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All about size? – The potential of downsizing in reducing energy demand

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HIGHLIGHTS

- Building size has huge impact on residential energy consumption.
- There is significant underoccupation in English homes, even in cities.
- Huge energy savings are possible if people downsize (move into smaller homes).
- Lack of alternative, smaller accommodation structural barrier to downsizing.

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ABSTRACT

Residential energy consumption is one of the main contributors to CO_2 emissions in the UK. One strategy aimed at reducing emissions is to increase retrofitting rates of buildings. In this paper, an alternative approach is discussed and its potential impact on energy use assessed, that of downsizing (moving to smaller homes).

Reviews of previous research show that a wide range of what can be termed psychological barriers exist to downsizing, such as the loss of ownership and independence, concern about what to do with possessions, not having enough space for visitors, and attachment to one's home. Benefits of downsizing from a personal perspective are economic, with lower bills and/or rent, release of capital, lower maintenance costs, and also potential lifestyle improvements including living in easier-to-maintain and more age-appropriate housing. Wider societal benefits include the potential to significantly reduce energy consumption, and mitigating the housing crisis in cities where not enough properties are available. Empirical analysis on a nationally representative sample in England showed that building size alone accounts for 24% of the variability in energy consumption (compared to 11% of household size). If single-person households with more than two bedrooms downsized by one bedroom, energy-savings of 8% could be achieved, and if single-person households occupied only one bedroom, savings of 27%. Data also showed a significant amount of underoccupation, with almost two-thirds of households having more bedrooms than considered necessary compared to the bedroom-standard. However, analysis also revealed a structural barrier to downsizing, namely the lack of available alternative, smaller houses.

The evidence would suggest that downsizing could realize significant energy savings, and address a range of other social benefits. However, against this stand significant personal interests, inadequate alternative housing and other infrastructure issues. Promoting downsizing as a means to achieve energy policy goals is therefore a potentially significant but socially challenging policy option.

1. Introduction

Energy use in buildings is one of the largest contributors to global and local energy consumption. In the UK, Palmer and Cooper [1] estimate that 26% of total annual carbon emissions arise from energy use during the operational phase of residential buildings' lifecycles. The UK Government established the goal of reducing emissions from homes by 29% by 2020 [2]. Energy efficiency improvements in UK homes form a central part of the decarbonisation plans, with millions of retrofits of residential homes planned over the next decades [3]. However, uptake of a main recent Government policy to promote energy efficiency renovations has been much lower than expected [4], casting doubt how successful energy reduction through retrofitting will be. Another strategy that has been tested repeatedly is to give occupants individual or comparative feedback on their energy consumption, with the aim of achieving energy reductions (e.g. [5,6]); however, whilst energy

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savings were achieved they were not near the region of energy savings needed and indeed, not always realized, often focused on electricity savings only, and reduced in magnitude over time (for a review, see [7]). In addition, according to current projections, the number of households in England is predicted to increase from currently 22.3 million to 27.5 by 2037 [8], which despite a falling household size is likely to be associated with increased national energy demand [9] which would dwarf savings from any feedback interventions.

This paper explores the opportunities of, and challenges associated with, a different route towards reducing residential energy consumption: housing downsizing, that is, people moving to a smaller dwelling. It is likely to be an option primarily for the elderly who continue to live in big family homes even once their children have moved out [10]. Only few estimates of the prevalence of downsizing exist, and "there remains considerable controversy even about what the facts are about downsizing at older ages" [11, p.3]. The authors estimated that over a 10-year period one in four British home owners over 50 years of age relocated whereas in the US it is one in three. Those within Britain who relocated reduced the size of their home on average by 1.4 rooms indicating downsizing (if of smaller magnitude than in the US with 2.2 rooms). Hence, data indicate that some downsizing occurs but only of limited prevalence and limited effect. Downsizing of equipment to realize energy savings has been discussed, e.g. with suggestions that energy-efficiency measures can have the added benefit of reducing the size of equipment such as HVAC [12,13]; or a smaller size engine in cars [14]. However, downsizing in the sense of reducing one's living space and its implications for energy use has received very little attention in both research and policy, making this paper novel in terms of its literature review, data analysis, and policy recommendations. It is to be expected that this topic will receive greater attention in the future in particular in cities which see continuous population growth. In fact, Policy Think Tanks have identified downsizing as an important topic (e.g. [15]). In the introduction this paper will present current thinking and findings on downsizing with a particular focus on prerequisites for, barriers to, and benefits of downsizing, and by showing evidence on the impact of building size on energy consumption. In the empirical part, it sets out to address four main aims:

- to make the case for downsizing by showing the impact of dwelling size versus other predictors on energy consumption;
- to exemplify the potential for energy savings through downsizing;
- to show in detail the mismatch between the number of bedrooms households have and need;
- to describe the socio-demographic characteristics of underoccupiers.

The discussion then draws together empirical findings and findings from the literature review.

1.1. Benefits of and barriers to downsizing

Beyond the central focus on energy savings and hence the reduction of carbon emissions, downsizing has other benefits. The one that has received most attention is the potential economic benefit [10,11]. Bills and, in the case of renters rent, will usually be lower for a smaller dwelling, reducing monthly spending. For owner-occupiers, maintenance cost might decrease, and in particular money freed up when selling one's home and buying a smaller one in return. In addition, the – not necessarily monetary – costs of maintaining a large home would reduce; such as cleaning. Also, a newly chosen property might be more age-appropriate, e.g. without stairs, with wide doors, and in close proximity to amenities or public transport. Leach [16] carried out interviews with home owners between 65 and 75 years who had downsized and they reported finding life after downsizing liberating, with lower household bills to pay and a smaller house to manage. Finally, if the elderly downsized to a smaller property, space would be freed up for younger people and families. The housing crisis, i.e. a lack of available, appropriate properties, and high housing costs, is often seen as a core issue of intergenerational justice [17] where the older generation is better off than the younger generation.

However, despite those benefits of downsizing most moving that happens in older age is for other reasons, in particular health reasons [18,19], widowhood [19], or to be closer to children [18]. In addition, various barriers towards downsizing have been identified.

Leach [16] had interviewed home owners between 65 and 75 who did not want to downsize, giving as reasons that moving to a smaller house would make it harder to store possessions and that new buildings were too tiny. The latter is corroborated by facts: The UK has indeed the smallest homes in Europe, and new builds are on average even smaller than existing buildings [15]. Interviews with a nationally representative sample in England showed that bungalows were the preferred housing option and only 1% of the elderly would chose to live in a modern building [20]; however, in particular in cities like London flats are currently predominantly being built.

Another barrier is the desire to protect property as a means to ensure inheritance for children [21–23]. When selling one home and buying another, most likely capital is freed up which then is subject to inflation, making it if anything decline in value whereas house prices have seen an increase in the last decades. Also, in the UK, buying a home demands payment of 'stamp duty land tax' when purchase price is above a certain amount of currently £125,000 [24] above which 2% or 5% of the purchase price need to be paid. This money is basically lost from the inheritance. In fact, Leach [16] found that both those who did not downsize thought that stamp duty concessions could encourage people to move. Selling a home and moving into rented accommodation is not attractive as it would expose occupants to insecurity in the sense of potentially rising rental prices [25]. Also, living in one's own home is seen as a sign of independence [26]. This again might make moving into rental accommodation unlikely, but may not prevent moving to a smaller home. Finally, strong attachment to one's home could prevent moving at an older age [27].

1.2. Prerequisites for and barriers to downsizing

In order for downsizing to be a viable option, a significant amount of under-occupying must occur. In the UK, the 'bedroom standard' as The Housing (Overcrowding) Bill of 2003 is usually referred to, determines how many bedrooms are deemed necessary for a given living situation [28]. A separate bedroom is allocated to

(a) A person living together with another as husband and wife (whether that other person is of the same sex or the opposite sex).
(b) A person aged 21 years or more.
(c) Two persons of the same sex aged 10 years to 20 years.
(d) Two persons (whether of the same sex or not) aged less than 10 years.

(e) Two persons of the same sex where one person is aged between 10 years and 20 years and the other is aged less than 10 years.
(f) Any person aged under 21 years in any case where he or she cannot be paired with another occupier of the dwelling so as to fall within (c), (d) or (e) above.

The Office for National Statistics [28] estimated that around 16.1 million households out of the 23.4 million households in England and Wales were estimated to be under-occupying their accommodation in 2011–12 of which 8.1 million had at least two bedrooms and the rest one bedroom more than needed according to the bedroom standard. There was no equivalence in terms of overcrowding which affected 1.1 million households. Hence, a pure redistribution of housing would not work to reduce under-occupying; indicating that of the available properties, many are too large (in terms of number of bedrooms) to mitigate under-occupation. Assuming that properties were available, owner-occupiers would be in the best position to downsize; given the very high prevalence of under-occupation with more than 8 in 10 (82.7%) owner occupied households having at least one spare bedroom. However, also in the privately rented sector 49.5% and in the social housing sector 39.4% of households were considered under-occupying their home. Whilst the capital city London which has seen huge growth in the last years has a significant amount of overcrowding (11% of all households), underoccupation in much more prevalent, occurring in about 50% of all homes [28].

Hence, the potential for downsizing in England and Wales is huge; however, given the low rate of overcrowding, a simple redistribution of households within the existing housing stock would not achieve a better match of household sizes to house sizes. In Section 4 opportunities for mitigating mismatch are reviewed.

1.3. Determinants of residential energy consumption

In order for downsizing to be a viable option, the relationship of building size to energy consumption needs to be demonstrated. A large number of studies have looked at the impact of building variables on energy use (for an excellent summary and overview, see [29]). Building factors were found to explain about 42% and 54%, respectively, of the variability in energy use [29,30]. Building size and building type were generally the strongest predictors [29,31–33], more important than retrofit measures. Without providing a combined score for the total predictive power of building factors, [34] also found that they were more important than occupant characteristics in explaining space-heating demand. Occupant variables explain a significant amount of variability in residential energy consumption; however, their impact is much lower than that of buildings variables with estimates ranging from 4.2% [29] to 20% [34]. Household size and household income are generally the most important socio-demographic predictors: energy consumption increases with higher income [35–37], and larger household size [36,37]. The role of householder age is unclear – a negative [38], a positive [29,39], and no relationship [35] between age and energy consumption has been reported. Other socio-demographics, occupant heating behaviour, self-reported energy-related behaviours and attitudes towards climate change only play a very minor role [31]. Previous research has already established that dwelling size and type are the strongest predictors of residential energy consumption, making them a potentially important target area towards a goal of reducing energy consumption. However, no study has explicitly compared to role of building size in determining energy consumption in contrast to other factors, and has not calculated the potential for energy savings through downsizing.

2. Methods

2.1. Data set

The data analysed for this paper formed part of the Energy Follow-Up Survey 2011 (EFUS), commissioned by the Department of Energy and Climate Change [40] and of the English Housing Survey (EHS) 2011/12. The two surveys were matched allowing information from both sources to be combined. The EHS collects detailed information about the English housing stock alongside socio-demographics of the occupants. The EFUS encompassed a self-completion survey in which householders reported details of their dwelling and their heating practices. Gas and electricity meter readings were obtained in a subsample of homes, and were used to estimate yearly consumption. The sample size for EFUS was $N = 2616$; meter readings were available for $N = 1345$ households. Of those 1345 households further households were excluded from the sample on the following grounds:

(1) there was a positive reply to the question if physical changes to the dwelling had been carried out since the last EHS; as it was not recorded what exactly changed and when, the impact on energy consumption could not be assessed,
(2) there was a positive reply to the question if the household composition had been changed since the last EHS; again, as it was not recorded how and when the household changed, the impact on energy consumption could not be assessed,
(3) the annual energy consumption was considered an outlier (± 3 SD from the sample mean of energy consumption),
(4) usage of heating fuels other that gas or electricity (to avoid subsamples that were too small), and

Hence the total remaining sample size was $N = 991$ households for the EFUS data.

For analysis based only on the EHS, all cases were included ($N = 14,386$). In each part of Section 3, it is clearly stated whether analysis is based on EFUS data matched with EHS, or EHS data only.

2.2. Analysis methods

Data were analysed to meet the main aims as set out in Section 1. Correlational analysis was used to understand the relationship between energy consumption, dwelling size, and occupancy, and linear regression analysis tested the impact of the different predictors on (log-transformed) annual energy consumption (3.1). Selecting the subsample of single-occupant households, ANOVA was used to show the impact of living in a dwelling with various numbers of bedrooms and simple projection used to demonstrate energy savings potential of downsizing (3.2). Correlational analysis was used to highlight the relationship between the number of bedrooms a household has versus needs (3.3). To characterize householders who under-occupy their home, logistic regression was used (3.3).

3. Results

3.1. Impact of dwelling size, type, and household size on residential energy consumption

The EFUS data matched with EHS data formed the basis for this analysis ($N = 991$). The correlation between dwelling size, expressed in m^2, and energy consumption (kW h) was $r = .49$, $t(989) = 17.82$, $p < .001$. Number of bedrooms correlated even slightly more highly with annual energy consumption than floor area, $r = .52$, $t(989) = 19.23$, $p < .001$; however, given that floor area is a more precise description of property size, it is used in subsequent regression analysis. The correlation between household size and energy consumption was $r = .34$, $t(989) = 11.39$, $p < .001$. Only a weak correlation existed between household size and building size of $r = .27$, $t(989) = 8.70$, $p < 0.001$.

To examine the relationship between residential energy consumption and household size and floor area, linear regression analyses were carried out. A model using only floor are as predictor was significant, $F(1, 989) = 317.50$, $p < .001$, $R^2 = 24.32\%$ i.e. 24% of the variability in energy consumption is explained by building size. A model only using household size as a predictor explained 11% of the variability in energy consumption, $F(1, 989) = 129.60$, $p < .0001$. A combined model using dwelling type and household size as predictors showed an adjusted $R^2 = 28.66\%$; $F(2, 988) = 201.80$, $p < .001$. Table 1 shows unstandardized coefficients (B) and their standard error (SE) and standardized regression coefficients (β). Note that despite the moderate correlation between household size and floor area, inspection of the variance inflation factor showed there was no issue of multicollinearity (VIF < 1.1).

Hence, correlation analysis, comparison of R^2, and standardized regression coefficients all indicate that dwelling size has a larger impact on residential energy consumption than household size. In fact, is it the strongest impact factor: A recently published paper using this data but a much wider range of predictors spanning across building characteristics, socio-demographics, attitudes and behaviours showed that total explanatory power using rises only to 41.9%, i.e. half of the variability can be explained by dwelling size alone [31].

Table 1
Regression coefficients and standard errors (B, SE, β).

Predictor	B (SE)	β
Dwelling size (m^2)***	0.006 (0.0003)	0.433
Household size***	0.101 (0.0124)	0.199

*** Indicates significance at <.001.

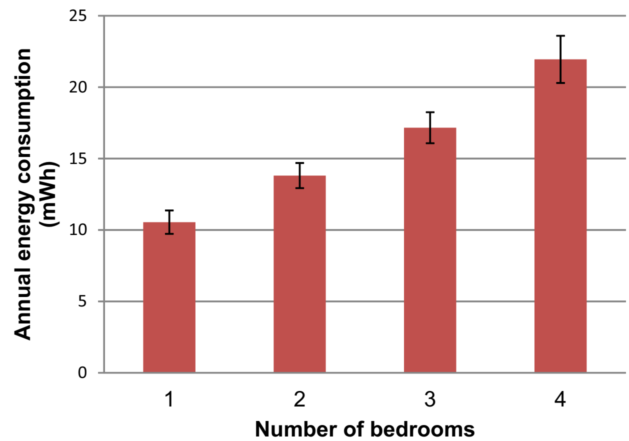

Fig. 1. Mean annual energy consumption (mW h) per number of bedrooms in a single-person household and standard error of the mean.

3.2. Example of potential for downsizing

A complete calculation of potential energy savings due to downsizing is beyond the scope of this paper as the actual savings would highly depend on the quality of the building stock that would be available for occupants. We exemplify the effect in terms of number of bedrooms in the subsample of all homes with a single occupier, taken from the EFUS data combined with EHS data. $N = 258$ households were occupied by one person only; the one single-person household occupying six bedrooms was considered an outlier and excluded from further analysis, resulting in a sample size of $N = 257$. Using number of bedrooms as a way to divide the sample is in line with calculation of underoccupation [28]. Fig. 1 shows how average annual energy consumption varies with the numbers of bedrooms. Data show an approximately linear relationship; for each additional bedroom, energy consumption increases by roughly 3750 kW h.

Average gas prices are 4.29 pence/kwH and 14.05 pence/kwH for electricity [41]. Hence, an increase by 3750 kwh/annum for each additional bedroom means roughly an additional £270/annum (assuming 70% of the increase are for gas, and 30% for electricity).

Table 2 shows the breakdown of single-person households against number of bedrooms in the sample, and in two downsizing scenarios. In the first one, it is assumed that only those having three or four bedrooms would reduce by one room, i.e. to a dwelling with two or three bedrooms, respectively. In the second scenario, it is assumed that all households downsize to a one-bedroom dwelling.

Fig. 2 shows the changes in the sum of annual energy consumption for all single-person households in the sample and the two downsizing scenarios. For each different number of bedrooms, the number of cases for that bedroom number was multiplied with the average annual consumption for that bedroom number; the products across bedrooms were then summed.[1] The value displayed is the sum of multiplying the number of cases for each bedroom with the annual energy consumption for that bedroom, converting from kW h into mW h.

Table 2
Prevalence of number of bedrooms in one person households in sample and scenarios.

No bedrooms (floor area m^2)	Energy consumption (kW h) p.a.	% in sample (N)	% Scenario 1	% Scenario 2
1 (45.27)	10,548	24.12 (62)	24.12 (62)	100 (257)
2 (62.49)	13,809	41.25 (106)	71.6 (184)	
3 (86.82)	17,159	30.35 (78)	4.28 (11)	
4 (138.38)	21,947	4.28 (11)		

Scenario 1 would mean a reduction in yearly energy consumption of about 8% and Scenario 2 of about 27%. Hence, even moderate downsizing, i.e. allowing a spare bedroom for those who have two or more bedrooms at the moment would be associated with significant energy savings.

Of course, this analysis is simplified; it does not account for differences in, for example, building quality, and is based on a sample with only with a limited number of cases ($N = 257$ single-person households). But even assuming a wide error margin, this would still be a significant reduction, and illustrates the potential for energy savings through downsizing, and given the significant reduction in terms of kW h, substantial financial savings.

3.3. Over- and under-occupying

As reviewed in Section 1.2, a large share of households are underoccupying with much lower rates of overcrowding. This mismatch is reflected by the moderate correlation of $r = .37$ ($p < .001$) between how many bedrooms households have and how many they need to meet minimum requirements (EHS data, $N = 14,386$). Fig. 3 exemplifies this mismatch by plotting across the sample the percentage of households that have a certain number of bedrooms and the percentage of households that would need a certain numbers of bedrooms.

[1] For example, for the actual data the bar results from 62 ∗ 10548 + 106 ∗ 13089 + 78 ∗ 17159 + 11 ∗ 21947. The graph shows mW h.

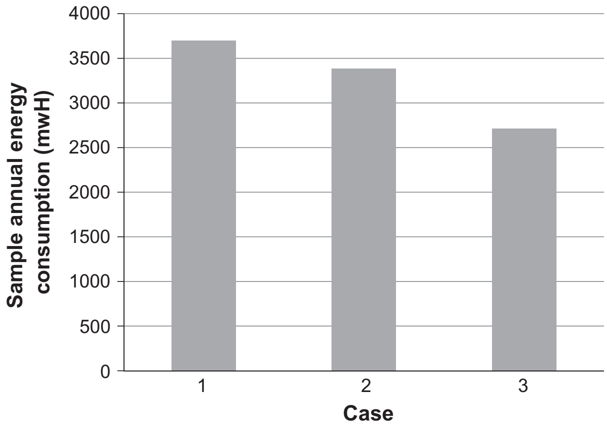

Fig. 2. Total annual energy consumption (mW h) in the different cases.

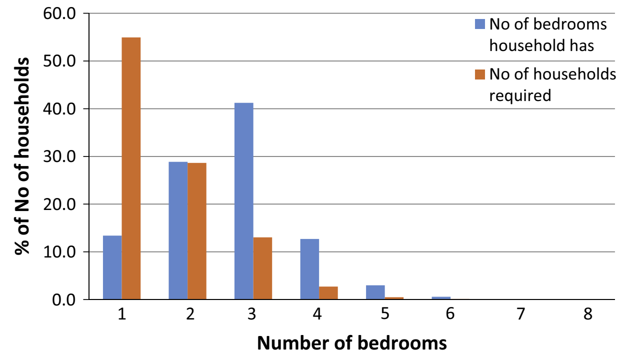

Fig. 3. Percentage of households that have a certain number of bedrooms versus percentage of households needing a certain number of bedrooms (N = 14,386).

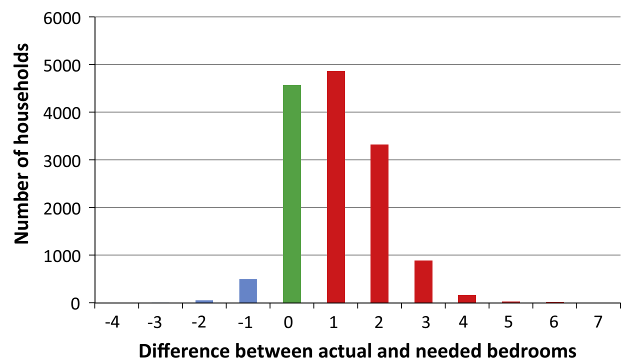

Fig. 4. Difference between the number of bedrooms a household has and needs. Positive numbers indicate underoccupation.

Across the sample, in particular for the one-bedroom case, the mismatch was striking, with only about 12% of households having a one-bedroom dwelling but more than 50% needing one. At the upper end, the picture reversed, with more large properties than needed.

When, for each household, subtracting the number of bedrooms a household actually needs from the number of bedrooms it has, the following picture emerges, Fig. 4.

Fig. 4 shows the findings as reported in 1.2 (as they are based on the same data set but without weighting in this case) but in greater detail. About 30% of households occupy a dwelling with exactly the number of bedrooms deemed necessary under the bedroom standard whereas almost two-thirds of households were underoccupied according to that standard.

In a next step, we characterized households that were underoccupying versus those that were not. In order to avoid a very small group size for 'overcrowding', the households that had the appropriate number of bedrooms and those considered as overcrowded were summarized into one category. Logistic regression was used to predict underoccupying (coded as '1') versus not underoccupying (coded as '0'). Because of missing data on some variables used as predictors in subsequent analysis, the total sample size was N = 14,281, with N_{under} = 9215 and N_{not_under} = 5066. Table 3 shows the variables used as predictors and their distribution over the two groups. HRP stands for 'Household Reference Person' which refers either to the sole owner or the tenant of a property, or, if there is more than one occupant, the person with the highest income, and in the case of equal incomes, the oldest of those [42].

The mean household size was amongst underoccupiers M = 2.18 (SD = 1.10) and amongst non-underoccupiers M = 2.79 (SD = 1.62). Those underoccupying had lived on average M = 15.65 years (SD = 14.85) in the dwelling and those not underoccupying only M = 7. 17 (SD = 8.01).

Inspection of Table 3 already points to differences between the two groups, with for example, e.g. householders underoccupying tended to be in higher income classes, not having dependent children, and being home owners.

Logistic regression was then used to test for statistically significant relationships between predictor and outcome variable (underoccupying vs. not) A test of the full model against a constant only model was statistically significant, indicating that the predictors as a set reliably distinguished between underoccupiers and non-underoccupiers (chi square (21) = 4813.10, p < .001). Prediction success overall was 76.3%, with a higher success rate of 83.6% for underoccupation than not-underoccupation (62.9%); Nagelkerke's R^2 = .393.

Table 4 lists summarizes the regression results for the variables predicting underoccupation and non-underoccupation.

Exp(B) gives the odds-ration, i.e. indicating if a predictor makes it more or less likely that a household is underoccupying. Results indicate that those in the highest two income-groups are significant more likely to be underoccupying than those in the lowest income group. Households with no one working are less likely to underoccupy, Households with an HRP under 45 are less likely to underoccupy than those between 45 and 64 years, and home owners and private renters are more likely to underoccupy than social renters. Not having dependent children in the house is associated with a higher likelihood of underoccupying. All ethnic origins not white are less likely to underoccupy. A larger household is associated with being less likely, a longer residency with being more likely to underoccupy.

4. Discussion

This paper is the first to systematically summarize previous findings on motivations for and barriers against downsizing, and to show empirical evidence on the potential of downsizing in reducing energy consumption and delivering substantial social and personal benefits. The empirical analysis has demonstrated clearly that building size is by far the strongest predictor of residential energy consumption and has exemplified the potential for downsizing. It supports earlier findings on the importance of building size as a predictor [29,31–33] but allows specifically comparing the effect of building size versus number of occupants, showing the much greater impact of the former on energy consumption than the latter. It also identified that home owners who are still working, have a high income but no dependent children in the house are most likely to underoccupy. If more householders would downsize, significant energy savings could be achieved, contributing to

Table 3
Distribution of predictors across households underoccupying and not underoccupying.

Predictor	Underoccupying *N* (%)	Not underoccupying *N* (%)
Equivalized income[a]		
1st *quintile*, *lowest*	1431 (15.5)	1678 (33.1)
2nd quintile	1771 (19.2)	1564 (30.9)
3rd quintile	1859 (20.2)	918 (18.1)
4th quintile	1944 (21.1)	606 (12.0)
5th quintile (highest)	2210 (24.0)	300 (5.9)
Anyone in household sick or disabled		
Yes	3032 (32.9)	1910 (37.7)
No	6183 (67.1)	3156 (62.3)
Employment status HRP & partner		
One or more full-time work	4469 (48.5)	2182 (43.1)
One or more part-time work	785 (8.5)	556 (11.0)
None working, one or more retired	3042 (33.0)	981 (19.4)
None working, none retired	919 (10.0)	1347 (26.6)
Age HRP		
16–29 years	664 (7.2)	855 (16.9)
30–44 years	2040 (22.1)	1841 (36.3)
45–64 years	3594 (39.0)	1519 (30.0)
65 and above years	2917 (31.7)	851 (16.8)
Presence of dependent children		
Yes	7069 (76.7)	2654(52.4)
No	2146 (23.3)	2412 (47.6)
Ethnic origin HRP		
White	8606 (93.4)	4117 (81.3)
Black	176 (1.9)	322 (6.4)
Asian	268 (2.9)	339 (6.7)
Other	165 (1.8)	288 (5.7)
Tenure		
Own with mortgage	2695 (29.2)	749 (14.8)
Own outright	3262 (35.4)	259 (5.1)
Privately rent	1450 (15.7)	1310 (25.9)
Rent from local authority	850 (9.2)	1338 (26.4)
Rent from Social Landlord	958 (10.4)	1410 (27.8)

[a] Income was coded as equivalized income, meaning that household incomes were adjusted for household composition and size such that those incomes can reasonably be directly compared with each other. This implies increasing the incomes of small households and decreasing the incomes of large households and the extent of these increases and decreases is determined by an internationally agreed set of scales.

Table 4
Results of the logistic regression to distinguish underoccupiers and not-underoccupiers.

Predictors	*B*	S.E.	Wald	df	Sig.	Exp (B)
AHC equivalised income quintiles (Ref = 1st quintile, lowest)			108.48	4	.000	
2nd quintile	0.162	.060	7.16	1	.007	0.851
3rd quintile	0.013	.067	0.04	1	.846	1.013
4th quintile	.0149	.074	4.07	1	.044	1.161
5th quintile (highest)	0.696	.087	64.15	1	.000	2.006
Anyone in household sick or disabled (Ref = No)	0.038	.049	0.60	1	.438	0.962
Length of residency (years)	0.049	.002	382.01	1	.000	1.050
Employment status HRP & Partner (Ref = min 1 full-time)			11.29	3	.010	
One or more part-time work	0.075	.080	0.89	1	.345	0.928
None working, one or more retired	0.323	.104	9.63	1	.002	0.724
None working, none retired	0.149	.070	4.45	1	.035	0.862
Age HRP (Ref = 45–64 years)			10.63	3	.014	
16–29 years	0.242	.075	10.26	1	.001	0.785
30–44 years	0.116	.058	3.94	1	.047	0.891
65 and over	.018	.098	0.04	1	.851	0.982
Presence of dependent children (Ref = dependent children)	141	.064	4.88	1	.027	1.151
Ethnic origin HRP (REF = white)			88.08	3	.000	
Black	0.620	.109	32.08	1	.000	0.538
Asian	0.475	.099	22.95	1	.000	0.622
Other	0.748	.116	41.82	1	.000	0.474
Tenure (Ref = tenant with social housing landlord)			1220.41	4	.000	
Own with mortgage	1.771	.074	578.85	1	.000	5.879
Own outright	2.234	.086	672.58	1	.000	9.336
Privately rent	0.874	.067	169.77	1	.000	2.396
Rent from local authority	0.131	.066	3.90	1	.048	0.878
Household size	0.345	.022	242.90	1	.000	0.708

the national goal of carbon emission reduction. Other benefits would include freeing up living space for the younger generation, creating more disposable income and more age-appropriate living conditions.

Given the large impact of building size in determining energy consumption and the high prevalence of underoccupying, promotion of downsizing would seem an obvious choice to reduce a nation's energy consumption. However, the barriers to downsizing are significant and significant changes would be needed to make downsizing a possible and attractive option. One immediate logistical barrier is the lack of alternative accommodation into which to move. There are simply not enough smaller dwellings to allow downsizing. Indeed, one reason why the bedroom tax was doomed to fail was the unavailability of smaller dwellings: The bedroom tax, formally known as "under-occupancy charge" was implemented to penalize social housings tenants who have more bedrooms than needed [43]. Occupants lose a share of their entitled benefits for occupying more space than deemed necessary. However, this scheme has been highly criticized because of the lack of alternative housing to which tenants could move in order to avoid the penalty [44]. Hence, creating attractive alternative housing is a main structural challenge. It would have the potential of promoting the economy, e.g. through jobs in the construction industry if dwellings were converted into smaller, multiple unit-properties. Also, when increasing the density of living, additional amenities need to be created, such as GP practices, public transport, and entertainment options which might generate new revenue but will also need substantial investment. When creating new properties, it needs to be kept in mind that the UK already has amoungst the smallest mean floor area per dwelling for its housing-stock in Europe, in particular for new-build properties [15]. Morgan and Cruickshank [45] hypothesize that people underoccupy because they perceive their rooms as too small and make up for it by having more rooms.

Putting the structural barriers aside, a number of 'psychological barriers' remain. As reviewed in the introduction, a range of concerns have been identified around downsizing. For some of them, the right incentive might help to overcome them. For example, the loss of space is a crucial aspect; in fact, Leach [16] reported that elderly couples felt it necessary to have spare rooms, not just for visitors but also for themselves if both were retired/staying at home. Whilst feeling the need to have a lot of personal space might be hard to overcome, providing space more visitors could be arranged differently. As an example, several communal housing projects have shared facilities for guests which each household in the commune can make use of. If converting a large house into multiple dwellings it is likewise feasible to keep spare bedrooms for visitors; it seems unlikely that all regular occupants would have visitors at the same time. Similarly, arranging for communal storage space (e.g. individual compartments in the attic) could help address concerns about not enough storage space when downsizing.

The concern about loss of ownership and the desire to preserve inheritance for children [21–23] could be addressed if home-owners would not downsize by selling their building but by moving into rented accommodation, with a contract limiting any potential rent increases to address the concern of moving into a volatile renting market [25]. A pilot scheme was designed in London, the Redbridge "Free Space" project, in which property owners leave their house to move to smaller, more appropriate housing, but retain ownership of their house. The dwelling is rented out by the Council who takes care of all landlord responsibilities.[2]

Taking a lodger would be an alternative to reduce underoccupation but allowing homeowners to stay in their home to which they are attached [27]. Schemes exist that bring benefits beyond monetary gains such as promoting intergenerational justice and easier maintenance. Germany, for example, has a scheme called "Wohnen fuer Hilfe"[3] ("Living for help") where students or apprentices live (almost) free of charge in a household of an elderly person but provide other support in exchange, such as shopping, household chores, and companionship. The UK and other countries have similar schemes. In particular in large cities like London where rental prices have increased significantly in the last years, such a scheme might be highly successful.

Finally, one commonly given incentive for downsizing is the monetary benefit [10,11]. However, this might be a double-edged sword: Whilst being potentially a powerful incentive, in particular when combined with favourable selling conditions such as reduced or no stamp duty [16], it has also the potential for rebound effects regarding energy savings if those who downsize would then use the freed up money for other energy-intensive activities such as long-distance flights. This rebound effect has been demonstrated repeatedly and can mitigate or negate energy savings achieved (e.g. [46,47]).

To conclude, promoting downsizing as a means to achieve energy policy goals is challenging and controversial. The evidence would suggest that it could realize significant energy savings, and address a range of other social benefits. Against this stand significant cultural factors and personal interests. As with many potential environmental measures, this pits the social against the personal and would require, in the UK at least, changes in the composition of the building stock, social attitudes towards house size as a symbol of wealth and social status, and innovation in housing provision, financial models and legal structures to be achieved. One might speculate that resentment against initiatives towards downsizing might be particularly strong, given the social status associated with owning larger homes, and for many, the legacy of familial memories associated with having spent years living in a particular environment. We do not underestimate the significance of these challenges, but note that there may be ways to mitigate such sources of resistance to downsizing while increasing the benefits. Given the potential of downsizing in saving energy, it seems worth researching this idea further, through focus groups and nationally representative surveys to assess motivations and barriers to downsizing in more focused ways and to understand what desirable housing looks like. After identifying the most common barriers, motivations, and prerequisites, interventions could be developed to incentivize downsizing. Choice experiments could give an initial insight into potential downsizing rates following different incentives, but ideally, eventually this would cumulate in a randomized control trial of policy measures to quantify actual downsizing rates. Tax incentives for those who downsize [16] might be a viable policy measure and provision of desirable housing such as bungalows [20].

[2] http://www.ilfordrecorder.co.uk/news/redbridge_scheme_for_older_homeowners_hailed_by_housing_minister_1_1180475.

[3] http://www.hf.uni-koeln.de/wfh.php?id=30203.

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References

[1] Palmer J, Cooper I. United Kingdom energy housing fact file. Retrieved from <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/201167/uk_housing_fact_file_2012.pdf>; 2012 [accessed 29.08.14].
[2] DECC. The UK low carbon transition plan: national strategy for climate and energy. London: Department of Energy and Climate Change, The Stationary Office; 2009.
[3] UK CCC. Fourth carbon budget. London, UK: UK Committee on Climate Change; 2010.
[4] DECC. Green deal and energy company obligation. Monthly statistics: March 2015. Retrieved from: <https://www.gov.uk/government/statistics/green-deal-and-energy-company-obligation-eco-monthly-statistics-march-2015>; 2015 [accessed 20.04.15].
[5] Ueno T, Inada R, Saeki O, Tsuji K. Effectiveness of an energy-consumption information system for residential buildings. Appl Energy 2006;83(8):868–83.
[6] Schultz PW, Nolan JM, Cialdini RB, Goldstein NJ, Griskevicius V. The constructive, destructive, and reconstructive power of social norms. Psychol Sci 2007;18(5):429–34.
[7] Abrahamse W, Steg L, Vlek C, Rothengatter JA. A review of intervention studies aimed at household energy conservation. J Environ Psychol 2005;25:273–91.
[8] DCLG. 2012-based household projections: England, 2012–2037. Retrieved from <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/407556/Household_Projections_-_2012-2037.pdf. Accessed 14.05.2015>; 2015.
[9] Huebner GM, Durand-Daubin M, Shipworth D, Shipworth M, McMichael M, Summerfield A. Daily temperature profiles, household size, and ageing: the shape of things (to come). In: eceee Summer Study Proceedings 2013; 2013. p. 2355–66.
[10] Doteuchi A. "Downsizing" of housing and lifestyles for a low carbon aging society. NLI research. <http://www.nli-research.co.jp/english/socioeconomics/2008/li080626.pdf>; 2008 [accessed 22.05.15].
[11] Banks J, Blundell Z, Oldfield J, Smith P. Housing price volatility and downsizing in later life. NBER working paper series. <http://www.nber.org/papers/w13496>; 2007 [accessed 22.05.15].
[12] Mills E, Rosenfelds ART. Consumer non-energy benefits as a motivation for making energy-efficiency improvements. Energy 1996;21(7/8):707–20.
[13] Trianni A, Cagno E, De Donatis A. A framework to characterize energy efficiency measures. Appl Energy 2014;118:207–20.
[14] Simmons RA, Shaver GM, Tyner WE, Garimella SV. A benefit-cost assessment of new vehicle technologies and fuel economy in the U.S. market. Appl Energy 2015;157:940–52.
[15] Evans AW, Hartwich OM. Unaffordable housing: fables and myths. London: Policy Exchange; 2005.
[16] Leach J. Understanding downsizing. Retrieved from <http://www.if.org.uk/wp-content/uploads/2012/04/Understanding-Downsizing-Why-People-Choose-to-Downsize-or-Not.pdf>; 2012 [accessed 11.03.15].
[17] Morton A. Housing and intergenerational fairness. Retrieved from <http://www.policyexchange.org.uk/images/publications/housing%20and%20intergenerational%20fairness.pdf>; 2012 [accessed 13.03.15].
[18] Choi NG. Older persons who move: reasons and health consequences. J Appl Gerontol 1996;15:325–44.
[19] Sheiner LM, Weil DN. The housing wealth of the aged. NBER working paper no. 4115. Cambridge, MA: National Bureau of Economic Research; 1992.
[20] Ipsos MORI. Retrieved from <https://www.ipsos-mori.com/researchpublications/researcharchive/973/Bungalows-Are-Peoples-Choice-In-England.aspx>; 2002 [accessed 14.03.15].
[21] Hill G. Inheritance law in an aging society. J Aging Social Policy 1995;7:57–83.
[22] Kane R. From generation to generation: thoughts on legacy. Generations 1996;20:5–8.
[23] Langbein J. The inheritance revolution. Public Interest 1991;102:15–31.
[24] UK Government. Stamp duty land tax. <https://www.gov.uk/stamp-duty-land-tax/print>; 2015 [accessed 22.05.15].
[25] Skinner J. Comment on: aging and housing equity: another look. In: Venti, Wise, editors. Perspectives on the economy of aging. Chicago: Chicago University Press; 2004.
[26] Haak M, Fänge A, Iwarsson S, Ivanoff S. Home as a signification of independence and autonomy: experiences among very old Swedish people. Scand J Occup Ther 2007;14(1):16–24.
[27] Curry L, Gruman C, Robison J. Medicaid estate planning: perceptions of morality and necessity. Gerontologist 2001;41(1):34–42.
[28] ONS. Overcrowding and under-occupation in England and Wales. <http://www.ons.gov.uk/ons/dcp171776_360082.pdf>; 2014 [accessed 12.03.15].
[29] Guerra Santin O, Itard L, Visscher H. The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. Energy Buildings 2009;41:1223–32.
[30] Sonderegger RC. Movers and stayers: the resident's contribution to variation across houses in energy consumption for space heating. Energy Buildings 1978:313–24.

[31] Huebner G, Hamilton I, Chalabi Z, Shipworth D, Oreszczyn T. Explaining domestic energy consumption – the comparative contribution of building factors, socio-demographics, behaviours and attitudes. Appl Energy 2015;159(1):589–600.
[32] Kelly S. Do homes that are more energy efficient consumeless energy?: a structural equation model of the english residential sector. Energy 2011;36(9):5610–20.
[33] Theodoridou I, Papadopoulos AM, Hegger M. Statistical analysis of the Greek residential building stock. Energy Buildings 2011;43(9):2422–8.
[34] Steemers K, Young Yun G. Household energy consumption: a study of the role of occupants. Build Res Inform 2009;37(5–6):625–37.
[35] Abrahamse W, Steg L. How do socio-demographic and psychological factors relate to households' direct and indirect energy use and savings? J Econ Psychol 2009;30:711–20.
[36] Brandon G, Lewis A. Reducing household energy consumption: a qualitative and quantitative field study. J Environ Psychol 1999;19:75–85.
[37] Druckman A, Jackson T. Household energy consumption in the UK: a highly geographically and socio-economically disaggregated model. Energy Policy 2008;36(8):3177–92.
[38] Gatersleben B, Steg L, Vlek C. Measurement and determinants of environmentally significant consumer behaviour. Environ Behav 2002;34(3):335–62.
[39] Liao HC, Chang TF. Space-heating and water-heating energy demands of the aged in the US. Energy Econ 2002;24:267–84.
[40] DECC. Energy follow-up survey (EFUS): 2011. <https://www.gov.uk/government/statistics/energy-follow-up-survey-efus-2011>; 2014 [accessed 22.01.15].
[41] Energy saving trust. Our calculations. Retrieved from <http://www.energysavingtrust.org.uk/corporate/our-calculations>; 2015 [accessed 05.02.2016].
[42] ONS. Harmonised concepts and questions for social data sources: primary standards – demographic information, household composition and relationships. London: Office of National Statistics. Retrieved from <http://www.ons.gov.uk/ons/guide-method/harmonisation/primary-set-of-harmonised-concepts-and-questions/demographic-information-household-composition-and-relationships.pdf>; 2012.
[43] Welcome Reform act. Retrieved from <http://www.legislation.gov.uk/ukpga/2012/5/pdfs/ukpga_20120005_en.pdf>; 2012 [accessed 01.06.15].
[44] Dugan E. 'Big lie' behind the bedroom tax: families trapped with nowhere to move face penalty for having spare room – UK Politics – UK. The Independent; 2013. Published 05.08.2013 [accessed 01.06.15].
[45] Morgan M, Cruickshank H. Quantifying the extent of space shortages: english dwellings. Build Res Inform 2014;42(6):710–24. http://dx.doi.org/10.1080/09613218.2014.922271.
[46] Binswanger M. Technological progress and sustainable development: what about the rebound effect? Ecol Econ 2001;36(1):119–32. http://dx.doi.org/10.1016/S0921-8009(00)00214-7.
[47] Sorrell S, Dimitropoulos J, Sommerville M. Empirical estimates of the direct rebound effect: a review. Energy Policy 2009;37(4):1356–71. http://dx.doi.org/10.1016/j.enpol.2008.11.026.