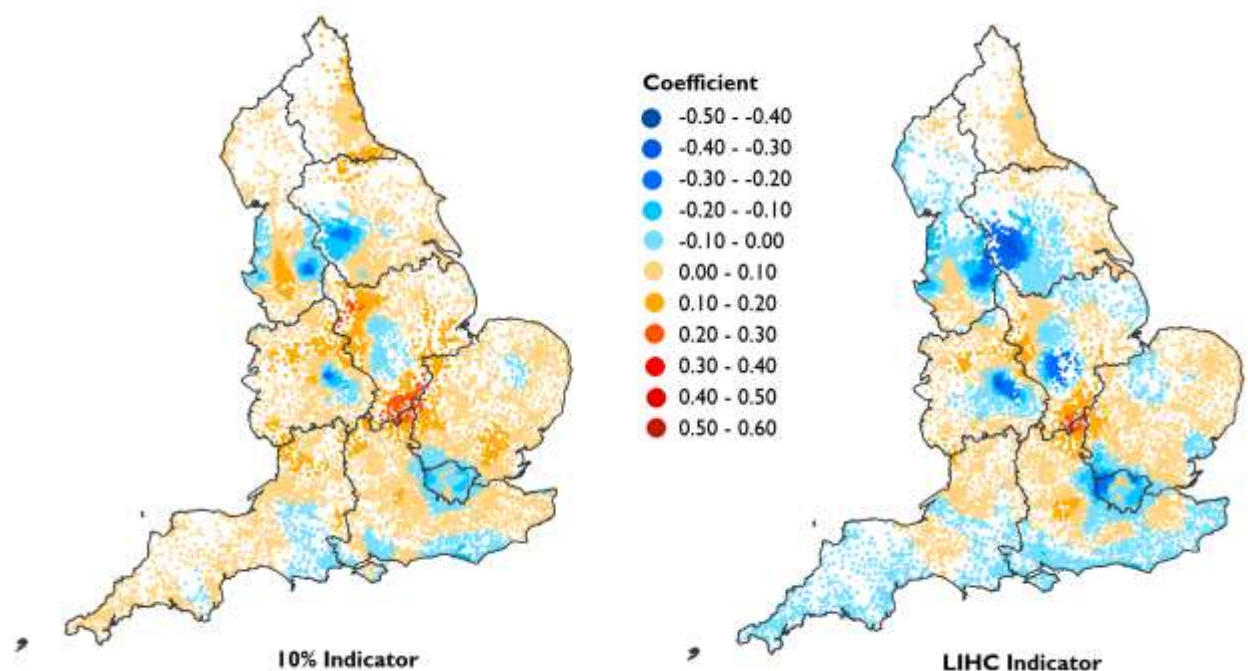

Figure 3. GWR coefficient estimates for all pensioner household variable. Source: ONS (2011b.)

Underrepresented socio-spatial vulnerabilities and neighbourhoods

The GWR models highlights that some vulnerability variables may be poorly represented by both indicators when considering their spatial distribution. Using the OLS model, seemingly the LIHC indicator better represents vulnerability amongst lone parent families. However the GWR demonstrates that the 10% indicator is in fact slightly preferential in its representation of the spatial distribution of lone parents, having a less strong positive relationship with lone parent households in rural areas compared to the LIHC indicator. Whilst approximately 75% of LSOA have a positive coefficient value using the LIHC indicator, these are concentrated in rural areas in the Midlands, Yorkshire and the Humber and the East of England. Whilst some city regions have positive relationships (e.g. Newcastle and Liverpool) others exhibit negative relationships (e.g. Manchester, Birmingham and Leeds). These spatial patterns fail to represent the concentration of lone-parent households in large urban conurbations (ONS 2011a.). The analysis scale may contribute towards this lack of recognition, as 2.4% of LSOA are included in the bandwidth of each GWR regression equation. Given that lone parent households are highly spatially concentrated relative to other variables, a large bandwidth may be smoothing the results, masking pockets of LSOA where the relationship is positive. The complexities associated with deprivation amongst lone parent families, who are likely to experience a myriad of challenges in balancing employment and childcare, may also be more difficult to represent using a single indicator (Gingerbread 2013).
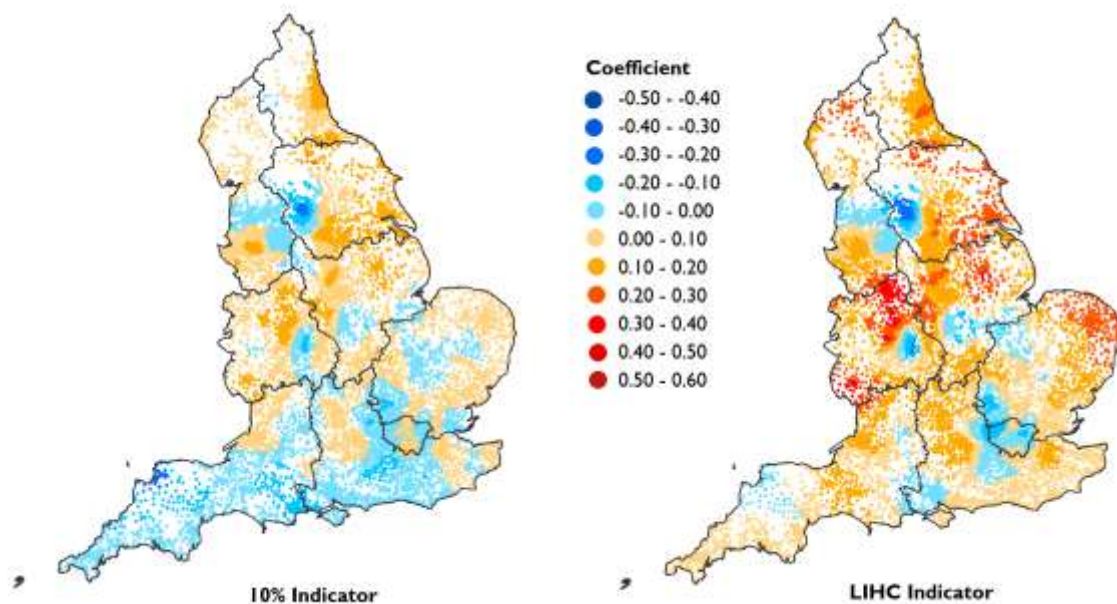

Figure 4. GWR coefficients for lone parent household variable. Source: ONS (2011b.).

To a lesser extent, socio-spatial vulnerabilities associated with some young families with children may also be underestimated by the fuel poverty indicators. The OLS estimate for the 10% indicator is weakly negative whilst for the LIHC indicator it is positive. In the GWR models for both indicators approximately 50% of LSOA have a negative relationship with fuel poverty. However, for the 10% indicator the highest positive coefficient has a value of +0.36 whilst for the LIHC indicator the value is considerably higher, +0.56. Geographically, families with young children are clustered in urban areas and some select rural neighbourhoods (ONS 2011a.). Using the 10% indicator, the city of Birmingham has a large concentration of positive coefficient estimates. For the LIHC indicator, East Lancashire, Leeds and Birmingham also have a strong positive relationship. Despite the LIHC indicator being a slight improvement in representing vulnerabilities amongst families with young children, there are many neighbourhoods where their socio-spatial vulnerability may be underrepresented, particularly in large urban conurbations that do not exhibit a positive relationship with fuel poverty.

Additionally, the analysis suggests that particular facets of vulnerability within variables are ignored in certain neighbourhoods. Snell *et al.* (2015) recognises that neither fuel poverty indicator is able to represent the myriad of vulnerability dimensions that enhance the likelihood of those with a disability experiencing fuel poverty. These concerns are reflected here by the absence of particular spatial patterns anticipated when exploring the relationship between disability or long term illness and fuel poverty. The North East has the highest percentage of households with a disability or long-term illness (29.26%) yet the region has relatively low mean coefficient values for the 10% indicator (+0.01) and LIHC indicator (+0.02). Disabled households are geographically clustered in coastal communities, particularly former seaside towns (ONS 2011a), where a range of social problems and derivations tend to manifest, including a high percentage of elderly residents, low employment levels and physical isolation (Fernandez-Bilbao 2011). Yet neither GWR model detects the concentration of households with a disability in these communities. Meanwhile, both indicators have a negative relationship with the non-gas central heating vulnerability variable in large urban conurbations suggesting that neither recognises the socio-spatial vulnerabilities experienced in inner-city areas that rely on more expensive electricity to heat the home. Vulnerabilities associated with inner-city areas are often not as well articulated or explored in England as elsewhere in Europe (e.g. Tirado-Herrero and Urge-Vorsatz 2012). This is despite wider recognition of vulnerability amongst young urban adults, a precarious

and transient group that are likely to live in inner-city areas without access to the gas network (Bouzarovski *et al.* 2013).

Limitations of the analysis

It is worth noting that the selected variables represent relatively broad categorisations within which different capacities, inequalities and vulnerabilities exist. Categorisation using demographic characteristics can risk underestimating the complexities associated with vulnerability to fuel poverty (Walker and Day 2012). Some categorisations are broader than others and it should not be assumed a household characterised by a variable is necessarily fuel poor (Boardman 2010). For example, concerning the all pensioner household variable, the challenges of fuel poverty amongst older people may arise from a diverse range of vulnerability factors that are by no means universal to all pensioners, many of whom benefit from a comfortable retirement supported by generous final-salary pension schemes and property ownership. This partially explains why certain socio-spatial vulnerabilities are not well represented by the spatial distribution of the existing fuel poverty indicators. Thus, some variables may be less useful in the measurement of fuel poverty when used in isolation but may be more powerful when combined with other vulnerability factors, for example, low income. This draws attention to the problematic nature of universal income support measures targeted at a particular demographic as a means of alleviating fuel poverty – an issue previously highlighted by Walker and Day (2012), for example the Winter Fuel Payment paid to every person of pensionable age in the UK.

Aspects of a group's vulnerability may also be captured by an alternative vulnerability variable. For instance, elements of a pensioner's vulnerability may be subsumed within the non-gas central heating and disability or illness variables. Meanwhile, there has been a dramatic increase in the number of families bringing up children in privately rented accommodation with families making up 40% of private renters in England (Citizens Advice, 2017). Therefore the private renter variable is likely to capture aspects of the vulnerability experienced by young families.

A further consideration is the diversity that exists in the deprivation and affluence of households within neighbourhoods defined as rural, compared to their denser urban counterparts. Concern has been voiced within multiple deprivation research about how

measurement approaches tend to prioritise urban areas that are more homogenous; thus masking rural deprivation (Commins 2004). These arguments are relevant in light of the concentration of positive relationships between the fuel poverty indicators and several vulnerability variables in urban areas. Conversely, some variables are primarily concentrated in rural areas, for example, the inability to access the gas network. This variable is therefore likely to represent a more diverse range of households that do not necessarily experience other socio-spatial vulnerabilities that characterise the fuel poor.

Conclusion: Challenging a one-size fits all approach

The initial aim of this paper was to understand how particular socio-spatial vulnerabilities and neighbourhoods are prioritised or underrepresented by existing fuel poverty indicators. Whilst the analysis focuses upon England, the findings have implications for alternative national contexts where a similar measurement approach is being considered, for example, Heindel (2015) and Legendre and Ricci (2015). We demonstrate how a national-scale shift in the type of household likely to be detected as fuel poor, from a 10% indicator that pinpoints fuel poverty amongst pensioner and off-the-grid households towards a LIHC indicator that better highlights fuel poverty amongst low income families has not been experienced uniformly. Whilst it is recognised that the variables used are relatively broad, the analysis highlights particular geographies not identified as fuel poor by the indicators that might be anticipated to have an enhanced vulnerability to fuel poverty. Socio-spatial vulnerabilities that neither indicator pinpoints include coastal communities with a high prevalence of disability and illness, an older population and entrenched income deprivation (Fernández-Bilbao 2013), and inner-city urban areas where transient populations are without access to the gas network (Bouzarovski et al. 2013, Bouzarovski 2014). Particular locales are also under-represented, for example, the high percentage of disability in the North East. More broadly, there is a general failure by both indicators to recognise the vulnerability of neighbourhoods with a high percentage of lone parents and, to a lesser extent, families with young children. Underrepresentation of these vulnerabilities suggests that the focus of existing indicators upon expenditure ignores more complex socio-spatial distributions pertaining to the efficiency, availability and flexibility of infrastructures, and specific household needs.

Exploration of these relationships helps to address our second aim, to provide further knowledge of the geographic characteristics of vulnerability to fuel poverty. The analysis

suggests that the socio-spatial distribution of vulnerability to fuel poverty is considerably more complex than the spatial distribution of fuel poverty as understood by either the 10% indicator or LIHC indicator suggests. A wide range of socio-spatial vulnerabilities exist that span both the urban and rural, that differ in the strength of their spatial concentration and in the likelihood of their manifesting in a locale characterised by other vulnerabilities. The analysis therefore emphasises the important role of place, and the contribution of surrounding neighbourhoods in seeking to understand the likelihood of a household falling into fuel poverty, and thus in succeeding in meaningfully measuring the phenomenon. This emphasis upon the importance of place has enabled us to avoid some of the simplistic assumptions that can be made in quantitative analyses about the needs and lives of vulnerable groups, better recognising the heterogeneity of vulnerable groups via their complex socio-spatial distribution (Gillard et al. 2017).

Pertaining to the final aim, the findings offer a means of challenging the indicators and associated policy, questioning why certain socio-spatial vulnerabilities are less well represented within a particular neighbourhood. Whilst wider fuel poverty research stresses the multi-dimensional and spatially variable nature of fuel poverty, exploring the complex socio-spatial distribution of drivers between different households (Middlemiss and Gillard 2015) and national contexts (Thomson and Snell 2013), policy-making has tended to seek a universal, 'one-size fits all' measurement approach. A relatively isolated example of an alternative approach is the area-based approach deployed in Northern Ireland (Walker et al. 2012). There is value in a 'one-size fits all' approach as it can provide a national benchmark of the number of fuel poor households emphasising the importance of the issue and measuring national progress (or lack of progress) in alleviation. However, our analysis suggests that when used in isolation neither indicator is likely to capture the diversity of socio-spatial vulnerabilities that enhance the likelihood of fuel poverty experienced between different demographics and geographies.

Fuel poverty indicators can be regarded as a form of governance (Davis et al. 2012) that can simultaneously make visible, create and conceal injustices. Insufficient representation of particular vulnerabilities by the chosen measurement approach contributes to a lack of recognition in fuel poverty policy and in the targeting of alleviation measures, further compounding the condition (Walker and Day 2012). Our analysis is useful in highlighting the explicitly spatial injustices associated with how socio-spatial vulnerabilities and losses of wellbeing that manifest in particular locales can be concealed, revealed or created by the

government's framing of fuel poverty using different indicators. This builds upon discussion of spatial injustices within existing neighbourhood effects (Rae 2012) and fuel poverty literature (Bouzarovski and Simcock 2017).

Recognition of the underrepresentation by existing indicators of particular households, locales and subsequent injustices affirms that additional means of measuring vulnerability to fuel poverty are required. An alternative approach should explicitly account for the socio-spatial variability of vulnerability and the important contribution of place to the manifestation of fuel poverty.

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