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Mapping household direct energy consumption in the United Kingdom to provide a new perspective on energy justice

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ABSTRACT

Targets for reductions in carbon emissions and energy use are often framed solely in terms of percentage reductions. However, the amount of energy used by households varies greatly, with some using considerably more than others and, therefore, potentially being able to make a bigger contribution towards overall reductions. Using two recently released UK datasets based on combined readings from over 70 million domestic energy meters and vehicle odometers, we present exploratory analyses of patterns of direct household energy usage.

Whilst much energy justice work has previously focussed on energy vulnerability, mainly in low consumers, our findings suggest that a minority of areas appear to be placing much greater strain on energy networks and environmental systems than they need. Households in these areas are not only the most likely to be able to afford energy efficiency measures to reduce their impacts, but are also found to have other capabilities that would allow them to take action to reduce consumption (such as higher levels of income, education and particular configurations of housing type and tenure). We argue that these areas should therefore be a higher priority in the targeting of policy interventions.

1. Introduction

Energy justice is a relatively recent and rapidly growing field of research [5,41]. It bears much relation to environmental justice, which as a concept, is seen as beginning in 1982 in the US with the objection by "communities of colour" in Warren County, North Carolina to the siting of hazardous waste landfill sites in their localities [52]. The focus of environmental justice work in the US has tended towards the unjust spatial relationships between particular social or ethnic groups and locations of industrial and waste sites, and the lack of public engagement with these minority groups. However, most non-US environmental justice work has focused on differences in the treatment based on socio-economic status (SES).

Energy justice work to date has, however, tended to focus on two main areas. Firstly, and with a clear link to much previous work on environmental justice, is the work around the siting of energy generation (see, for example, Refs. [37,18]). Within energy justice, this takes an interesting development with consideration not just of major infrastructure, as has been the focus of much *environmental* justice work, but also of small-scale and micro-renewables, and especially the financing of these (see for example Refs. [67,61]). The second area is around energy vulnerability. Particularly in the UK, the concept of energy vulnerability originated in work on 'fuel poverty' which focusses on the affordability of heating in relation to household income, but it is recently coming to cover a wide range of energy access issues including 'energy poverty', 'energy insecurity', energy deprivation' and 'energy precariousness' [38,70,19]. These issues of inequalities in relation to access to energy exist both within and between nations, and a third of the world's population (around two billion people) exist on less than US$2 a day and only have access to energy through combustion of biomass products. These people have been referred to as the Energy Oppressed Poor (EOP) [50].

The work in this paper considers disparities in household energy consumption and is thus related most closely to this second area. However, the work presented here does not take the energy vulnerable or energy poor as its focus. Instead it gives more attention to the opposite end of the spectrum, exploring levels of energy use amongst the highest users in developed countries (and therefore the world). Our main interest lies in how energy usage relates to greenhouse gas emissions. Therefore in drawing attention to disparities in energy consumption, we place less focus on the aspect

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of 'energy poverty' and those who potentially 'under-consume' (at least in national rather than global terms) than is usually done in this area (see for example Refs. [67,19,29]). With this emphasis on high energy use, we share the interest of Hall [41] in linking energy justice work grounded in environmental justice, to work on ethical consumption in order to help to highlight the justice issues around over-consumption of energy rather than just under-consumption.

2. Review of previous work on household energy in the UK

There is an existing body of work that focusses on household energy use and carbon emissions in the UK and how these are distributed according to a range of socio-demographic and other parameters (see Refs. [26,6,28,68,36,8,43]). However, due to limited datasets, to date this work has been restricted in its analysis of spatial patterns of use and emissions.

Previous studies in the UK have tended to be based around a set of sample-based surveys, primarily the English House Condition Survey/English Housing Survey and the Expenditure and Food Survey/Living Costs and Food Survey, but also the National Travel Survey, and Air Passenger Survey. Tables 1 and 2 summarise the main focus of these studies and explanatory variables investigated. There are two significant drawbacks to this sample-based approach. Firstly, although these surveys are generally based on multi-stage random samples (see for example Refs. [74,53]) with very significant sample sizes (often in excess of 20,000 households in any one year), they still represent a small proportion (0.08%) of the total 26 million UK households. Even if evenly distributed, this would represent roughly one household for every two Lower-layer Super Output Areas (the main spatial unit of analysis within this paper). Secondly, although some studies (in particular [28]) have used this data in combination with spatial data from the UK Census, the limited sample sizes mean that it is difficult to undertake mapping or spatial analyses using the data.

These studies have tended to find strong links between carbon emissions/energy use and income, with a significant degree in variation between urban and rural locations, indicating a combination of drivers for high levels of consumption that are both desire/ability driven and needs-based (with variations in need differing due to structural factors such as housing type). Work such as Buchs and Schnepf [9] has identified that these relationships vary depending on the type, or domain, of emissions (e.g. domestic or transport), but have not explored how these differing relationships between domains, may themselves differ spatially. With local and targeted interventions being seen as an increasingly important component of efforts to reduce carbon targets, understanding of spatial variations in usage and demand in each different domain are crucial to developing effective and efficient policies that take sufficient account of distributional impacts.

This paper opens the way for a more systematic exploration of variations in patterns of energy use by using new data that allow not only detailed area-based analysis but also relate to the three main domains through which households directly consume energy (gas, electricity and private vehicle use). Simultaneously investigating domestic and vehicular use is rare in the literature and yet is particularly important within the context of policy intentions to electrify all energy services in order to achieve decarbonisation. We combine these new datasets from the UK Government (to be discussed later) with data from the latest UK Census in 2011 to consider not only the location and basic characteristics of areas, but the extent to which constraints on energy use, or increased prices, may adversely affect those areas already challenged by poverty or less able to take action for other structural reasons.

This work is framed in terms of the UK Climate Change Act 2008 [59] and its 'legally binding' targets for an 80% reduction in greenhouse gas emissions by 2050. It is not uncommon for this target to lead to tacit assumptions that all sectors, all households and all individuals need to reduce their carbon footprints by 80%. It is increasingly recognised, however, that at a sectoral level, not all emission sectors (such as agriculture and forestry) are likely to be able to make reductions to this degree and thus some sectors, such as the transport sector in the UK, are being called on to decarbonise almost entirely [17]. This establishes a precedent that an equal, proportional reduction in emissions should not be looked for from all sources and activities.

Within the domestic sector, we argue that due to very large disparities in household energy consumption, households with very high levels of consumption ought to be a greater target of early energy/carbon reduction policies as this should enable both larger overall reductions in energy use to be achieved quickly as well as potentially allowing relatively easy wins compared to households who already consume little. Once reductions are achieved in these households, it may then be more practicable to focus on those households with much lower consumption, particularly where current energy vulnerability means that, in the short-term at least, fuel poverty/energy vulnerability policies may still be trying (directly or indirectly) to increase energy consumption in order to ensure that basic energy service needs are met. Moreover, the lessons learnt in any successful reduction process for high consumption households may provide important insights into controlling any aspirational tendencies for low consumption households wishing to achieve high consumption status. This is not to say that low income groups should not benefit from policies aimed at reducing their energy bills for financial reasons, simply that purely targeting this group may not lead to energy/carbon savings commensurate with the UK's very strong targets.

The driver for this work is therefore set in the practical aspiration for more efficient policy making rather than any particular theoretical notions of environmental/energy justice. Environmental justice has been recognised "as a 'broad church' within which different notions of justice are encompassed" [71], p. 656). Therefore, we acknowledge a number of framings of justice here that bear relation to our work, both in terms of two central themes of procedural justice and distributive justice [29]. Firstly, in the context of a constrained energy generation system, whether due to infrastructure capacity or through emissions caps, energy is becoming

Table 1
Focus of previous sample based household carbon/energy research.

	Domestic Energy			Transport			Indirect (Goods and Services)	CO_2/GHGs	Energy
	Gas	Elec.	Other	Car	Public Transport	Aviation			
Dresner and Ekins [26]	Y	Y	Y					Y	Y
Brand and Boardman [6]				Y	Y	Y		Y	
Druckman and Jackson [28]	Y	Y	Y					Y	Y
Thumin and White [68]	y	Y	Y	Y				Y	
Gough et al. [36]	Y	Y	Y	Y	Y	Y	Y	Y	
Buchs and Schnepf [8,9]	Y	Y	Y	Y	Y	Y	Y	Y	
Hargreaves et al. [43]	Y	Y	Y	Y	Y	Y		Y	
Preston et al. [61]	Y	Y		Y	Y	Y		Y	Y

Table 2
Explanatory variables used in previous household (HH) carbon/energy studies.

	Income	HH Size/Composition	Education	Economic Status	Urban/Rural	Ethnicity	Age	Tenure	Dwelling Type	Heating Type	No. of Rooms	Gender	Car Ownership	Appliances
Dresner and Ekins [26]	Y[a]	Y					Y[a]							
Brand and Boardman [6]	Y[a]	Y[a]		Y[a]								Y	Y[a]	
Druckman and Jackson [28]	Y[a]	Y[a]		Y	Y[a]		Y	Y[a]	Y[a]					
Thumin and White [68]	Y[a]	Y[a]		Y	Y		Y[a]	Y[a]	Y[a]	Y	Y[a]	Y	Y	Y
Gough et al. [36]	Y[a]	Y[a]		Y[a]				Y						
Buchs and Schnepf [8,9]	Y[a]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y			
Hargreaves et al. [43]	Y[a]	Y[a]		Y[a]			Y[a]			Y[a]	Y[a]		Y[a]	
Preston et al. [61]	Y[a]				Y[a]			Y[a]		Y[a]			Y[a]	

[a] Indicates variable flagged up by authors as particularly important.

a limited resource and issues of distributive justice around equity, equality and need come to the fore [24,69,32]. In short, how much more energy should some households be allowed to consume than others, and on what basis should this decision be made?

Secondly, the question of who should pay most for efforts to reduce household energy and carbon emissions? Within environmental management, the 'polluter pays principle' has long been a foundation of how costs should be borne equitably for addressing the damage from environmental degradation [33,65]. However, within the energy system, the individual consumer often has little control over the emissions associated with their energy use, and particularly in the context of fuel poverty work, the proportional relationship between energy use and income has become important. Some energy justice work (for example, Refs. [67,61]) has focussed specifically on justice issues around how the inclusion of additional charges within energy bills means that low-income households pay for measures that benefit the better-off (such as Feed-In Tariffs). Also, with some energy services seen as fulfilling a basic need, much policy in the UK has tried to address how these needs can be met without the expenditure of an undue proportion of income. Within this paper we consider whether, in terms of carbon reduction policy, this approach needs to be changed, with focus being placed not only on those with the highest ratio of energy costs to income, but instead focussing attention on those with the highest energy consumption (and particularly those who *also* have high income). This would be done in order to be able to achieve sizeable reductions from those who can afford to, and have the ability to, change their patterns of consumption. Focussing on areas of high energy consumption, we raise the issue of whether this consumption can be attributed to structural factors (housing type, inaccessibility by public transport etc.) and, if so, whether this can simply be considered a 'need' rather than a 'choice' (an issue discussed by Jackson and Papathanasopoulou [48] in the context of 'luxury' or 'lock-in'). Whilst possibilities for low-energy use may be constrained by spatial or structural factors in the short-term, ultimately living in these locations and locking-in high energy consumption could, with a longer term view, be considered to have been a choice (albeit possibly a constrained choice for some). By taking an aggregated areal approach we seek to examine some of the broader structural and social patterns that underlie the personal choices of individual households. In doing so, we offer our work as being complementary, rather than an alternative to, more granular work at the level of individual households.

Lastly, we link our work to the problem of the 'Tragedy of the Commons' [42], whereby the short-term, self-interested and rational acts of individuals cause little or no harm in and of themselves in terms of damage to or depletion of a resource but, when combined, lead to a serious threat to the shared resource and harm to the collective interest. With regard to carbon emissions, the use of energy causes little, if any, immediate perceptible negative impact on the well-being of the consumer, but in total, these emissions are causing significant problems for current and future generations. Indeed it is peak load, i.e. when overall consumer demand for energy is highest, that is the most environmentally damaging [46,39], a manifestation of collective demand rather than individual consumption. Within this framing, the commons in question (in this case either the available energy resources or the 'carbon headroom' that remains before total global emissions will result in "dangerous climate change") need to be regulated in the interests of the many rather than the individuals [72].

In this paper, we do not seek to use these theoretical perspectives directly. Instead we take new datasets that have recently been made available by the UK Government in order to look at what patterns might be found in household direct energy usage from gas, electricity and private car use, with a view to investigating how this information might inform policy and interventions. How

much energy a person, or household, uses, is not just a matter of choice, particularly not in the moment of use itself, which will be conditioned by many previous choices as well as social and structural circumstances. Unequal distribution/use of energy alone is not enough to make claims to injustice, but systematic inequalities and uneven distributional impacts of policies may rapidly lead to equity issues, particularly where there may be spatial and structural causes.

By mapping data on energy use at a relatively fine spatial scale, and linking to a range of other socio-demographic, economic and geographical data, we seek to identify two types of area: firstly, where households may be energy vulnerable and challenged in meeting basic levels of energy services and, secondly, where more energy is used than that required to meet basic needs, therefore offering scope for reduction in use without significantly impacting on quality of life. In summary, to paraphrase 19th Century French politician Louis Blanc, we set out a method which should help in being able to justly address energy reduction policies by ensuring that energy is available to each according to their need, but that reductions in demand come from each according to their ability.

After an initial description of the datasets, we present a set of exploratory analyses which examine how different patterns of energy use are distributed with respect to a range of factors, including income, rural and urban location, social profile, housing tenure, property type and employment status. This is done in order to identify potential justice issues regarding both energy consumption and possible policy interventions to reduce it.

3. Methodology

Energy usage and carbon emissions from domestic gas and electricity and through private car use are estimated to contribute around 42% of all household emissions (around 30% from gas, electricity or solid fuels, and around 12% from private car use), with the remaining 58% arising through embedded emissions and from use of goods and services [27]. However, direct energy use provides an important and coherent starting point for this analysis for two reasons. Firstly, direct energy use is the part of their carbon footprint where households potentially have most control over the nature of emissions (i.e. what fuels are used and to what extent, rather than a simple choice of whether to purchase or not). Secondly, under current plans in the UK [21], direct energy use for heating, cooking and transport is going to become increasingly electrified and therefore looking at all direct energy use, whether from electricity, gas or petrol/diesel is vital in considering the combined impacts of these being channelled into a single energy source.

In this paper, we describe two new datasets released by the UK Government that together provide both near-universal coverage and spatial information about three key elements of direct household energy/carbon footprints: domestic gas and electricity consumption and private car usage. We demonstrate how these data can be of use in understanding socio-demographic and spatial influences on patterns of energy use. The datasets contain information from over 70 million individual domestic energy meters and vehicle odometers. The domestic energy data is based on readings from 24.5 million electricity meters and 21 million gas meters,[1] and the car usage data from odometer readings for over 27 million individual vehicles [14]. Although these datasets come with their own limitations (which are discussed below), we believe they can both provide a useful comparison to elements of the survey-based work described above, and provide new insights of their own.

3.1. Household gas and electricity consumption data

Since 2004 the UK Department of Energy and Climate Change (DECC) has produced data on domestic gas and electricity consumption at a sub-national level based on household level meter data for all domestic properties[2] provided by the energy supply companies [23]. Since 2008, this data has been made available at the resolution of Lower-layer Super Output Areas (LSOAs). LSOAs are census areas developed for the UK England and Wales Census with a minimum size of 1000 residents, or 400 households, and a maximum population of 3000 residents or 1200 households [57]. In total there were 34,753 LSOAs in the 2011Census in England and Wales, with an average of approximately 700 households and 1600 residents each. Their design is intended to make them reasonably compact, and to allow significant social homogeneity within each area. Due to differences in Census methodologies in England and Wales compared to Scotland, only analyses for England and Wales are presented in this paper. For a small number of parameters, such as accessibility and deprivation, it has only been possible to undertake the analysis for the 32,844 English LSOAs; these are highlighted below.

For each area,[3] data are available for the number of domestic meters for electricity (both standard and dual tariff,[4] n = 24,486,595) and gas (n = 21,309,223), the total energy use for these, and the average energy use per meter. DECC report that, "the combined electricity and gas provide a good indication of overall annual household energy consumption in Great Britain at local authority, MSOA [Middle-layer Super Output Area]/IGZ [Intermediate Geography Zone][5] and LSOA level due to the robustness of the data collection and collation process [from individual meters]" [23], p. 19). This data thus provides details of universal metered domestic energy use from gas and electricity, albeit at a cost of lack of granularity, with individual household use averaged over around 700 households. It is important to take into account that gas consumption data has a weather correction factor applied to it[6] whilst electricity consumption is not weather corrected. This creates some potential issues regarding the comparison of gas and electricity usage related to heating, particularly when looking at the data longitudinally. Whilst longitudinal analysis is being undertaken, it is not reported on in this paper.

The upper maps in Fig. 1 show the spatial distribution of energy consumption. The key is based on deciles of energy consumed under the domain for each map. Because populations are kept relatively constant across LSOAs, this has the effect of making rural

[1] Annual estimates for 82% of all domestic gas and 80% of electricity meters are based on two meter readings at least six months apart, with the final reading in the reference period. Elsewhere, annualised consumption is estimated from historical information and profile information relating to the meter. Distinction between domestic and non-domestic users is made purely on the basis of a quantity based cut off point: 73,200 kWh for gas and 100,000 kWh for electricity (although validation is made for properties with electricity consumption between 50,000 and 100,000 kWh. The majority of domestic meter readings (non-half hourly meters) are not aligned completely with the calendar year (from 1st October to 30th September for gas and 1st February to 31st January for electricity). Gas consumption data have been weather corrected.

[2] This differs to the UK National Energy Efficiency Data framework (NEED) which only represents a sample of households where energy efficiency measures are known.

[3] Although in some areas with low numbers of meters, LSOAs are merged to add confidentiality to the data. Where LSOAs have been merged, the mean electricity/gas usage for the whole area has been allocated to each of the LSOAs.

[4] The UK operates a dual tariff system known as 'Economy 7' where cheap off-peak electricity is available at night from base-load generation. This is commonly used in off-gas grid areas in combination with electric storage heaters.

[5] MSOAs are an England and Wales census area with a minimum/maximum population of 5000/15,000 residents and 2000/6000 households. IGZs are the comparable area for the Scotland Census.

[6] Weather correction is applied to energy statistics to "help users better understand underlying trends in energy consumption, which can be affected by fluctuations in temperature" [63], p. 2).

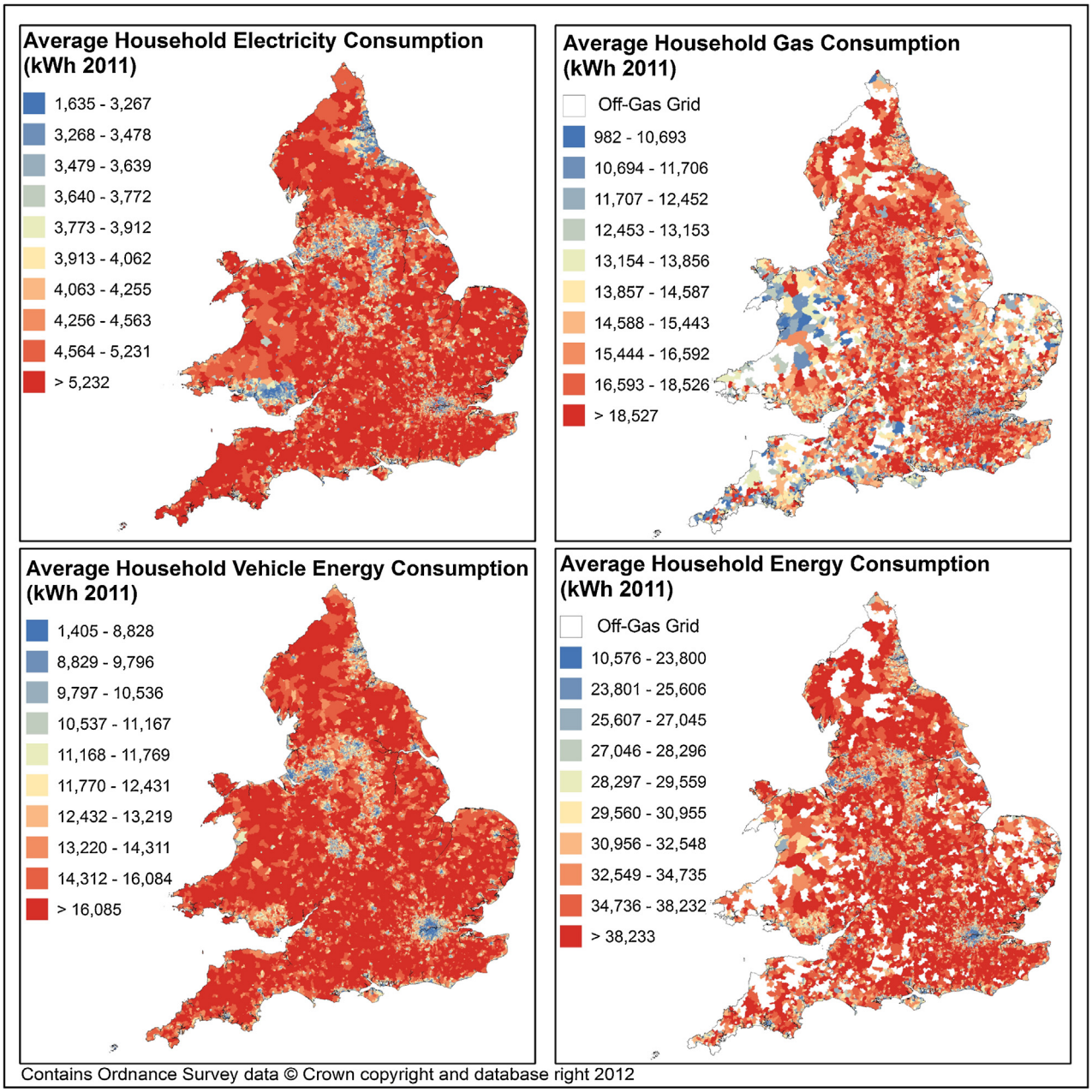

Fig. 1. Maps of variations in mean household direct energy consumption from gas, electricity and private car use in England and Wales by LSOA (keys based on deciles).

LSOAs greater in area and to dominate the map visually. Within England and Wales there are a number of areas that are not connected to the national gas supply grid (n = 623, 1.8% LSOAs, marked as white in the upper and lower right hand maps). In some households in these off-grid areas, gas will be replaced by electricity as a heating fuel, and this is usually used to operate storage heaters on the 'Economy 7' dual tariff. Oil, LPG (Liquefied Petroleum Gas) wood and coal are also used for heating systems. Currently, 83% of homes in Great Britain are heated by gas, 9.3% by electricity, 4.4% by heating oil, 1.2% by solid fuel (coal or wood) and 0.7% by LPG [3]. Due to the lack of information in the DECC statistics on alternative (non-gas/electric) heating fuels, LSOAs where the entire area has no mains gas supply has been discounted from the analysis so as to not create bias through an overly low recorded energy usage in these areas. Future work is intended to use some of the sample based analyses to estimate heating fuels in these areas. As electric heating technology becomes more commonplace, it is likely that these areas would benefit from special policy attention in any case.

The maps indicate that high energy use tends to be dominant in rural, low population density (and hence larger) LSOAs. It is important to note that when considering aggregated energy consumption, even over relatively small areas such as these, that there are likely to be very significant and substantial variations between different households within each area. Looking solely at gas consumption, in a report for the UK Department of Energy and Climate Change, Fell and King [31] reported that the top 10% of consumers used four times as much gas as the bottom 10%, and that current quantitative modelling based on property, household income and tenure, was only able to represent less than 40% of this variation. Similarly, Hargreaves et al. [43] found that the richest 10% of households emit three times more than the poorest 10% across domestic fuel, private car, public transport and aviation in total, but with

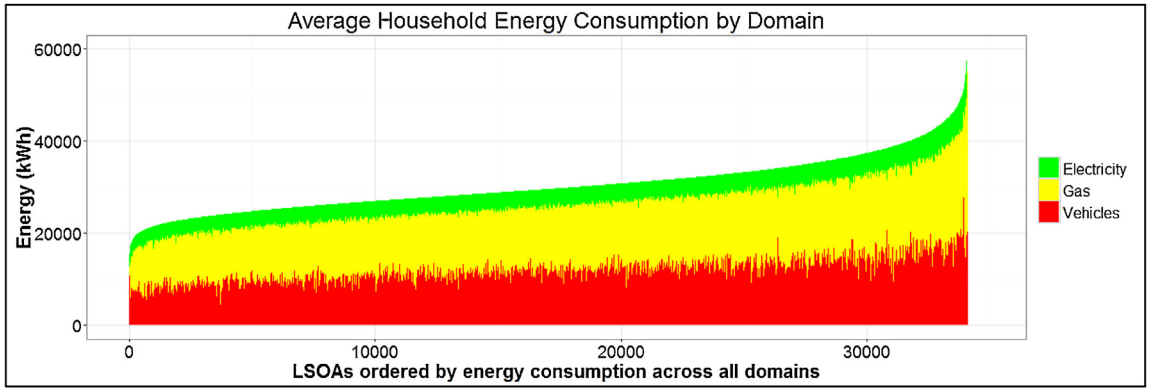

Fig. 2. Average household energy consumption from electricity, gas and private vehicles in England and Wales by LSOA.

much greater differences from transport of seven to eight times from private car use and ten times as much for aviation. However, the aggregation to relatively small, socially homogenous areas within this study permits an overview of spatial patterns in energy use that may arise, at least in part, from variations in structural conditions. As such, it provides a valuable context in which consumption patterns of individual households might be considered.

3.2. Private car use data

In 2010, the UK Department for Transport (DfT) began publishing the records from the annual vehicle roadworthiness inspections, known in the UK as 'MOT' (Ministry of Transport) tests. These data provide details of the make and model of each vehicle, engine size, fuel type, date of first registration and colour, along with the recorded mileage at each test. By interpolating between the test dates, it is possible to estimate the annual mileage of every vehicle in Great Britain (see Refs. [76,77,11]). From the key vehicle parameters of fuel type, engine size and vehicle age (and consequently Euro standard) it is also possible to estimate the fuel economy, annual energy usage, and air pollution and greenhouse gas emissions from each vehicle [14,16]. Multiplying each of these by the vehicle's mileage gives an estimate for fuel/energy use and emissions for each vehicle over a calendar year. The MOT dataset is linked to additional data from the Driver and Vehicle Licencing Agency (DVLA) which allows privately owned vehicles (n = 27,048,665) to be separated from vehicles registered to commercial organisations and then for each vehicle to be linked to the LSOA of the registered keeper. This is used to calculate the average 2011 energy consumption per vehicle for every LSOA.

In order match this data with the data on average household gas/electricity consumption, it is necessary to calculate a value for average household energy use from vehicles at an LSOA level. Using data from the 2011Census, the average number of cars per household (that have access to a car or van[7]) was calculated for each LSOA. This was then multiplied by the figures from the LSOA vehicle profile (described above) in order to estimate the annual emissions and energy footprints for an 'average' household per LSOA.

4. Overall patterns of energy use

Fig. 1 shows maps of the distribution of energy consumption across all three domains (gas, electricity and vehicles) as well as total direct energy consumption (all three combined). The maps show a similar general tendency for rural areas to have higher levels of energy consumption, whilst major urban areas have lower levels of consumption in the South East (London), in the centre of the country (Birmingham), further north (Sheffield, Manchester Leeds and Liverpool), and in the far North East (Tyne and Wear). There are some variations between domains though, with low gas consumption tending to be much more tightly clustered around urban centres, and whilst low electricity consumption is more pervasive around Tyne and Wear and less so around London, the reverse is true for vehicle energy use.

In order to provide an indication of how absolute energy consumption varies across these domains, Fig. 2 shows how overall household energy use in each LSOA is comprised of contributions from electricity (mean = 13%), gas (mean = 47%) and private vehicle use (mean = 40%). There is a strong positive correlation between gas and electricity usage (r = 0.64), and those areas with higher domestic (gas plus electricity) energy consumption also tend to have higher energy consumption from vehicle use (r = 0.5). Average LSOA domestic energy consumption also tends to be greater than through car usage. Fig. 2 also demonstrates how planned increases in electrification of cooking and space heating, as well as electrification of the vehicle fleet [21], are likely to result in a six-fold increase in household electricity demand should there be a direct switch in energy requirements. It may be possible to achieve significant end-use efficiencies through new technologies related to the fuel shift, however the energy services to be electrified currently make up an average of 87% of total household direct energy consumption.

The tendency for energy use to be linked across all domains is demonstrated in Fig. 3, where LSOAs have been divided into deciles for energy use across each of the domains and plotted against three axes (with energy consumption from car use on the z-axis as a function of gas and electricity consumption). It is apparent that the areas that consume the most electricity *and* gas also use the most energy through private vehicle usage. Fig. 4 shows the varying proportion of LSOAs in each electricity-gas decile combination, highlighting that in terms of frequency, both the high and low consumption areas stand out sharply.

Whilst this pattern of linked consumption across the three domains is of interest in and of itself, it raises questions as to what circumstances are leading to these patterns of high and low consumption. Are consumers in the low consumption areas achieving low usage through energy efficient lifestyles that still provide them with the full benefits of energy services required for an acceptable standard of living? Or are they potentially limited in their consumption through lack of income? At the other end of the spectrum, might those households in the high consumption areas in Fig. 3 be victims of circumstance, trapped in a position of high 'energy

[7] As the main interest of this work is to examine patterns of high energy use, this method concentrates on representing those households with cars in any area, rather than creating a potentially misleading figure for car usage averaged over both households with and without a car.

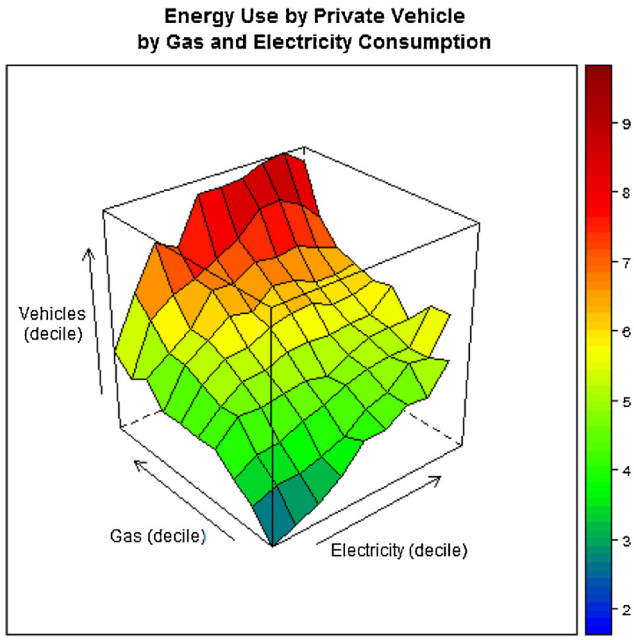

Fig. 3. Relationship between domestic (gas and electricity) consumption and energy use by private car in England and Wales.

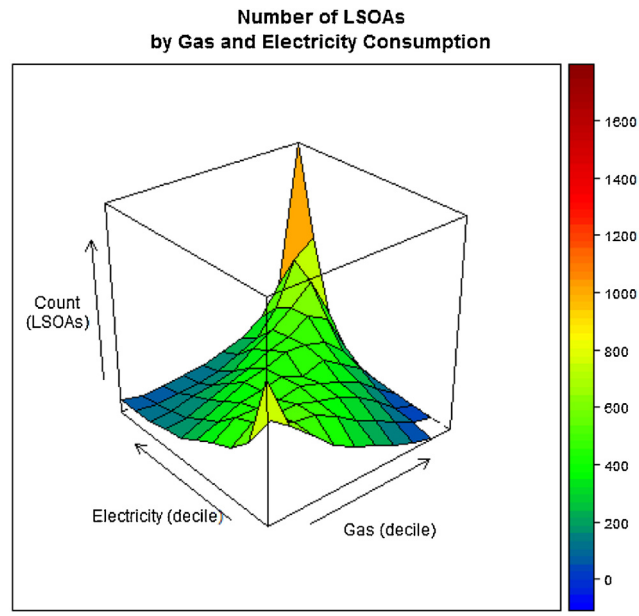

Fig. 4. Number of LSOAs in England and Wales in each combination of gas and electricity consumption decile.

need' (for example living in poorly maintained homes in rural areas inaccessible by public transport, cycling and walking)? Or might these areas represent a profligate use of energy where wealth and circumstance allow high energy consumption through choice (something that might be termed 'energy decadence[8])? However, as highlighted above, short-term needs may be a product of longer-term choices that have locked out possibilities for lower levels of consumption. To facilitate this assessment, further analyses are presented in the following sections looking at how these patterns of consumption relate to geography (urban/rural location), socio-economic factors, and a range of parameters around housing and transport.

5. Assessing variations in energy use

Once average household total direct energy usage from gas and electricity consumption and private vehicle use is estimated for each LSOA in England and Wales, it is possible to link this to a wide range of socio-demographic information from the 2011 Census and other sources to ascertain whether there is any relationship between these factors and average household energy usage. Three sets of analyses are presented here: firstly an analysis based on the relationship between average energy use within each LSOA and the median household income within that area; secondly, an investigation of the spatial patterns in energy consumption with regard to differences in urban/rural location; and thirdly, a deeper breakdown of the socio-demographic and geographic factors that relate to different patterns of energy usage and how these may indicate differing levels of ability to control energy consumption.

5.1. Energy use and income

Using median household income data for LSOAs [30] an initial investigation was undertaken of the relationship between income and energy consumption. Fig. 5 shows how average household energy consumption tends to increase by income decile. Whilst each median is significantly higher than the one before it, there is a considerable overlap of the boxes, whiskers and outliers between deciles. Similar patterns were evident when looking at all three domains individually. Whilst income clearly varies, this suggests that it is not the overall determining factor in energy consumption. Indeed, it is hard to support a claim that income alone would *drive* energy consumption directly, only that it would *allow* the indulgence in more energy services. Indeed, as has been found with finance [60], increased wealth may actually bring more efficiencies in consumption than can be achieved by lower income groups.

Table 3 shows the differences in the average household consumption across all three domains between the lowest and the highest income deciles. Depending on the mode of energy usage, average household consumption in the lowest consuming decile varies between 62% and 78% of that in the highest decile. This suggests that there is a very significant baseline for energy usage across all modes under which consumption rarely falls irrespective of income. However, on average, the highest consuming areas use 42% more energy from electricity and 71% more gas, than the lowest consuming areas, but only 29% more energy from private vehicles. Comparing this to the figures from Fell and King [31] (p. 3) who report that, at an individual household level, "the top ten per cent of gas users consume at least four times as much gas as the bottom ten per cent" it becomes clear that within the highest and lowest consuming areas or indeed within other areas, there are likely to be households that are well in excess, or well below average household energy consumption figures per LSOA. However, given that these areas are designed to be demographically similar (including housing type) then there is some likelihood that the highest consuming households will be located in the highest consuming areas.

5.2. Spatial patterns of energy usage

The analysis on the basis of income above does not provide any great detail on patterns of energy use. Therefore the direction of the inquiry was reversed, with differences in energy being the main means of grouping LSOAs. In order to do this, and specifically to manage a grouping based on differences across the three energy domains, a cluster analysis was undertaken on the basis

[8] Decadence: "Luxurious self-indulgence" Oxford Dictionaries http://www.oxforddictionaries.com/definition/english/decadence.

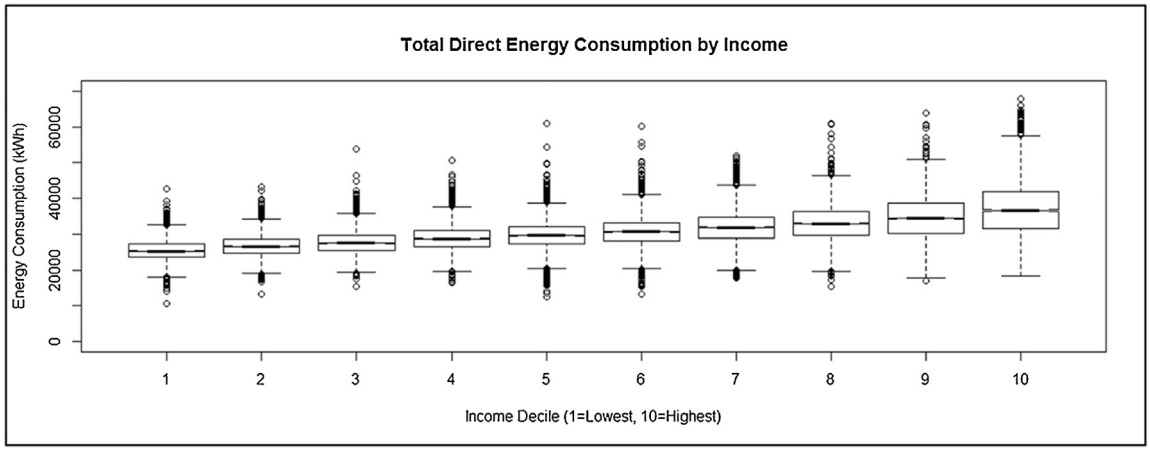

Fig. 5. Total direct energy consumption by median income decile. The bottom and top of the boxes are the first and third quartiles, the bands inside the boxes are the median, and the ends of the whiskers represent the lowest datum still within 1.5 IQR of the lower quartile, and the highest datum still within 1.5 IQR of the upper quartile.

Table 3
Differences between energy consumption between highest and lowest income deciles.

	Electricity	Gas	Vehicles	Domestic	Total
Lowest income decile (kWh)	3,505	11,614	10,349	15,119	25,468
Highest income decile (kWh)	4,972	18,681	13,330	23,653	36,983
Min as% of Max	70	62	78	64	69
Max as% of Min	142	161	129	156	145
Correlation of Income and Energy (r)	0.54	0.60	0.29	0.53	0.55

of the average household energy consumption from car, gas and electricity usage. In contrast to classic psychographic or psychodemographic segmentation, where clustering is undertaken on the basis of a range of attitudinal or socio-demographic characteristics [1,2], the cluster analysis presented here was undertaken *only* using the data on variations in the three energy domains. These domains were subsequently analysed to investigate the socio-demographic characteristics of each energy cluster.

A two-step process using a combination of hierarchical and non-hierarchical (K-means) cluster analysis was chosen as the most appropriate method for determining clusters in order to compensate for weaknesses in using each method on its own [40]. The clustering was carried out using the open source statistics program R [62]. K-means cluster analysis combines data into a pre-selected number of clusters, then iteratively reassigns data to groups until data in any one group are more alike than they are to data in another group, at which point clusters are defined as distinctive. The use of K-means requires the pre-selection of the number of clusters to be identified. No standard objective selection procedure exists for K-means clustering [40]. Here we considered a plot of within groups' sum of squares, identifying the 'elbow' in the plot which shows the point at which the marginal return of adding one more cluster is less than the marginal return for adding the clusters prior to that [35], and dendograms from exploratory hierarchical clustering using Ward's method [40]. In this analysis, between three and eight clusters were considered to be potential solutions. Repeated runs were then undertaken for these numbers of clusters in order to establish where cluster divisions lay, and how adding more clusters subdivided the existing sets. Eventually six clusters were judged to be optimal as further subdivisions only occured in the central clusters rather than at the extremes. The clustering was run five times to check the stability of the clusters. Based on a ranking of clusters by total energy consumption, less than 0.5% of LSOAs changed cluster between iterations. There was a maximum difference in mean total energy consumption of 0.14% between the mean total energy consumption values across these five test runs, indicating that the clusters were highly stable.

The clusters were labelled A to F on the basis of the mean total energy consumption in each (A lowest to F highest). The clustering process split the clusters into 4 main groups (A, B, C, DEF) with around a quarter of LSOAs in each, and with the highest group subdivided into three (D–F). Table 4 and Fig. 6 provide information on the differences in energy consumption between the clusters. As with total energy consumption, electricity consumption also increases across the clusters from A to F. However, the same is not the case for energy from gas consumption or vehicle use. Cluster C tends to have lower energy consumption from gas usage than clusters B and D, whilst having higher energy consumption from vehicles.

Within the highest three clusters, D has higher gas consumption than E, but much lower energy use from vehicles. However, E and F have similar levels of energy use from vehicles but F has higher consumption from electricity and gas, leading to a markedly higher total consumption. Bivariate scatterplots of all LSOAs by cluster across all domains are provided in the Supplementary file. The bottom row of the table provides a ratio of the proportion of the total energy consumed by each cluster to the proportion of households that are within the cluster. Thus, overall, cluster A consumes 25% less energy than its 'fair share' whilst cluster F consumes 68% more.

5.3. Income differences between the clusters

Returning to the income based analysis, Fig. 7 shows the median income by energy cluster. This shows a more complex picture of the relationship between energy and income than Fig. 5 with a greater spread of outliers, and a complex pattern within the upper clusters (DEF). Income is clearly not the defining factor in terms of which energy cluster an area has been allocated to, and therefore we now move to investigating other, more structural factors.

Table 4
Details of the clusters (size and proportional energy consumption).

Cluster	A	B	C	D	E	F	DEF
Number of LSOAs	8,991	8,826	7158	4,268	2,542	1,111	7,921
% LSOAs	27.3	26.8	21.8	13	7.7	3.4	24.1
% of Households	29.0	26.8	21.2	12.1	7.6	3.1	22.8
Mean Electricity (kWh)	3,436	3,796	4,056	4,503	5,421	6,461	5,072
Mean Gas (kWh)	11,205	14,452	13,631	18,608	16,212	23,969	18,591
Mean Vehicle (kWh)	9,688	10,796	13,668	12,865	17,205	16,804	14,794
Mean Total (KWh)	24,329	29,045	31,356	35,946	38,838	47,235	38,457
% of Total Energy Consumed	21.8	25.6	22.4	15.3	9.9	5.2	30.4
Ratio of Energy Consumption to Households	0.75	0.96	1.06	1.26	1.30	1.68	1.33

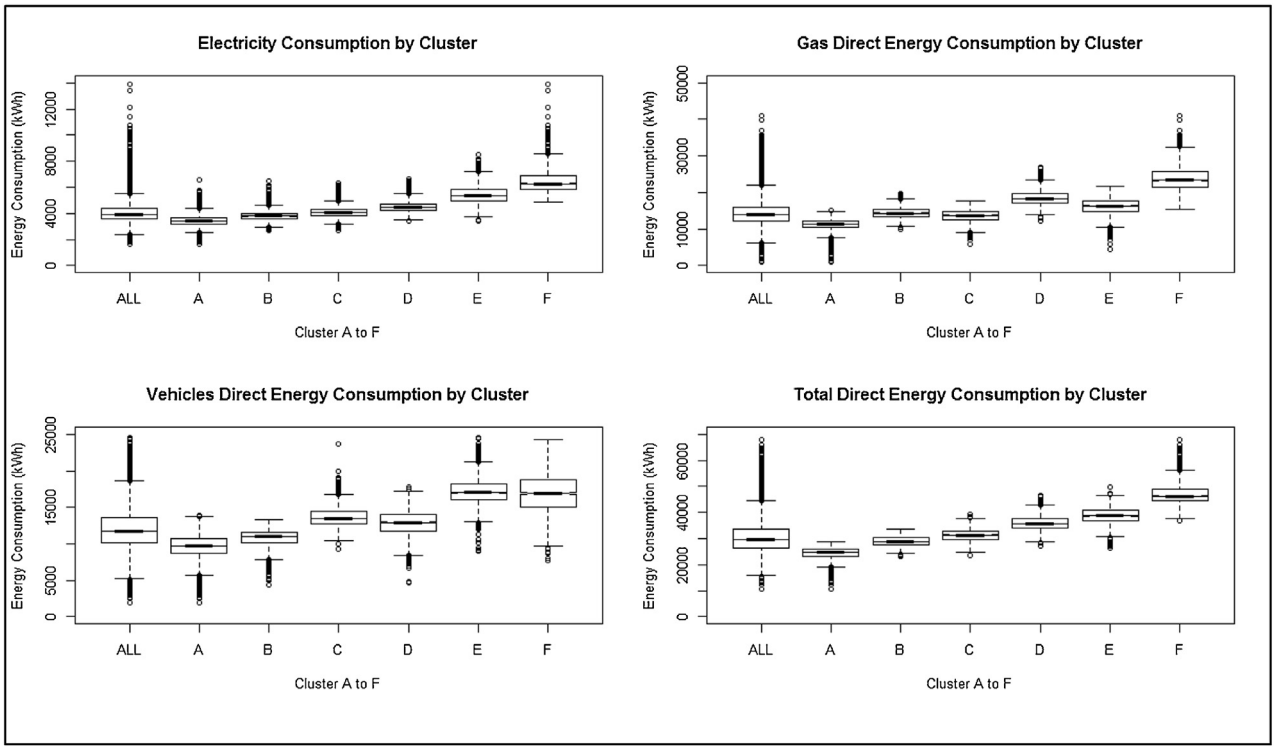

Fig. 6. Variation in energy consumption by cluster.

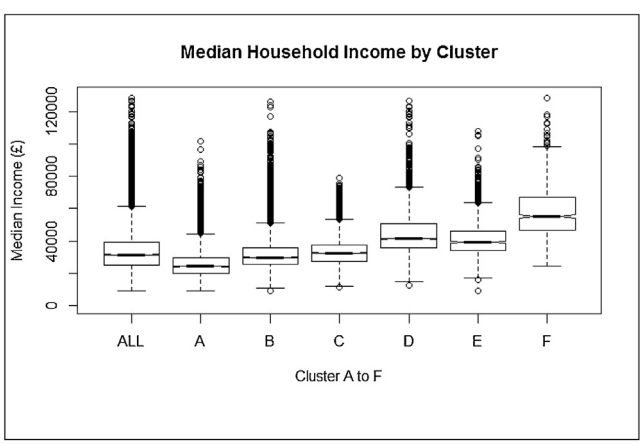

Fig. 7. Average median household income by energy cluster.

5.4. Urban/Rural differences between the energy clusters

To further investigate differences in the urban/rural nature of the clusters, data was used from the UK Office for National Statistics (ONS) 2011 Rural-Urban Classification [4]. This classifies each LSOA into one of five main classes based on the level of urbanisation (Major Conurbation, Minor Conurbation, City and Town, Rural: Town and Fringe, and Rural: Village). Fig. 1 shows the composition of clusters according to the ONS Rural-Urban Classification. On the left hand side of the plot is a column showing the overall distribution of LSOAs. The low energy consumption clusters, A and B have an over-representation of urban areas (97.6% and 95.0% respectively), particularly with regard to major/minor conurbations (47.5% and 50.1%). Cluster C on the other hand, is dominated by smaller cities and towns, including those in rural locations (81.2%). Examining the high consumption clusters again shows the value of taking this approach. As with the different patterns of energy consumption across the three domains shown in Fig. 6, here it is noticeable that cluster D tends to have a predominantly urban composition (87.8%), whilst cluster E is predominantly rural (79.8%), which goes some way to explaining the differences in gas and vehicle energy consumption identified above. Cluster F however, the highest energy consumption cluster, appears less influenced by specific geographic factors and is spread across both urban and rural areas evenly (though having a disproportionate amount of rural LSOAs when compared to the overall balance) (Fig. 8).

In order to further explore the variations between the clusters, they were analysed in terms of a range of parameters in three areas:

socio-economic (age, employment, social grade); housing (housing type and tenure); and transportation (car ownership, mode of travel to work and accessibility of town centres and employment centres by car or public transport). In addition to the analysis in the next sections, box and whisker plots for all parameters have been provided in the online annex.

5.5. Socio-economic differences between the clusters

A selection of socio-economic variables was made from census data [47],[9] as well as median household income data [30], two measures of the percentage of households counted in fuel poverty in each LSOA[10] [22], and the English Index of Multiple Deprivation [20] which provides a composite relative measure of deprivation (across seven domains) experienced by people living in an area (a higher IMD score indicates a greater level of deprivation, with IMD scores for individual LSOAs ranging from 0.53 to 87.8). These were analysed using a Multiple Analysis of Variance (MANOVA) test using R in order to establish the extent to which there was a significant difference in the parameter across one or more of the clusters. The test was carried out to assess differences across all clusters (A to F) and between the high consumption sub-clusters (DEF). All parameters were found to vary significantly at the level of $p < 0.01$, with almost all varying significantly at $p < 0.001$. F-values were calculated to indicate the degree to which variation amongst the means was more than would be expected by chance. Table 5 provides the mean value for each parameter across the clusters as well as the F-value for the all clusters (A–F) and high clusters (DEF only). Cells have been shaded to indicate the ranking from lowest (dark green) to highest (dark red) mean. The tested variables have also been ordered in the table on the basis of the 'all clusters' F-value to show the variable with the highest variation across all clusters (% self-employed) to lowest (% under 18 years).

The high energy using clusters tend to have the oldest populations, with the most households classified as social grade AB and the highest median household incomes. The lowest energy cluster (A) has the highest levels of people economically inactive through being sick or disabled, the highest levels of unemployment (6.6%), and the greatest number of students and people under 18. The proportion of households classed as social grade C2, and the proportion of people in both full-time and part-time employment were greatest in the mid-consumption cluster C. Both median and mean age increased linearly from lowest to highest cluster, and the highest proportion of under 18s was in cluster A, whilst the highest proportion of over 65s was in clusters E and F. The highest energy clusters have the greatest income and lowest levels of deprivation and vice versa. However, the relationship is not completely linear as cluster E had slightly lower income and higher deprivation than cluster D.

In terms of fuel poverty, there was not a clear relationship across the clusters. It is interesting to note how, using the 10% of income metric, clusters E and F have the highest proportion of households in fuel poverty despite the high median income in these areas. Under the newer Low Income High Cost definition, the proportion of households in fuel poverty is much more even, varying only between 9.1%–12.7%, with clusters D, E and F ranked second, fourth and third highest respectively.

5.6. Housing differences between the clusters

The same analysis was undertaken for a number of housing parameters relating to housing type and tenure within each cluster. Table 6 provides the F-values for each housing parameter, as well as the means for each of the clusters. The greatest variation in the means arose from differences in the number of rooms within the households, likely to a reasonably good indicator of overall household size. This varied from an average of only 4.7 rooms in cluster A to 7.1 rooms in cluster F. This was then followed by the proportion of detached housing and levels of outright ownership – both of which were greatest in the highest consumption clusters. Differences in the levels of detached housing were particularly pronounced for clusters E and F (as opposed to D). Levels of social housing, privately rented properties, flats and terraced housing were all greatest for cluster A. Social housing levels were very low in the high consumption clusters, and the proportion of flats was very low in clusters E and F, but not D. Terraced housing was uncommon across the high use clusters, but particularly so in cluster F. In terms of household composition, single households varied most between clusters, with the greatest proportion in cluster A and the lowest in cluster F. The proportion of households with children was very even across all clusters, however the proportion of family (i.e. married and cohabiting) households with no children was lowest in cluster A and highest in clusters E and F despite a >50% increase in the average number of rooms.

5.7. Transport differences between the clusters

The MANOVA analysis was carried out again assessing the variance between the clusters across a set of transport related parameters. These included data from the census on car ownership: the number of households without access to a car or van, the average number of cars per household across those households with access to a car, and the average number of cars across all households. Mode of travel to work data was also taken from the census and grouped into four groups: the proportion of people who travel to work by private motor transport (as a driver or passenger in a car, or by motorbike or scooter), by public transport (bus or train/tram/metro) and by active transport (cycling or walking), as well as the proportion of people who normally work from home. The census also provided the average distance travelled to work (by all modes) for each area. Accessibility data from the UK Department of Transport was used to provide an estimate of the average travel time for each LSOA by both car and public transport to either town centres or employment centres, as well as the density of public transport stops in each area [25].

The strongest variation in means was regarding the level of car ownership, both across all households and only those with cars. This may in part be due to the way that vehicle energy use is attributed to an average household level, but is likely to be predominantly associated with both greater mileages arising from vehicle availability, as well as less accessible places requiring higher levels of car ownership. Both measures of car ownership had an upward linear increase across all clusters from A to F. The number of households without access to a car/van was greatest in cluster A and lowest in cluster F.

In terms of accessibility, for public transport, travel time to both town centres and employment centres was lowest for clusters A and B, and greatest for clusters E and F. This was also the case for car travel to town centres. Car travel time to employment centres was more mixed, although the greatest times were for clusters E

[9] Social grade is a socio-economic classification used by the Market Research and Marketing Industries, most often in the analysis of spending habits and consumer attitudes http://www.abc1demographic.co.uk/The scale places people into six Grades: A: Upper middle class, B: Middle class, C1: Lower middle class, C2; Skilled working class, D: Working class, E: Those at lowest level of subsistence.

[10] These two measures are the, firstly, where households would need to spend 10% of their income to achieve adequate (domestic) energy services, and the more recent UK "Low Income High Cost" (LIHC) definition [45] that defines a household as fuel poor where it spends more than the UK median on its (domestic) energy bill AND that expenditure pushes it below the poverty line.

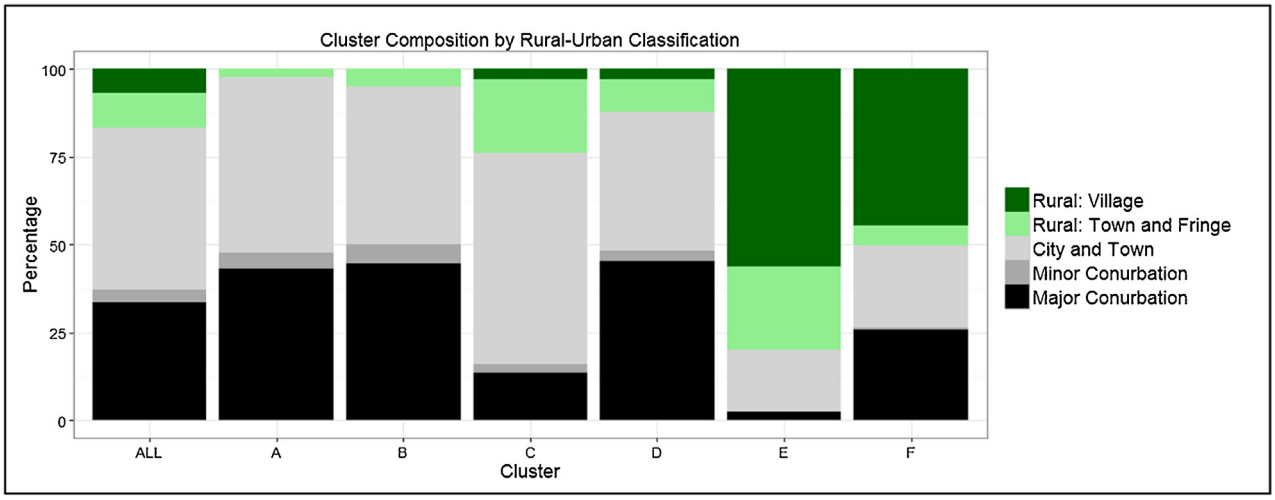

Fig. 8. Variation in ONS Rural-Urban classifications in each energy cluster.

Table 5
Socio-economic parameters for each cluster (ANOVA F-values and means). (For interpretation of the references to color in this Table, the reader is referred to the web version of this article.)

	F-value (A-F)	F-value (DEF)	A	B	C	D	E	F
Self-Employed (%)	4,553	1,425	7.2	8.9	9.4	11.9	14.9	17.1
IMD (Higher = Greater Deprivation)	3,795	57	35.7	21.8	15.9	10.9	11.4	8.5
Social Grade AB (%)	3,306	567	15.1	21.1	20.9	34.8	31.2	44.5
Social Grade DE (%)	3,205	266	35.4	26.1	23.9	15.1	15.3	9.7
Income (£'000s)	3,043	686	26.3	32.4	33.8	44.2	41.6	58.2
Sick Leave (%)	2,904	126	6.4	4.1	3.4	2.4	2.3	1.6
Unemployed (%)	2,492	217	6.6	4.6	3.8	3.0	2.5	2.1
Age (Years - Median)	1,621	157	35.5	39.6	40.7	43.2	45.5	45.7
Age (Years - Mean)	1,149	60	36.9	39.7	39.9	42.0	43.0	43.3
Social Grade C2 (%)	1,061	886	20.8	21.5	24.2	17.1	22.5	14.8
Old >65 (%)	1,037	120	7.0	8.8	9.0	10.2	11.3	11.3
Retired (%)	799	17	11.4	14.3	14.7	16.6	17.4	17.0
% Households in Fuel Poverty (LIHC Measure)	568	186	10.2	12.7	9.1	12.6	10.6	12.3
% Households in Fuel Poverty (10% Measure)	515	151	14.1	15.4	12.0	15.0	17.4	17.4
Carers (%)	383	182	5.2	4.2	4.1	3.9	3.8	5.0
Part-Time Employed (%)	373	144	13.4	13.9	15.1	13.8	14.3	13.0
Social Grade C1 (%)	351	191	28.7	31.2	31.1	33.0	31.0	31.1
Full-Time Employed (%)	319	153	37.0	39.1	41.0	38.2	37.1	34.8
Student (%)	255	164	10.1	8.8	6.8	8.6	6.1	7.6
Young <18 (%)	158	13	19.7	18.5	19.4	17.9	17.8	18.4

and F. The density of public transport stops was greatest in cluster A and lowest in clusters E and F.

The average distance travelled to work was lowest in clusters A and B, and highest in clusters E and F. Levels of active travel and public transport usage to work were highest in clusters A and B, whilst use of private motor vehicles was greatest in clusters C and E. Levels of home working were lowest in cluster A and highest in cluster F (Table 7).

5.8. Summary profiles of clusters

The following section provides short descriptive summaries analysing the clusters in terms of patterns of energy consumption, level of urbanisation, and their socio-economic, housing and transport characteristics.

5.8.1. Cluster A

This is the lowest energy consuming cluster across all three domains (energy:household ratio = 0.75). It is comprised almost entirely of urban areas with low incomes and high levels of deprivation. This is likely to be due to a combination of high levels of economic inactivity (through unemployment and sickness/disability) as well as both a relatively young population and a high proportion of households that are classed as social grade D or E. There tends to be high levels of rented accommodation (both private sector and social housing), over two-thirds of which is either flats or terraced housing. Houses tend to have fewer rooms,

Table 6
Housing parameters for each cluster (ANOVA F-values and means). (For interpretation of the references to color in this Table, the reader is referred to the web version of this article.)

	F-value (A-F)	F-value (D-F)	A	B	C	D	E	F
Number of Rooms in Household	10,198	1,606	4.7	5.3	5.6	6.1	6.5	7.1
Detached (%)	5,801	1,064	6.5	14.8	28.6	34.0	51.8	59.1
Outright Ownership (%)	4,022	86	19.0	32.2	33.2	42.4	41.1	45.5
Social Housing (%)	3,309	155	33.2	14.6	13.6	5.7	8.1	4.8
Single Occupancy Households (%)	2,554	218	35.6	30.4	26.1	25.5	23.1	21.7
Family Households with No Children (%)	2,117	1,061	14.3	16.7	19.3	18.3	23.2	21.0
Mortgaged (%)	1,930	7	25.6	33.9	38.9	37.3	37.0	36.2
Flats (%)	1,626	449	34.4	20.2	11.0	15.1	5.1	8.6
Terraced Housing (%)	1,197	125	34.0	27.1	23.6	14.7	13.4	8.4
Private Rented (%)	596	40	19.9	17.4	12.5	13.0	11.4	11.2
Semi-Detached (%)	576	361	24.9	37.7	36.2	35.9	28.3	22.9
Households with No Central Heating (%)	568	137	3.4	2.8	2.1	1.7	2.4	1.8
Household Size (Residents)	545	56	2.3	2.4	2.4	2.5	2.4	2.5
Households with Dependent Children (%)	84	22	29.4	29.2	31.4	29.6	28.6	30.0

Table 7
Transport related parameters for each cluster (ANOVA F-values and means). (For interpretation of the references to color in this Table, the reader is referred to the web version of this article.)

	F-value (A-F)	F-value (D-F)	A	B	C	D	E	F
Cars per Household (all)	13,238	3,160	1.3	1.5	1.6	1.7	1.9	1.9
Cars per Household with Cars	10,420	2,376	0.8	1.1	1.4	1.4	1.7	1.8
Work from Home	6,400	1,758	2.0	2.7	3.2	4.6	7.0	8.5
Percentage of Households without Access to Car/Van	6,278	927	41.1	27.0	17.0	15.4	8.3	7.1
Average Distance to Work (km - All Modes)	3,006	1,364	12.5	13.5	15.8	15.6	20.8	19.9
Travel to Work by Private Motor Vehicle	2,681	539	28.8	36.2	46.3	40.5	48.3	41.5
Density of On-Street Public Transport Stops (per km^2)	1,740	1,198	21.9	18.0	11.4	11.9	2.5	3.8
Travel Time to Employment Centre-Public Transport (minutes)	1,443	774	7.1	7.5	8.8	8.5	14.0	11.8
Travel Time to Town Centre-Public Transport (minutes)	1,434	946	12.0	12.5	17.1	14.2	26.6	20.7
Travel to Work by Active Travel	995	154	11.1	9.1	7.7	6.6	5.5	4.8
Travel to Work by Public Transport	759	613	14.3	12.1	6.2	11.2	4.1	9.3
Travel Time to Town Centre-Car (minutes)	280	472	6.1	6.1	7.0	6.3	9.5	7.6
Density of Off- Street Train/Metro/Tram Stops (per km^2)	65	30	0.3	0.2	0.0	0.1	0.0	0.0
Travel Time to Employment Centre-Car (minutes)	18	51	5.3	5.2	5.3	5.2	5.9	5.5
Density of Off- Street Bus/Coach Stops (per km^2)	11	6	0.2	0.2	0.1	0.0	0.0	0.0

although the average number of residents is not much smaller than the overall average (despite a higher proportion of single occupancy households). This cluster also has the highest proportion of households without central heating. Areas within cluster A tend to be close to both town centres and employment centres, which are readily accessible by both car and public transport, with there being a high density of public transport stops. There is a very high proportion of households (>40%) without access to a car or van. Over a quarter of the workers in this cluster travel to work by either public transport or active travel modes.

5.8.2. Cluster B

This cluster is the low-medium consumption cluster (energy:household ratio = 0.96). It is comprised of a very similar urban-rural mix as cluster A, with a fraction more rural town and fringe areas. Housing type is very mixed, about two thirds is terraced or semi-detached, with the other third comprised of a roughly 2:1 mix of terraced and detached housing. About a third of housing is owned outright and a third mortgaged, the rest being private rented and social housing. Households have comparatively fewer rooms than clusters C to F however, a similar average number of residents per household. Again, there are a relatively high number of single occupancy households indicating that multi-occupancy households must have higher numbers of residents than in the higher energy consuming clusters. These areas are very similar in their access times to town and employment centres as cluster A. Over a third of workers travel to work by motor vehicle, and over a fifth by public transport or active travel. The density of public transport stops is only slightly lower than cluster A. Whilst the number of households with no access to a car or van (27.0%) is slightly lower than the national average (25.6%), it is much lower than for cluster A.

5.8.3. Cluster C

Comprised predominantly of areas in cities and towns outside conurbations, areas in cluster C tend to use slightly more electric-

ity than cluster B, but markedly more energy from vehicle usage and slightly less from gas consumption. These areas have an overall energy:household ratio of 1.06. This cluster has the greatest proportion of people in employment (both full-time and part-time). Only a quarter of properties are rented, but this cluster has the highest level of mortgages (38.9%). There are roughly twice as many detached properties (28.6%) as in cluster B, but only half as many flats (11.0%). Terraces and semi-detached properties are similar in number (23.6% and 36.2% respectively). This cluster has the highest proportion of households with dependent children (albeit only by a small amount), however, the average number of residents per household is very similar to the other clusters. Travel time to employment centres are not greatly different to cluster B, however travel time by public transport to town centres is noticeably worse, reflecting the lower density of public transport stops (about half that of cluster A). Around half as many people go to work by public transport in this cluster (6.2%) as in cluster B, whilst almost half travel to work by motor vehicle (46.3%), the highest of any cluster.

5.8.4. Cluster D

This is the lowest energy consuming of the three high use clusters, representing around 12.1% of households and 15.3% of energy use (energy:household ratio 1.26). These areas are predominantly urban, with these urban areas split about 50:50 between conurbations and smaller cities and towns. Electricity consumption is slightly higher than cluster C, whilst gas consumption is markedly so (partially because of cluster C's relatively low gas consumption). Energy usage from vehicles is broadly similar. Although slightly fewer people are in employment in this cluster than cluster B, median household incomes are around a third higher than cluster B, probably due to the much greater proportion of households classed as social grade AB. Around 80% of properties are owned outright (42.4%) or mortgaged (37.3%) and around 70% are either detached (34%) or semi-detached (35.9%). Travel times to employment centres are very similar to cluster C, but travel times to town centres, by both car and public transport, are somewhat lower. Although there is a very similar density of public transport stops to cluster C, almost twice as many people use public transport to travel to work. The average distance travelled to work is 15.6 km, similar to cluster C, but much lower than for clusters E and F.

5.8.5. Cluster E

These areas contain 7.7% of households and consume 9.9% of energy (energy:household ratio 1.30). They have somewhat higher electricity usage than cluster D, and markedly higher vehicle energy consumption. However, gas consumption is slightly lower. They are predominantly rural, with only a fifth of areas being urban (and only a very small proportion of these being in conurbations). This cluster, in common with cluster F has the oldest populations, with a large number of retirees. Median income is slightly lower than for cluster D, and levels of deprivation slightly higher. Over half of housing is detached (51.9%) and 28.3% is semi-detached. There are very few flats (5.1%). Levels of outright ownership (41.4%) and mortgages (37.0%) are very similar to cluster D, but there is a slight increase in social housing (8.1%), possibly reflecting the older population. This cluster has the highest proportion of family households without children, and the lowest proportion with dependent children. This cluster has the third highest proportion of houses without central heating, which may be related to its rural composition and is likely to include some households that are not on the gas network. Travel times to town and employment centres are much greater than for cluster D, though more so by public transport (26.6 min and 14.0 min) than by car (9.5 min and 5.9 min). Very few people travel to work by public transport (4.1%) and close to half travel by motor vehicle (48.3%).

5.8.6. Cluster F

This cluster stands out as the highest consuming areas, with 3.4% of areas using over 5% of total energy (energy:household ratio = 1.68). Both gas and electricity consumption are markedly higher for this cluster than for cluster E. However for energy use from vehicles, whilst the median is similar to cluster E, the interquartile range is much greater (Fig. 6). This is likely to be due to the approximately 50:50 split in this cluster between urban and rural areas. Whilst cluster D was mainly urban and cluster E mainly rural, the high consumption in this cluster appears not to be driven by location to such a large extent. Whilst this cluster had the lowest levels of full and part-time employment, it has the greatest number of self-employed people, and with 44.5% of households classed as grade AB, median incomes are by far the highest in these areas (>£58k). The age profile is very similar to cluster E, with a similar proportion of retirees, but slightly more children. This is reflected in this cluster having the second highest percentage of households with dependent children, and (marginally) the highest average number of residents per household. It also has the second highest number of family households without dependent children, but the lowest number of single occupancy households. Almost 60% of properties are detached and the majority of the remainder are semi-detached. Over 45.5% are owned outright and over a third mortgaged (36.2%). Because of the urban-rural mix in this cluster, average travel times tend to be longer than for cluster D but shorter than for cluster E. Reflecting the high levels of self-employment (17.1%), this cluster also has the highest proportion of people working from home (8.5%). Although there is an overall paucity of public transport stops in these areas, almost 10% of workers travel by public transport (more than for clusters C and E), however, less than 5% use active travel and over 40% travel by motor vehicle.

5.9. Capacity for controlling energy consumption

The analyses above draw out a range of factors which differ across the energy clusters. Some of these are likely to lead to a locking in of greater energy use (for example rural locations leading to higher vehicle energy consumption through greater travel distances and lack of public transport, as well as higher domestic energy through colder ambient temperatures in the absence of an urban heat island). Some factors such as higher incomes or ownership, rather than rental, of property may give a greater capacity for reducing energy consumption through providing a greater degree of choice and control over lifestyle, and ability to exploit energy efficient technologies. Other factors are not as clear cut, however. For example, detached properties may generally lead to higher heating costs through having a greater number of external walls and being larger, but there may be a greater ease of implementing significant energy reduction measures such as solid wall insulation.

In this section we take a selection of the factors that might provide a greater degree of control over energy consumption and examine how these vary between the lowest and highest consuming clusters. Fig. 9 shows a selection of the socio-economic factors and how they differ between the lowest and highest energy (approximate) quartiles. Fig. 10 presents differences in some of the more structural factors. The comparative energy:household ratios are: cluster A = 0.75, clusters DEF = 1.33. Here D–F have been grouped together to represent approximately the same number of households as cluster A. Although we have highlighted that there is variation between clusters DEF in terms of some factors, they are presented here combined partly to simplify the presentation but also to reinforce our finding that there is potentially a greater capacity for control amongst all high energy consuming clusters.

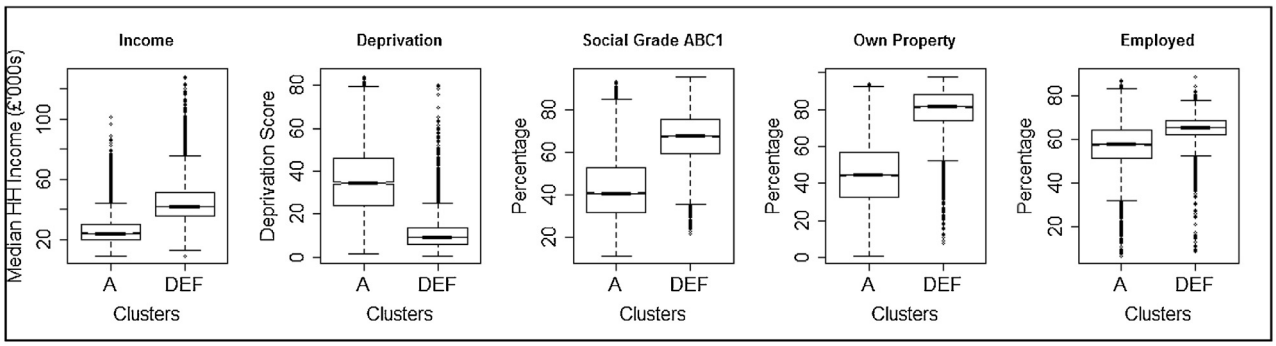

Fig. 9. Comparison of socio-economic factors between low (A) and high (DEF) consumption clusters.

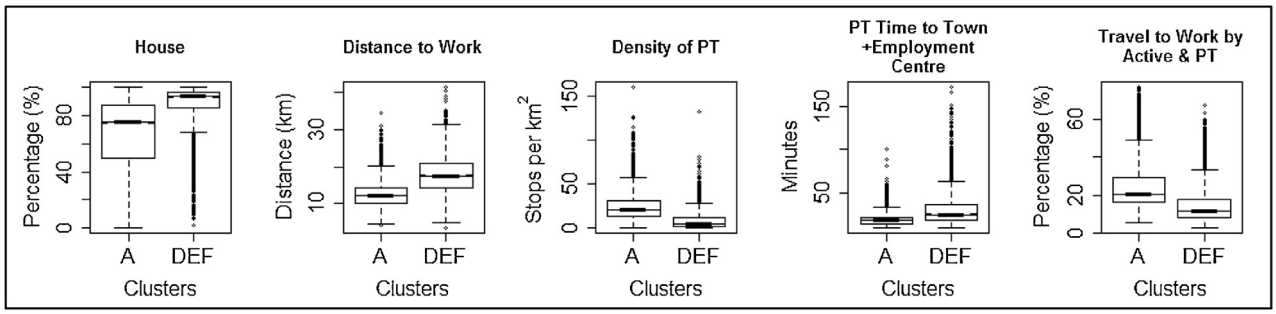

Fig. 10. Comparison of structural factors between low (A) and high (DEF) consumption clusters.

5.9.1. Income and deprivation

Poverty, both as identified in conventional (low income) and more recent 'capabilities' framings [64,55] has been linked to lack of control over one's environment [44]. Thus, in comparing the high and low clusters, the very significant difference in levels of income and deprivation identified between these clusters indicates that expectations or compulsions for individuals and households to reduce their energy consumption might be placed much more fairly on the high energy using clusters, where high income and low deprivation may indicate a greater capacity for inhabitants of these areas to exert agency on their surroundings and in terms of how they carry out their lifestyles.

5.9.2. Social grade

Fig. 11 groups together social grades AB and C1 as those grades identified as "the middle classes". The grades reflect a range of parameters that, whilst including income, also incorporate both education and profession. Whilst the adoption of middle class lifestyles is recognised as leading to higher levels of energy consumption, both in Europe and globally (for example Refs. [12,75]) conversely the higher levels of education and economic freedom, and sometimes the value systems associated with the middle classes can potentially unlock both an informed ability and greater willingness to take up energy efficiency measures, if not necessarily resulting in energy reduction [12,10].

5.9.3. Own property

This is a composite variable made by combining levels of outright ownership and mortgaged properties. Within clusters DEF, there are much higher levels of property ownership which suggests a greater capacity for energy consumers in these areas to have the ability to undertake work on and control the physical structure of their home to reduce energy consumption. Particularly where houses are owned outright, there may well be much greater disposable income due to the reduction in monthly housing costs.

5.9.4. In employment

This is a composite of full-time employed, part-time and self-employed, and provides an indication of the variation in the overall numbers of people in employment. This may reflect a complex range of different factors, such as time spent in the home, but has been included here as an indicator of both general level of capability and of bringing in income to the household, and to some extent the reliability of this income. Employment can also be an important factor in the ability to obtain credit and loans. Thus higher levels of employment in clusters DEF would again potentially make them a more just target of early pressure to reduce energy consumption.

5.9.5. Travel to work

The percentage of people who travel to work by means other than car has been used here as a proxy variable to indicate levels of car dependency (i.e. where high proportions of people, walk, cycle or use public transport to access work, these areas are likely to have a combination of good non-car transport provision and local, or accessible, facilities that make car use optional). There is a greater tendency in cluster DEF for travel to work to be undertaken by car, however, there are still well over half of areas where the majority of travel to work is by non-car modes and these areas could form the target of behavioural interventions to encourage mode shift amongst high car users. Where distances to work, or to town centres are great though, simple behavioural interventions are unlikely to be possible and infrastructure and service provision for non-car modes would need to be reviewed.

5.9.6. Distance to work

This is a complex factor that is linked in structurally to the distance to town and employment centres, but also in terms of lifestyle and expectations to social grade. In the higher social grades, specialised types of employment and expectations of work may lead to much greater travel times being taken on irrespective of where the nearest employment sites might be. This is particularly true in the

case of dual-career households where choice of residential location may be a compromise between two very different work locations.

5.9.7. House

This is a composite variable representing the proportion of people living in houses (Detached, Semi-detached or Terraced) rather than flats or apartments. Inhabitants of these types of properties potentially have a greater degree of control over making changes to the fabric of the building, particularly in terms of insulation measures. This also tends to be strongly correlated with tenure as only a smaller proportion of flat/apartment households are owner occupiers. Again, the higher proportion of houses in clusters DEF indicates that there is likely to be greater potential for gains to be made through targeting these areas. Over half the housing in cluster A is terraced housing which offers somewhat less control over certain deep retrofit measures, due to size (internal solid wall insulation), shared external walls (external insulation), proximity to neighbours (air source heat pumps).

6. Discussion

The analyses above highlight a complex pattern of household energy use across England and Wales. Whilst there is a general pattern demonstrated that energy consumption, and thus strain on the energy system, increases in line with income, it is not income directly that leads to this, but a complicated pattern of structural factors and lifestyle choices that will condition and constrain the behaviours and activities that result in energy consumption at the point of use. Energy justice work in the context of energy consumption has tended to focus on ensuring that certain sectors of society identified as fuel poor receive support in order to allow them to meet their fundamental energy needs at a cost that is affordable by them. However, here we argue that in terms of both the just targeting of climate policies to reduce energy consumption, and strategies to create a more equitable use of national energy systems, there is a need to broaden the justice lens to consider not just the lower end of the consumption spectrum, but also the higher end too. Additionally, we widen the consideration of most energy justice work on domestic energy consumption to also include energy use from private household vehicles, particularly with regard to looking ahead to the increasing electrification of transport and an increase in energy for vehicles being sourced from domestic electricity supplies.

The use of cluster analysis to explore energy consumption across the three domains of gas, electricity and vehicle use resulted in the identification of four main clusters, each representing approximately a quarter of areas and households across England and Wales, as well as three subdivisions of the highest consumption group. These high consumption clusters use, proportionally, between 26% and 67% more energy than the average, and between 68% and 124% more than the lowest cluster. Analysis of the clusters, and particularly variations between the three high sub-clusters, demonstrates the benefits of looking across all three domains within the single study. It becomes clear that there are two high consumption clusters (D and E) that are distinctive in their energy patterns through their locations mainly in urban and rural locations respectively. The urban nature of areas in cluster D affords the ability to consume less energy through vehicle use, due to greater accessibility to services and availability of public transport. However, the highest consuming cluster, which remained stable when the number of clusters was increased, appears to be largely independent of urban-rural location.

The analysis of the clusters across a range of socio-economic and structural variables identifies how a variety of factors intermesh to determine energy consumption. Whilst income rises with total energy consumption across the clusters, it is not a direct relationship, i.e. people do not simply spend more money on energy because they have it available. It appears to permit increased consumption through, for example, ownership of more cars, or larger detached properties. The former enables greater distances to be travelled to work and services, thus permitting rural living where there are fewer public transport services and allowing a choice to be made to become locked-in to a higher energy lifestyle.

It is likely that, in trying to meet UK targets for greenhouse gas emissions, it will be necessary to reduce energy consumption. This reduction will be necessary in terms of a direct reduction in fossil fuel consumption, as well as a reduction in overall energy consumption in order to facilitate current gas and oil-related energy services to be electrified without requiring an implausible amount of electricity to be generated. In order to make these reductions, rather than assuming a need for an 80% reduction across all of society, it makes sense to at least examine the potential for reducing consumption in that sector of society that is consuming greater than 30% more energy per household than the average. In doing this we have identified that there are a number of reasons why these areas make suitable targets for promoting energy reduction. Perhaps most importantly, the high income in these areas means that problematic pay-as-you-save schemes for funding energy retro fits, such as the UK's (former) 'Green Deal' [34], should generally not be necessary. Also, the higher levels of education (indicated here through social grade) should mean that the uptake of, often quite complex, energy reduction strategies should be more readily achievable. By investigating these areas more closely, it is also worth asking the question – if these high income, highly educated people cannot take up lower energy lifestyles, then how can we expect this of more constrained sectors of the population? However, with some of the more structural issues around housing and transport there is some divergence in the degree to which efforts to reduce energy consumption are constrained. Whilst there is some indication that the nature of properties and ownership levels for housing should make it more practicable for energy efficiency measures to be instituted in the higher energy consumption clusters, it is apparent that transport poses more of an issue, with longer access times to services, much lower availability of public transport and longer distances to work. These latter will require much greater levels of societal and structural intervention to be resolved. The spatial analysis provided by our study does afford a significant further drilling down into variations between clusters at local levels, so as to be able to develop particular blends of policy targeted at specific local circumstances, though there has not been space to describe this here. Also, as highlighted earlier, behind all these aggregates will be a considerable spread of energy consumption across the individual households, but this will only be identifiable at a much finer scale of analysis, for which the broad picture presented here will provide important context.

7. Conclusions

The exploratory analyses shown here suggest that there is considerable value in utilising these two new UK government datasets on vehicle ownership and use, and domestic energy consumption in parallel to explore patterns of household direct energy usage. Through their spatial coverage, they can be used to link energy consumption with both levels of deprivation and poverty, and to physical and geographic characteristics, such as rural/urban location, housing type and a range of sociodemographic variables. These new datasets stand in contrast to previous work in the UK which has been based on limited samples of the population. The analyses in this paper are based on bottom up data representing actual readings from over 70 million individual readings from domes-

tic energy meters and vehicle odometers, thus allowing a greater understanding of spatial variation in energy use across the country than is permitted through sample-based analysis. It is accepted that the benefits of these datasets are limited by the need to aggregate data over areas due to data security reasons. However, the methods used here, based upon creating profiles for average households across relatively small (~700 household, ~1600 person) socially homogeneous areas provides a method for identifying energy consumption hotspots that would be suitable for the efficient targeting of localised interventions to achieve energy reductions. The methods also provide information about different energy-usage groups that would be useful both at a national and local level to appropriately target different policies and assess distributional impacts and other equity issues.

In contrasting the characteristics of the highest and lowest energy-using areas, we build upon previous sample-based work that has also identified many of these same factors driving variation in energy consumption (e.g. Refs. [68,36,9,43]). However, the ability to confirm these observations about energy consumption through simultaneous examination of gas, electricity and car usage from near-universal datasets, enabling detailed mapping of variations in both energy use and drivers for energy use, allows these patterns to be visualised and understood at scales (both nationally and locally) that have not been previously achievable. Through the analysis of patterns of energy use, on a spatial basis, we have drawn attention away from energy consumption solely being a matter of short-term choice, to being closely related to structural issues such as location, housing and transport accessibility. It is notable that in assessing energy consumption at an areal level, we have found that all the key factors identified in the previous household level work are still relevant when aggregated upwards. However, we also identify that some of them do not necessarily have a straightforward linear relationship with energy consumption across all three domains.

Considering the traditional focus of the majority of energy justice work, particularly in the UK, on issues of fuel poverty or globally on energy vulnerability, this work contributes to the more limited amount of research directed at exploring the consumption patterns and drivers of high energy users. Where previous work on high-end energy consumers/carbon emitters has considered equity issues of mitigation policies, this has tended to focus on the greater ability to bear financial burdens of measures such as carbon taxes or the levying of 'green tariffs' on household energy bills (e.g. Refs. [67,61]). In addition to simply identifying areas of high consumption, our analysis indicates that these users are likely to have a greater ability to undertake action to reduce their consumption, not only through a greater level of financial freedom (higher income and lower levels of multi-dimensional poverty) but also through more structural factors such as control over their housing, either through ownership or because they live in a house rather than a flat or apartment. Further work is required to investigate to what extent households within these areas have adopted some form of energy efficiency measures already, either in terms of their housing (using the Department of Energy and Climate Change's National Energy Efficiency Database (NEED), or in terms of low emission vehicles (using further data from the DfT vehicle test record dataset).

The dynamic between high energy consumption being a consequence of need (i.e. structural factors such as the type of house, or poor levels of public transport that lead to car dependency) as opposed to choice (the use of large amounts of electrical appliances, the making of many 'discretionary' journeys by car, or high thermostat settings) is not a simple one. There is increasing work being undertaken into establishing how basic needs in terms of access to goods and services translate into energy demand (for instance Ref. [66]). Through the type of analysis presented here using these new datasets, it is possible to begin to explore how these relationships may vary spatially. This work also raises an issue around the degree to which differences in energy consumption due to these structural variations can be considered to be a matter of need over choice, particularly with regard to whether people have chosen to place themselves in a position where meeting their needs is energy intensive (for example choosing to live in a location where they have to make a long, frequent car journeys to work), or living in a house that is larger than the minimum considered adequate for the number of household members. However, Jackson and Papathanasopoulou [48], (p. 92) have previously raised the issue that choice is not always based on solely individual decisions: "Having two parents at work is in part a choice about desired income levels. But from an individual or household perspective, people will more often only have a limited degree of real choice over where to live, where to work and how to get from home to work. These decisions are part of a much larger set of issues around the organisation of society and the evolution of social norms". In moving forward to establishing a just set of policies for achieving ambitious climate change and energy targets it will be necessary to much better identify the boundaries between choice and need, particularly in the context of high energy consumption where action is needed the most.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.erss.2016.04.013.

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