element energy

Further Analysis of Data from the Household Electricity Usage Study:

Consumer Archetypes

Final report for

Department of Energy and Climate Change

and

Department for the Environment Food and Rural Affairs

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1 Executive Summary

Objective

The diversity and variation in electricity consumption between different households across the UK represents a significant barrier to understanding future energy consumption and policy impacts at anything but highly aggregated levels, where most of the detail and fidelity is lost. Sorting these households into several well-resolved and characterised groups makes it possible to explore national electricity usage trends at more disaggregated levels, revealing consumption patterns and policy opportunities for different consumer archetypes. Cluster analysis is a statistical technique that allows households to be grouped on the basis of attributes such as demographics, attitudes and behaviour, where the differences in these attributes are minimised within each group and maximised between groups.

The Household Electricity Usage Study conducted by the Department of Energy and Climate Change (DECC), the Department for the Environment Food and Rural Affairs (Defra) and the Energy Saving Trust provides comprehensive data on the electricity usage patterns of 250 owner-occupier households in England between 2010 and 2011. Element Energy's objective in this project was to perform a comprehensive cluster analysis on the data from the Household Electricity Usage Study to group the 250 monitored households into a series of distinct consumer archetypes based on household attitudes to the environment, demographics, building details and electricity usage characteristics.

Approach

As part of the Household Electricity Usage Study, participants completed a survey including 29 questions on household attitudes and behaviours in relation to the environment, climate change and energy use. Factor analysis, which identifies the common themes underlying the survey questions, was used to condense the 29 survey questions into 3 factors on climate change and the environment:

- Current beliefs
- Current actions
- Beliefs about the future

These 3 factors were then combined with 9 further variables on household demographics, building characteristics and electricity use to complete the full set of clustering variables. These additional 9 variables were:

- National Readership Survey (NRS) social grade
- Household occupancy (i.e. the number of people living in each house)
- Building age
- Building floor area
- Number of electrical appliances

- Total electricity use per annum (excluding space heating[1])
- Percentage of electricity used in the 6-7pm peak period
- Appliance efficiency improvement potential (i.e. the electricity that could be saved by switching to modern energy efficient appliances such as those with classes of A+ or A++ and low standby power)
- Peak shift potential (i.e. the amount of electricity use that could feasibly be shifted out of the 6-7pm peak period)

Clustering analysis was performed using the software package, SPSS, via a multi-stage procedure involving hierarchical analysis (using Ward's method) and k-means analysis. The clustering methodology involves an iterative procedure to group the households so that the differences in attributes between groups are maximised and the differences within each group are minimised. The optimal variance between and within clusters was found to occur for a seven cluster solution.

The Seven Household Archetypes

The distribution of households across the seven household archetypes is shown below in Figure 1 and Table 1 gives a brief description of each of these clusters.

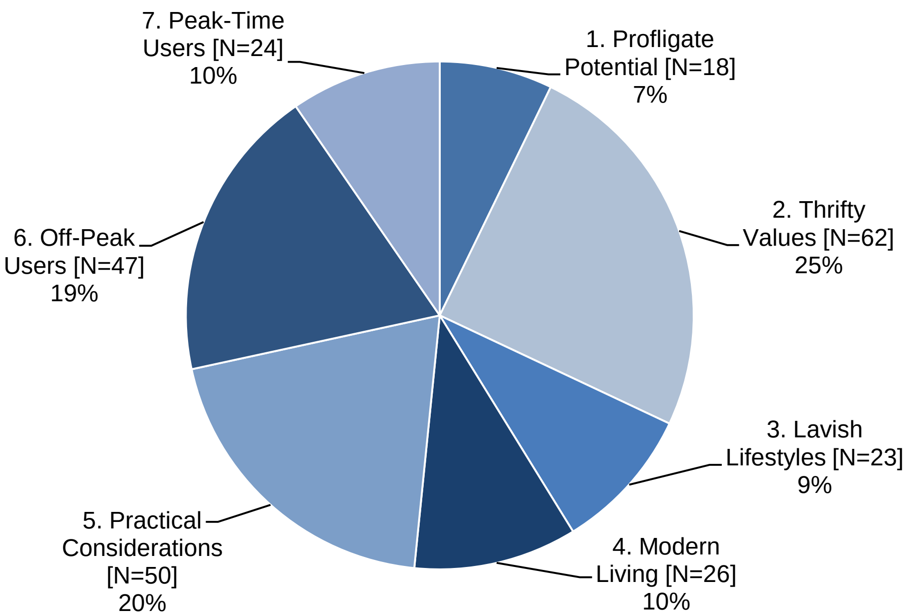

Figure 1: The relative size of each of the seven clusters produced for all households (N=250) in the Household Electricity Usage Study.

A more detailed profile of the specific characteristics of each group is provided in Table 2. This table includes the twelve variables used for the cluster analysis, and an

[1] Electricity use for space heating was not included in the total since many households were monitored outside of the November to March period in which space heating would typically be used.

additional variable describing the potential savings from switching heating fuel (or to a more efficient electric heating system) in each of the clusters. This additional variable could not be included in the clustering variables used for the cluster analysis because not all households were monitored in the November to March period in which space heating is generally used.

Table 1: Summary of the seven household archetypes.

1. Profligate Potential (7%) – these are high occupancy, low social grade households with the highest levels of electricity consumption and large numbers of inefficient appliances. While their beliefs may be relatively green, they are failing to put these into action and exhibit, by far, the greatest scope for appliance efficiency improvement.

2. Thrifty Values (25%) – this cluster consists of small, relatively low social grade households with few appliances and low levels of electricity use. Conservative electricity consumption is accompanied by non-green attitudes, indicating that the frugal focus of these households derives from cost-conscious values rather than environmental conservation.

3. Lavish Lifestyles (9%) – these are affluent households with the highest social grades and largest building floor areas. While they possess green beliefs, this is not reflected in their actions which are characterised by high electricity use and many appliances.

4. Modern Living (10%) – the small, predominately single occupant households in this cluster live in newly built homes and have medium to high social grades. These households use low levels of electricity which is well-aligned with their green actions and small household sizes.

5. Practical Considerations (20%) – these medium to high social grade households have the highest occupancy levels, yet still manage to constrain their total electricity usage to medium levels. These households have the lowest electricity use per person, reflecting the judicious use of electricity in densely occupied (i.e. lowest floor area per occupant) households with relatively green beliefs.

6. Off-Peak Users (19%) – these medium social grade households consume a small fraction of their total electricity use during the peak-time period. These households possess predominately retired respondents, which is linked to their off-peak electricity usage patterns.

7. Peak-Time Users (10%) – this cluster exhibits high levels of electricity use with a high fraction of this occurring during the peak-time period. These households have, by far, the highest peak shifting and fuel switching potential savings available, though their relatively non-green actions appear to be inhibiting the extent to which these are currently being realised.

Table 2: Characterising the seven household clusters. All quantities shown in brackets reflect the average value for the cluster.

		1. Profligate Potential	2. Thrifty Values	3. Lavish Lifestyles	4. Modern Living	5. Practical Considerations	6. Off-Peak Users	7. Peak-Time Users
Occupant Characteristics	Current beliefs (z-score)[2]	Very Green (0.36)	Not Green (-0.68)	Very Green (0.56)	Moderately Green (0.16)	Very Green (0.79)	Not Green (-0.35)	Moderately Green (-0.19)
	Current actions (z-score)[2]	Moderately Green (0.01)	Moderately Green (0.11)	Not Green (-1.25)	Very Green (0.65)	Moderately Green (0.00)	Very Green (0.22)	Not Green (-0.22)
	Beliefs about the future (z-score)[2]	Moderately Green (0.07)	Very Green (0.43)	Moderately Green (0.18)	Not Green (-0.41)	Very Green (0.27)	Not Green (-0.66)	Moderately Green (-0.15)
	Social grade (average NRS grade)	Low (C2)	Low (C2)	High (B)	High-Medium (B-C1)	High-Medium (B-C1)	Medium (C1)	Medium (C1)
	Household occupancy (average no. of people)	High (3.4)	Low (1.7)	High (3.3)	Low (1.2)	High (3.6)	Medium (1.9)	Medium (3.0)
Building Details	Building age (average age band)	Older (1930-1949)	Older (1930-1949)	Medium (1967-1975)	Newer (1983-1990)	Older (1930-1949)	Medium (1950-1966)	Medium (1967-1975)
	Building floor area (average m^2)	Medium (112)	Small (78)	Large (169)	Small (77)	Medium (107)	Medium (111)	Medium (97)
Electricity Usage	Electrical appliances (average no. of devices)	Many (53)	Few (27)	Many (53)	Few (31)	Medium (43)	Medium (48)	Medium (47)
	Total electricity use (kWh/year)	Very High (7839)	Low (2254)	High (5567)	Low (1868)	Medium (4084)	Medium (3491)	High (5871)
	Percentage of electricity used in the 6-7pm peak (%)	Low (5.6)	Medium (6.3)	High (6.9)	Medium (5.8)	Medium (6.2)	Low (5.5)	High (7.1)
Technical Potential	Efficiency potential (kWh/year)	Very High (1546)	Low (344)	High (719)	Low (323)	Medium (652)	Medium (516)	High (791)
	Peak shift potential (kWh/year)	Medium (31)	Low (11)	High (36)	Low (8)	Medium (24)	Low (14)	Very High (124)
	Fuel switch potential (kWh/year)	Medium (483)	Low (243)	High (530)	Very Low (62)	Low (321)	Medium (425)	Very High (1,049)

[2] The three factors are presented as z-scores (i.e. standardised scores) which indicate the number of standard deviations each household response differed from the mean response (which has a z-score of 0).

Conclusions and Recommendations

The unique characteristics of each of the seven household clusters (as defined by the demographic, behavioural and building characteristics in Table 2) make it possible to identify where different interventions could be best focused. We have examined the technical potentials (i.e. the maximum potential saving that could be achieved in each household archetype) for interventions relating to energy efficiency, peak shifting and heating fuel switching or optimisation. It should be noted that the technical potentials do not provide an indication of the likelihood of household change (which is linked more to other considerations such as lifestyle drivers), only the extent of the savings that are technically possible.

- Profligate Potential households offer by far the greatest technical potential for appliance efficiency savings with an average opportunity of 1546 kWh/year per household (about double that of any other cluster) or approximately 2.9 TWh/year nationally. When considered alongside the very green current beliefs of Profligate Potential households, there appears to be scope for uptake of appropriately targeted interventions. It is recommended that this household archetype be targeted for awareness raising and other policy interventions relating to energy efficiency.

- The medium levels of appliance efficiency savings potential per household (652 kWh/year) of the Practical Considerations cluster, when combined with their strong representation in the UK population (20%), yields a large potential for efficiency savings at the national level (3.4 TWh/year). Practical Considerations households also have very green current beliefs that may favourably predispose them towards appliance efficiency interventions. As such, this cluster should be considered a high priority group, alongside the Profligate Potential cluster, for energy efficiency interventions.

- The Peak-Time Users cluster offers, by far, the highest technical potential for shifting electricity use out of the evening peak demand period with a per household average capacity of 341 W during the 6-7pm peak (more than triple the next highest cluster) which equates to approximately 0.9 GW nationally. The Peak-Time Users cluster also offers the highest electricity savings for switching heating fuel (or to a more efficient electric heating system) – on average 1049 kWh/year per household and about 2.7 TWh/year nationally. However, these high technical potentials are combined with non-green current actions and only moderately green beliefs in this cluster indicating there may be limited willingness or motivation to address these areas at present. It is recommended that further work be conducted to investigate the drivers and incentives that could motivate households in the Peak-Time Users cluster to realise the high technical potentials of this household archetype, particularly in the context of future demand-side response strategies.

- The Lavish Lifestyles cluster also offers high heating fuel switching potential per household (530 kWh/year, which scales to about 1.3 TWh/year for the UK), the majority of which (82%), was from secondary electric space heating devices supporting a non-electric central heating system (i.e. natural gas or heating oil). This indicates significant potential for electricity savings by optimising use of the primary central heating system in this cluster (approximately 1.1 TWh/year across the UK) and it is recommended that awareness raising and other interventions in this area be targeted at this cluster. Such interventions will need to consider the lifestyle priorities (related to high social grades) that motivate this group and currently appear to hinder the adoption of environmentally friendly behaviours in this cluster.

- Finally, the well-defined clusters produced in this project offer excellent scope in future work for combining the household clusters with other low-carbon technology uptake and geographical mapping studies[3,4,5]. We recommend that future household studies examining low-carbon technology uptake, demand-side response strategies and policy impacts are structured so that they can be linked to the Household Electricity Usage Study clusters identified in this project, thereby revealing potential synergies with implications for policy development and grid management.

[3] Element Energy (2011) "Plug-in Vehicles Economics and Infrastructure: Quantifying Consumer Behaviour", for the Energy Technologies Institute.
[4] Element Energy (2009), "Strategies for the uptake of electric vehicles and associated infrastructure implications", for the Committee on Climate Change.
[5] Element Energy (2009), "Uptake of energy efficiency in buildings", for the Committee on Climate Change.

2 Introduction

The diversity and variation in electricity consumption between different households across the UK represents a significant barrier to understanding future energy consumption and policy impacts at anything but highly aggregated levels, where most of the detail and fidelity is lost. Sorting these households into several well-resolved and characterised groups makes it possible to explore national electricity usage trends at more disaggregated levels, revealing consumption patterns and policy opportunities for different consumer archetypes. At this level, the drivers and implications of consumption trends can be better understood, facilitating new insights into electricity usage and offering expanded opportunities to target policies and energy strategies that represent the needs of population sub-groups as well as the UK as a whole.

Cluster analysis is a statistical technique that allows households to be grouped on the basis of attributes such as demographics, attitudes and behaviour, where the differences in these attributes are minimised within each group and maximised between groups. This technique makes it possible to define categories of consumer archetypes based on multiple household characteristics, extending the scope of analysis beyond the limitations imposed by exploring each of these household metrics in isolation.

The Household Electricity Usage Study conducted by the Department of Energy and Climate Change (DECC), the Department for the Environment Food and Rural Affairs (Defra) and the Energy Saving Trust provides comprehensive data on the electricity usage patterns of 250 owner-occupier households in England between 2010 and 2011. Element Energy's objective in this project was to perform a comprehensive cluster analysis on the data from the Household Electricity Usage Study to group the 250 monitored households into a series of distinct consumer archetypes based on household attitudes to the environment, demographics, building details and electricity usage characteristics.

To accurately identify consumer archetypes within national electricity consumption, it is necessary to gather comprehensive data across a range of individual households that are representative of the entire population. Between 2010 and 2011, the Department of Energy and Climate Change (DECC), the Department for the Environment Food and Rural Affairs (Defra) and the Energy Saving Trust carried out a comprehensive study into the electricity usage behaviour of 250 owner-occupier households in England. Over the course of this investigation, referred to as the Household Electricity Usage Study, a large dataset was assembled characterising the appliance and electricity usage patterns of each monitored household, as well as various details about the occupants and the building in which they live.

In this report, we use the comprehensive Household Electricity Usage Study dataset to determine a set of household archetypes (also referred to as clusters) that, in aggregate, represent consumption at the national level. We also provide a robust characterisation of each household archetype which includes pertinent details on the demographics and attitudes of the occupants, their home and the way in which they use electricity. Using these well-defined clusters, it is then possible to identify which segments of the population are likely to offer the best opportunities for deploying various policies, demand-side response strategies and energy efficiency measures.

3 Methodology

The identification of household clusters within the Household Electricity Usage dataset involved a series of aggregation, analysis and interpretation steps as detailed below. Fundamentally, this process involved identifying and preparing appropriate variables on which to base the clustering analysis and then performing the statistical analysis itself.

3.1 Step 1: Factor Analysis

As part of the Household Electricity Usage Study, participants completed a Background Details Questionnaire including 29 attitudinal and behavioural questions as well as 5 demographic questions. These questions give an insight into the environmental beliefs and actions of the household occupants (though this is limited to the respondent that happened to complete the survey for each household) and as such were considered an important inclusion in the cluster analysis.

However, the inclusion of all the survey questions as separate variables in the cluster analysis would have given this aspect of the household an overly large weighting relative to the other pertinent household characteristics. The nature of the survey meant that many of the questions probed similar themes, providing the opportunity to condense these questions into a smaller number of factors which collate the findings along these common themes.

The 29 attitudinal and behavioural questions were selected for the factor analysis, with the five demographic questions being kept aside for separate analysis. To retain as much of the questionnaire data as possible, the few instances of missing answers (less than 5% or responses for each question) were substituted with the mean – an approach commonly used in these kinds of studies when the proportion of missing values represents less than 5% of the sample[6].

The assembled survey answers were subjected to a factor analysis using the principal component methodology (in a statistical package called SPSS) in order to reduce them to a smaller set of underlying factors. The fundamental assumption underlying the factor analysis is that variables showing similar patterns of variation across respondents are assumed to be associated with the same underlying factor. To determine the number of factors that best fits the data, Cattell's scree test was employed which suggests using the number of factors that corresponds to the start of the 'elbow' in the scree plot (shown in Figure 2)[7].

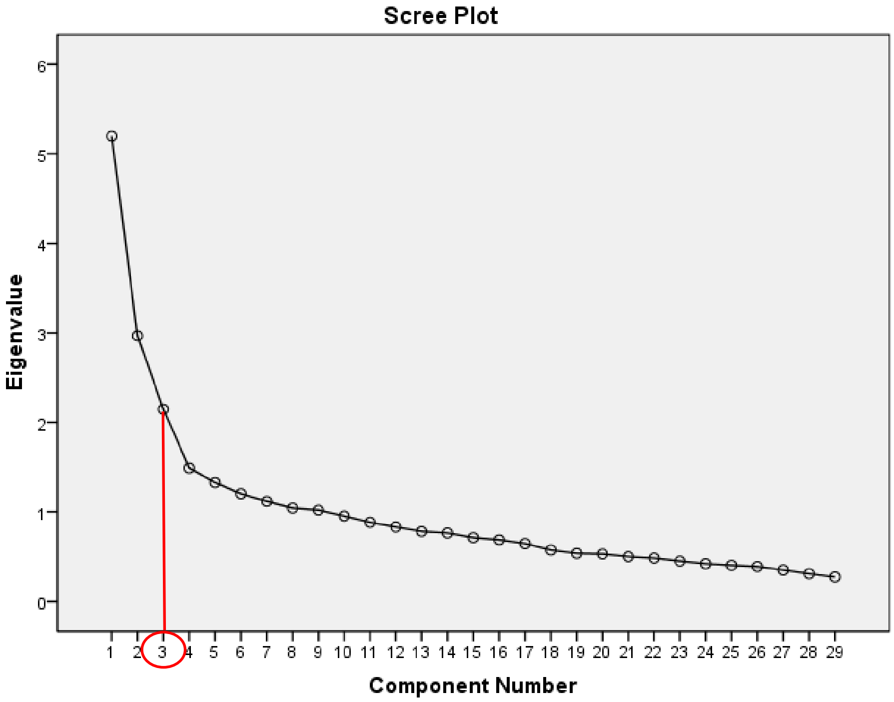

Figure 2: Scree plot showing the 'elbow' in eigenvalues (which represent the variance accounted for by each underlying factor) as the number of factors increased.

Since the position of the 'elbow' in Figure 2 is relatively subjective, the choice of 3 factors in this study was supported by additional testing of the fit for 2, 4 and higher factors. 3 factors gave the most relevant split of the survey

6 Schafer, J. L. (1999), "Multiple imputation: A primer", *Statistical Methods in Medical Research*, 8, 3–15.
7 Cattell, R. B. (1966), "The Scree Test for the Number of Factors" *Multivariate Behavioral Research,* 1(2), 245-276

questions for the purposes of this study. The 3 factors produced are summarised in Table 3 and further information on the allocation of each of the 29 survey questions into each of these 3 factors can be found in Appendix A.

Table 3: Outline of the three questionnaire factors.

Factor	Significance
Current beliefs	Level of concern regarding climate change and its causes
Current actions	Efficiency of resource use and electricity conservation in daily actions around the house
Beliefs about the future	Concern for future resource limitations and beliefs about future 'user-pays' taxation scenarios

The adequacy of the factors obtained was tested with the Kaiser-Meyer-Olkin measure of sampling adequacy (usually called the KMO) and the Bartlett test of sphericity. For both of these tests, the factor analysis performed in this study was found to be well within the required tolerances[8,9,10].

After confirming the validity of the factors produced, the aggregated results captured by the three factors were then retained for use as three of the input variables in the cluster analysis capturing household beliefs and actions with regard to climate change, the environment and energy conservation.

3.2 Step 2: Identifying the Clustering Variables

In addition to the 3 factors determined in Step 1 on household beliefs and actions, it was necessary to collate further data which captured relevant demographic, building, electricity usage and electricity savings potential information for each household. The objective here was to assemble a concise set of relevant and discriminating variables, without over-representing similar or highly correlated household characteristics (which would effectively weight these characteristics more heavily in the clusters produced).

[8] The KMO indicates the magnitude of partial correlations among variables with values ranging from zero to one. A large KMO value (>0.7) indicates a strong correlation between the variables, whereas a value below 0.5 indicates a low correlation amongst variables, reducing the relevance of the factor analysis. For this study, a KMO value of 0.798 was obtained, indicating that the factor analysis offered excellent correlation. Bartlett's test of sphericity checks whether the variables are correlated in the population (i.e. the 250 households) and therefore appropriate for factor analysis. The significance value obtained in the Bartlett's test of sphericity was several orders of magnitude less than minimum significance (0.050) considered suitable for this test.

[9] Kaiser, H. (1974), "An index of factorial simplicity", *Psychometrika*, 39, 31–6.

[10] Bartlett, M.S. (1954), "A note on the multiplying factors for various chi square approximations", *Journal of the Royal Statistical Society*, 16 (Series B), 296–8.

The resulting 12 variables selected for the cluster analysis were as follows:

5 Occupant Characteristics

- The 3 questionnaire factors from Table 3 on attitudes towards the environment (current beliefs, current actions and beliefs about the future)
- National Readership Survey (NRS) social grade
- Household occupancy (i.e. the number of people living in each house)

2 Building Characteristics

- Building age
- Building floor area

3 Electricity Usage Characteristics

- Number of electrical appliances
- Total electricity use per annum[11]
- Percentage of electricity used in the 6-7pm peak period

2 Technical Potential Characteristics

- Appliance efficiency improvement potential (i.e. the electricity that could be saved by switching to modern efficient appliances such as those with classes of A+ or A++ and low standby power – see Chapter 4.5.1 for a more detailed definition)
- Peak shift potential (i.e. the amount of electricity use that could feasibly be shifted out of the 6-7pm peak period – see Chapter 4.5.2 for a more detailed definition)

To ensure that no two of these variables were overly correlated with each other (resulting in overrepresentation of that particular household characteristic in the clustering solution) the correlation between each of the clustering variables was determined. It is generally recognised that absolute correlations above 0.9 should be avoided, and all variable correlations within

[11] Electricity use for space heating was not included in the annual total since many households were monitored outside the colder months (November to March) in which space heating would typically be used. For all other appliance types that were typically used throughout the year, a seasonality factor (determined from the 26 households that were monitored for the whole year) was used to estimate the annual electricity use for the 224 households that were monitored for only a month. For further information on the seasonality factor process and calculation of annual electricity use in this dataset, see: Cambridge Architectural Research, Element Energy and Loughborough University (2013), "Further Analysis of the Household Electricity Use Survey – Electrical Appliances at Home: Tuning in to Energy Saving", for DECC and Defra.

this study were found to be within this threshold (see Appendix B), indicating that there was no problematic levels of collinearity between the clustering variables – i.e. they were all sufficiently unique[12].

3.3 Step 3: Cluster Analysis

Cluster analysis is a frequently used method for market segmentation. This technique consists of grouping cases into clusters (sometimes referred to as segments, archetypes or groups) in such a way that objects in the same cluster are more alike to each other than to those in other clusters. This involves maximising the differences between groups whilst simultaneously minimising the differences within a group.

Several clustering models exist, all with the same underlying construct, but each with a different set of strengths and specifications. It is widely accepted that a two-stage approach involving hierarchical and k-means (non-hierarchical) clustering offers an optimal solution for the kind of data used in this study[13]. Non-hierarchical procedures are typically employed for large datasets, with k-means being a preferred non-hierarchical method for its excellent performance when a non-random starting point can be specified. A hierarchical procedure, which determines a grouping hierarchy as shown in Figure 3, represents a useful technique for determining this starting point.

Therefore, the two-stage procedure utilised in this study began with a hierarchical analysis to determine the cluster centres (i.e. starting points) that were then used in the subsequent k-means analysis. Both the hierarchical and k-means analysis were performed with SPSS.

3.3.1 Hierarchical Clustering

The objective of this process is to reveal the structure of the clusters that best represent the data. The hierarchical algorithm generates a series of solutions ranging from *n* clusters, where *n* is the total number of objects (i.e. 250 households) in the dataset, to a solution with only one cluster.

Within the hierarchical clustering, Ward's method was used to maximise homogeneity within the clusters. Ward's method is a frequently used criterion, which minimises the variance within the clusters to efficiently sort the households for each number of clusters tested (i.e. between 1 and 250)[14].

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[12] Mooi, E. and Sarstedt, M. (2011), "A Concise Guide to Market Research", Springer-Verlag, Berlin.

[13] Ketchen, D. J. & Shook, C. L. (1996), "The application of cluster analysis in strategic management research: an analysis and critique", *Strategic Management Journal*, 17(6), 441–458.

[14] Punj, G. & Stewart, D.W (1983), "Cluster Analysis in Marketing Research: Review and Suggestions", *Journal of Marketing Research*, 20, 134–148.

The outputs from this process are a dendrogram (Figure 3) that illustrates how the 250 households were aggregated, using Ward’s method, into the various cluster sizes, along with the cluster centres that apply in each case. It is these cluster centres (i.e. the mean for all members of each cluster) that were then used in the following k-means analysis.

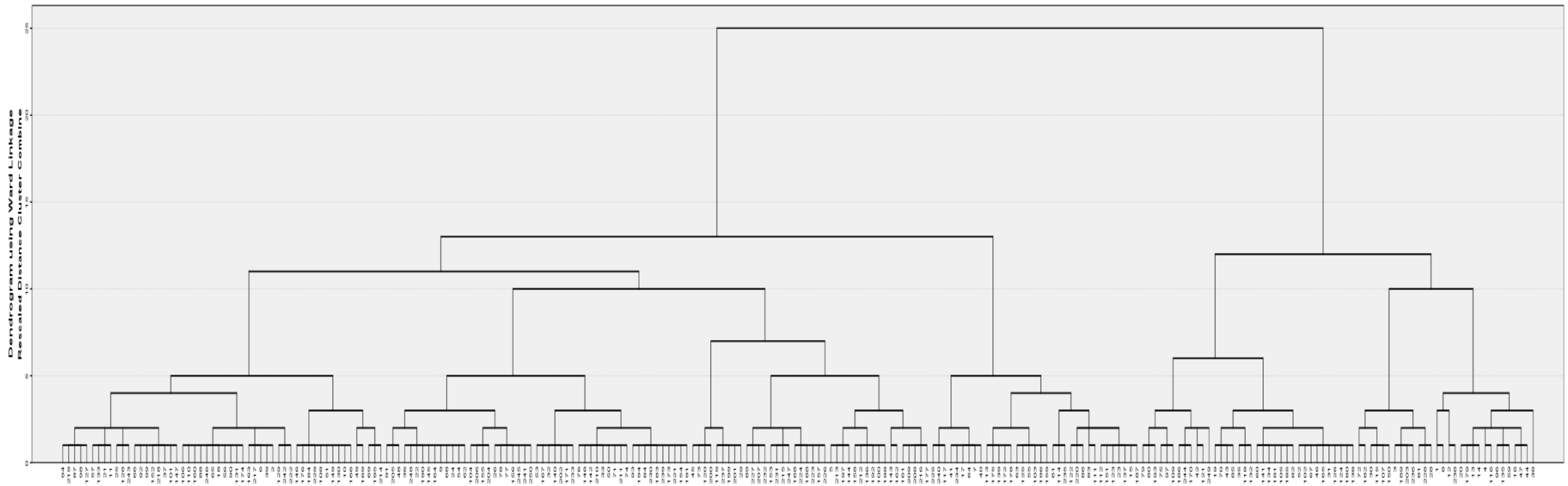

Figure 3: Dendrogram showing the hierarchical aggregation of the 250 households using Ward's method into clusters of different sizes.

3.3.2 K-Means Clustering

The cluster centres from the hierarchical analysis were then used as starting points for k-means clustering. Various numbers of clusters were run using the k-means approach in which each household was assigned to the cluster with the closest cluster centre. The k-means methodology then re-computes the cluster mean and reassigns households with the goal of minimising the variability within clusters whilst maximising the variability between clusters. During each re-calculation, households are moved from one cluster to another in search of a more homogeneous cluster.

An Analysis of Variance (ANOVA) procedure was used to examine the variability of the observations within each cluster as well as the variability between cluster centres, the ratio of which is called an F ratio (or F value). The higher the F ratio, the higher the variability between clusters compared to within them and the more discrete and concentrated are the groupings.

For determining the optimal number of clusters, a derivative of the F ratio is often used, such as the Variance Ratio Criterion (VRC)[15,16]. The VRC is calculated by adding the total F values for each variable in a cluster. The optimal number of clusters is then determined by comparing the variation in VRC between neighbouring numbers of cluster as given by ω_k in the equation below:

$$\omega_k = (VRC_{k+1} - VRC_k) - (VRC_k - VRC_{k-1})$$

Where:

$$VRC = \text{The Variance Ratio Criterion}$$
$$k = \text{The number of clusters}$$

An ANOVA was performed for cluster solutions of up to 17 clusters and the VRC was calculated for each case. The most promising ω_k values were obtained for between 5 and 10 clusters and are shown in Table 4. This procedure indicated that the 7 cluster solution had the lowest ω_k and was, therefore, the optimal solution. The 9 cluster solution offered the next lowest ω_k value, however, in this case the increased number of clusters resulted in the formation of several groups containing only a few households which were too small for meaningful analysis in the context of this study.

[15] Calinski, T. and Harabasz, J. (1974), “A dendrite method for cluster analysis” *Commun Stat Theory Methods,* 3(1):1–27.

[16] Milligan, G. W. and Cooper, M. C.(1985), “An examination of procedures for determining the number of clusters in a data set”, *Psychometrika*, 50, 159–179.

Table 4: F ratio scores for each of the cluster solutions along with the VRC and ω_k values derived from these.

Name of Variable	5 Clusters	6 Clusters	7 Clusters	8 Clusters	9 Clusters	10 Clusters
Current beliefs	18.13	18.74	18.13	22.43	19.61	17.17
Current actions	25.14	19.62	10.45	9.25	8.58	10.33
Beliefs about the future	8.62	8.80	8.09	8.81	8.63	11.67
House age	11.46	8.19	16.17	13.80	19.06	20.92
Household occupancy	40.55	31.28	32.16	26.73	23.83	21.27
Building floor area	47.59	32.96	31.52	27.32	38.69	34.81
Household social grade	18.62	20.70	16.33	16.47	14.34	13.42
Number of electrical appliances	39.04	36.27	39.98	31.04	26.00	20.92
Electricity use per annum	48.68	68.14	69.15	57.92	47.13	40.94
Percentage of electricity used in the 6-7pm peak period	6.44	6.57	2.89	10.15	8.42	9.10
Peak shift potential	160.01	127.18	105.82	93.35	79.52	70.97
Appliance efficiency potential	19.43	30.17	25.49	21.81	18.98	16.41
Total (i.e. the Variance Ratio Criterion)	443.77	408.69	376.23	339.12	312.86	287.98
ω_k	36.64	2.62	-4.65	10.84	1.38	14.27

3.4 Step 4: Interpreting and Profiling the Clusters

Once the number of clusters and the distribution of households between them were determined in the previous steps, it was useful to obtain a sense of the relative contribution of each clustering variable to the clusters formed and the distinctions between them. Table 5 ranks each variable according to their F values (i.e. the ratio of their variability between clusters to variability within each cluster) and, consequently, their importance in defining the clusters. The variables characterising technical electricity savings potential, total electricity usage and the building characteristics were found to rank highly in their impact on the household clusters. Table 5 also shows that the significance levels for all the variables were less than

0.05 indicating a clear distinction between the seven clusters in each case[17].

Table 5: Ranking of variables in terms of their importance in defining the cluster solution.

Rank	Variable	F value	Sig.[18]
1	Peak shift potential	105.828	.000
2	Electricity use per annum	69.157	.000
3	Number of electrical appliances	39.983	.000
4	Household occupancy	32.161	.000
5	Building floor area	31.529	.000
6	Appliance efficiency potential	25.495	.000
7	Current beliefs	18.135	.000
8	Household social grade	16.330	.000
9	Building age	16.174	.000
10	Current actions	10.458	.000
11	Beliefs about the future	8.096	.000
12	Percentage of electricity used in the peak period	2.892	.010

Finally, to better understand the distribution of household characteristics across the seven clusters, along with the implications for policy development and energy strategy, the cluster profiles were examined for each of the cluster variables along with several other relevant metrics from the Household Electricity Usage Study. The details of how each of these variables are distributed across the seven clusters are explored in the following chapter.

4 Profiles of the Household Archetypes

Each of the seven household clusters produced in this study can be thought of as archetypes that categorise the households across the UK (though the study households were technically all within England). To better understand the nature and composition of these archetypes, this

[17] Pallant, J. (2011), "SPSS Survival Manual", Allen Unwin, 253-4.
[18] The significance levels reported reflect the statistical significance of the differences between clusters for each variable. Values of less than 0.05 reflect a significant distinction between each of the seven clusters for the clustering variable in question.

chapter provides a general overview of the attributes of each cluster and then compares in more detail how these qualities vary between the seven archetypes.

The household characteristics examined include all the clustering variables as well as several other interesting parameters available in the Household Electricity Usage Study dataset that were not appropriate for use in the clustering process. These characteristics cover many aspects of the occupants (including their demographics, attitudes and behaviours), the buildings in which they live, how they use electricity and the savings potential available in their electricity consumption. This latter aspect has many important implications for demand forecasting, demand-side response strategies, energy efficiency improvement and policy development.

4.1 Overview of the Household Archetypes

The distribution of the 250 monitored households across the seven clusters is shown below in Figure 4.

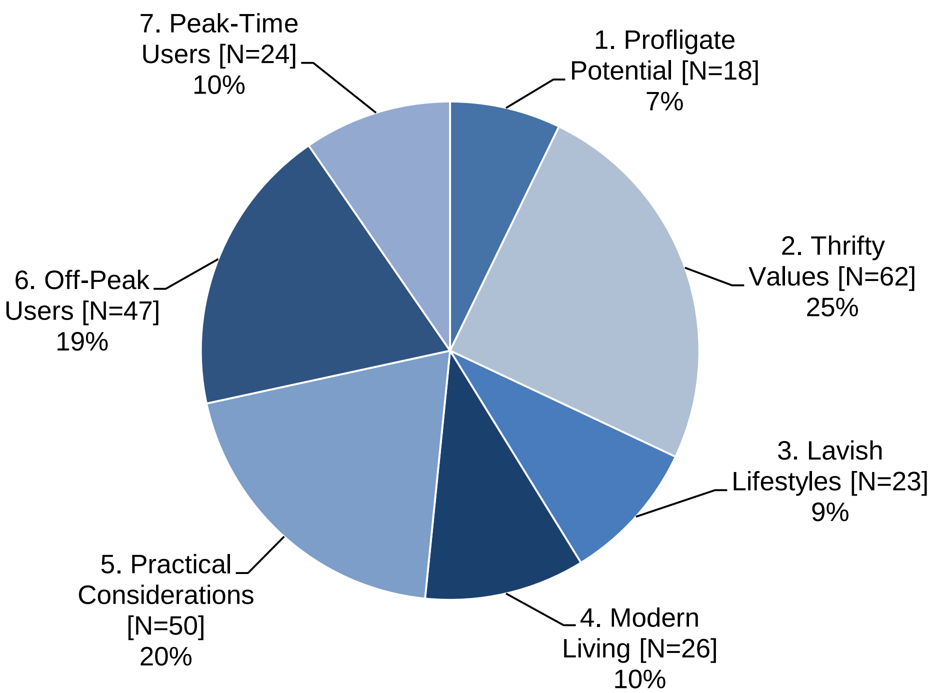

Figure 4: The relative size of each of the seven clusters produced for all households (N=250) in the Household Electricity Usage Study.

As a top-level overview, each of the seven clusters can be summarised as follows:

1. Profligate Potential (7%) – these are high occupancy, low social grade households with the highest levels of electricity consumption and large numbers of inefficient appliances. While their beliefs may be relatively green, they are failing to put these into action and exhibit, by far, the greatest scope for appliance efficiency improvement.

2. Thrifty Values (25%) – this cluster consists of small, relatively low social grade households with few appliances and low levels of electricity use. Conservative electricity consumption is accompanied by non-green attitudes, indicating that the frugal focus of these households derives from cost-conscious values rather than environmental conservation.

3. Lavish Lifestyles (9%) – these are affluent households with the highest social grades and largest building floor areas. While they possess green beliefs, this is not reflected in their actions which are characterised by high electricity use and many appliances.

4. Modern Living (10%) – the small, predominately single occupant households in this cluster live in newly built homes and have medium to high social grades. These households use low levels of electricity which is well-aligned with their green actions and small household sizes.

5. Practical Considerations (20%) – these medium to high social grade households have the highest occupancy levels, yet still manage to constrain their total electricity usage to medium levels. These households have the lowest electricity use per person, reflecting the judicious use of electricity in densely occupied (i.e. lowest floor area per occupant) households with relatively green beliefs.

6. Off-Peak Users (19%) – these medium social grade households consume a small fraction of their total electricity use during the peak-time period. These households possess predominately retired respondents, which is linked to their off-peak electricity usage patterns.

7. Peak-Time Users (10%) – this cluster exhibits high levels of electricity use with a high fraction of this occurring during the peak-time period. These households have, by far, the highest peak shifting and fuel switching potential savings available, though their relatively non-green actions appear to be inhibiting the extent to which these are currently being realised.

A more detailed profile of the specific characteristics of each cluster can be found in Table 6. This table includes the twelve variables used for the cluster analysis, and an additional variable describing the potential savings from switching heating fuel in each of the clusters. This additional variable could not be included in the clustering variables for the cluster analysis because not all households were monitored in the November to March period in which space heating is generally employed (i.e. if this variable were included in the cluster analysis, many households would have been unnecessarily excluded). However, the average value for this variable (from the households in each cluster that were monitored during the November to March period) provides a useful estimate of the savings potential available from switching heating fuel for each cluster.

Table 6: Characterising the seven household clusters. All quantities shown in brackets reflect the average value for the cluster.

		1. Profligate Potential	2. Thrifty Values	3. Lavish Lifestyles	4. Modern Living	5. Practical Considerations	6. Off-Peak Users	7. Peak-Time Users
Occupant Characteristics	Current beliefs (z-score)[19]	Very Green (0.36)	Not Green (-0.68)	Very Green (0.56)	Moderately Green (0.16)	Very Green (0.79)	Not Green (-0.35)	Moderately Green (-0.19)
	Current actions (z-score)[19]	Moderately Green (0.01)	Moderately Green (0.11)	Not Green (-1.25)	Very Green (0.65)	Moderately Green (0.00)	Very Green (0.22)	Not Green (-0.22)
	Beliefs about the future (z-score)[19]	Moderately Green (0.07)	Very Green (0.43)	Moderately Green (0.18)	Not Green (-0.41)	Very Green (0.27)	Not Green (-0.66)	Moderately Green (-0.15)
	Social grade (average NRS grade)	Low (C2)	Low (C2)	High (B)	High-Medium (B-C1)	High-Medium (B-C1)	Medium (C1)	Medium (C1)
	Household occupancy (average no. of people)	High (3.4)	Low (1.7)	High (3.3)	Low (1.2)	High (3.6)	Medium (1.9)	Medium (3.0)
Building Details	Building age (average age band)	Older (1930-1949)	Older (1930-1949)	Medium (1967-1975)	Newer (1983-1990)	Older (1930-1949)	Medium (1950-1966)	Medium (1967-1975)
	Building floor area (average m^2)	Medium (112)	Small (78)	Large (169)	Small (77)	Medium (107)	Medium (111)	Medium (97)
Electricity Usage	Electrical appliances (average no. of devices)	Many (53)	Few (27)	Many (53)	Few (31)	Medium (43)	Medium (48)	Medium (47)
	Total electricity use (kWh/year)	Very High (7839)	Low (2254)	High (5567)	Low (1868)	Medium (4084)	Medium (3491)	High (5871)
	Percentage of electricity used in the 6-7pm peak (%)	Low (5.6)	Medium (6.3)	High (6.9)	Medium (5.8)	Medium (6.2)	Low (5.5)	High (7.1)
Technical Potential	Efficiency potential (kWh/year)	Very High (1546)	Low (344)	High (719)	Low (323)	Medium (652)	Medium (516)	High (791)
	Peak shift potential (kWh/year)	Medium (31)	Low (11)	High (36)	Low (8)	Medium (24)	Low (14)	Very High (124)
	Fuel switch potential (kWh/year)	Medium (483)	Low (243)	High (530)	Very Low (62)	Low (321)	Medium (425)	Very High (1,049)

[19] The three factors are presented as z-scores (i.e. standardised scores) which indicate the number of standard deviations each household response differed from the mean response (which has a z-score of 0).

4.2 Occupant Characteristics

This section explores in greater detail how the occupant characteristics varied between clusters. In addition to the clustering variables in this category (attitude towards the environment, social grade, household occupancy), four further occupant characteristics (household type, respondent age, respondent gender and respondent working status) are included in this section. It should be noted that the age, gender and working status information only applies to the respondent that completed the questionnaire for each household – i.e. they are respondent specific rather than household averages.

4.2.1 Attitude towards the Environment

The variation in the three environmental attitude factors (as determined in Step 1 of the methodology: 'current beliefs', 'current actions' and 'beliefs about the future') across each of the seven clusters is shown below in Figure 5. It can be seen that environmentally friendly beliefs (i.e. 'current beliefs' and 'beliefs about the future') do not necessarily correlate with environmentally friendly 'current actions' for several clusters. It appears that other lifestyle priorities (in some cases linked with social grade) also play an important role in determining how beliefs translate into actions.

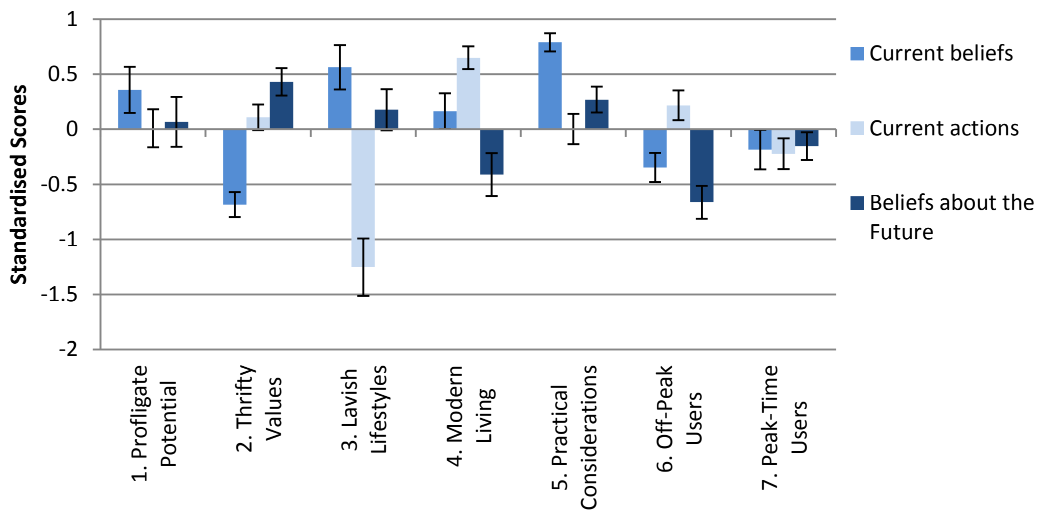

Figure 5: Comparison of the environmental attitude factors determined from the answers to the Background Details Questionnaire completed by the 250 surveyed households[20].

[20] The three factors are presented as standardised scores (i.e. z-scores) which indicate the number of standard deviations each household response differed from the mean response (which has a z-score of 0).

4.2.2 Social Grade

The Household Electricity Usage Study makes use of the National Readership Survey (NRS) social grading classification system as outlined below in Table 7.

Table 7: The NRS Grading System.[21]

Social Grade	Primary Income Earner's Occupation	% of Study Households[22]	% of UK Population
A	Higher managerial, administrative or professional	5	4
B	Intermediate managerial, administrative or professional	27	22
C1	Supervisory, clerical and junior managerial, administrative or professional	37	29
C2	Skilled manual workers	17	21
D	Semi and unskilled manual workers	9	15
E	State pensioners, casual or lowest grade workers, unemployed with state benefits only	4	8

The distribution of social grades in the seven household clusters is shown below in Figure 6. The Lavish Lifestyles cluster has by far the highest social grade group, predominantly characterized by social grades A and B. On the other hand, the Profligate Potential cluster represents the lowest social grade group, with approximately 6% of its households in social grade A or B, and the majority of the households being of social grade C2 or lower.

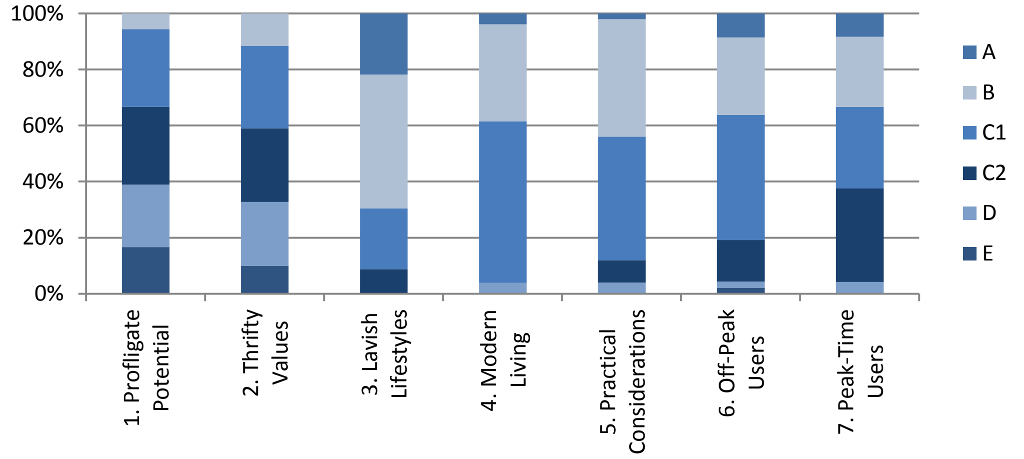

Figure 6: NRS social grade distribution for each household cluster.

[21] National Readership Survey, 2010. Available from http://www.nrs.co.uk/lifestyle-data/

[22] The correlation in demographic characteristics of the sample of 250 households in the Household Electricity Usage Study with broader national trends is discussed in greater detail in the AEA report "Household Electricity Survey: A study of domestic electrical product usage" for DECC, Defra and the EST.

4.2.3 Household Occupancy

The average household occupancy across all clusters was 2.5 people per household. As might be expected, household occupancy showed some correlation with the number of appliances and total electricity usage (Appendix B).

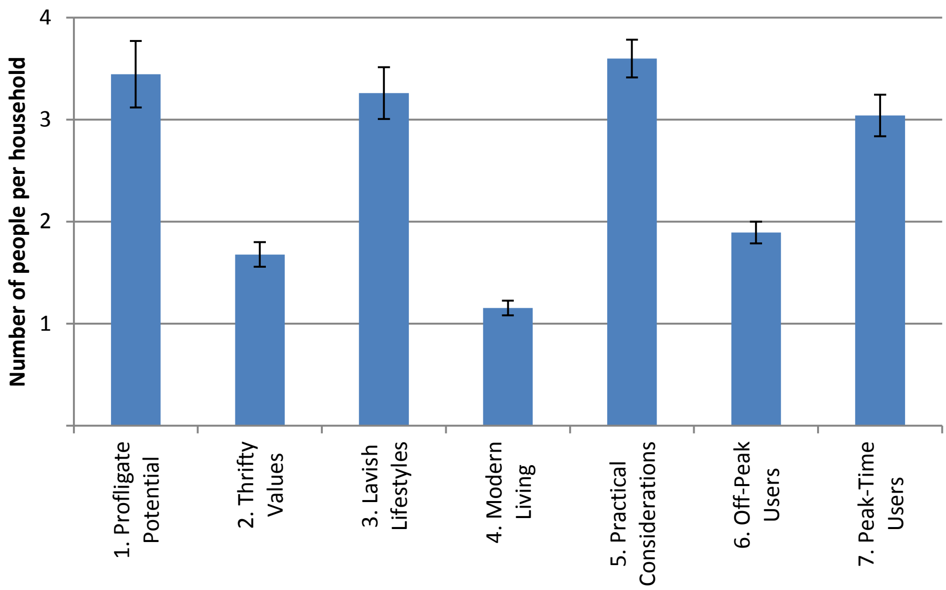

Figure 7: Average household occupancy for each cluster.

4.2.4 Household Type

The distribution of household types across each cluster can be seen in Figure 8. The 5 household types shown correspond to the classification system used in the Household Electricity Usage Study. The occupancy levels shown in Figure 7 are well correlated to the distribution of household types shown in Figure 8 with clusters containing high proportions of households with children and multiple person households with no dependent children having the highest occupancy levels (i.e. Practical Considerations, Profligate Potential, Lavish Lifestyles and Peak-Time Users). Similarly, clusters with a large fraction of single occupant household types had the lowest occupancy levels (i.e. Modern Living and Thrifty Values).

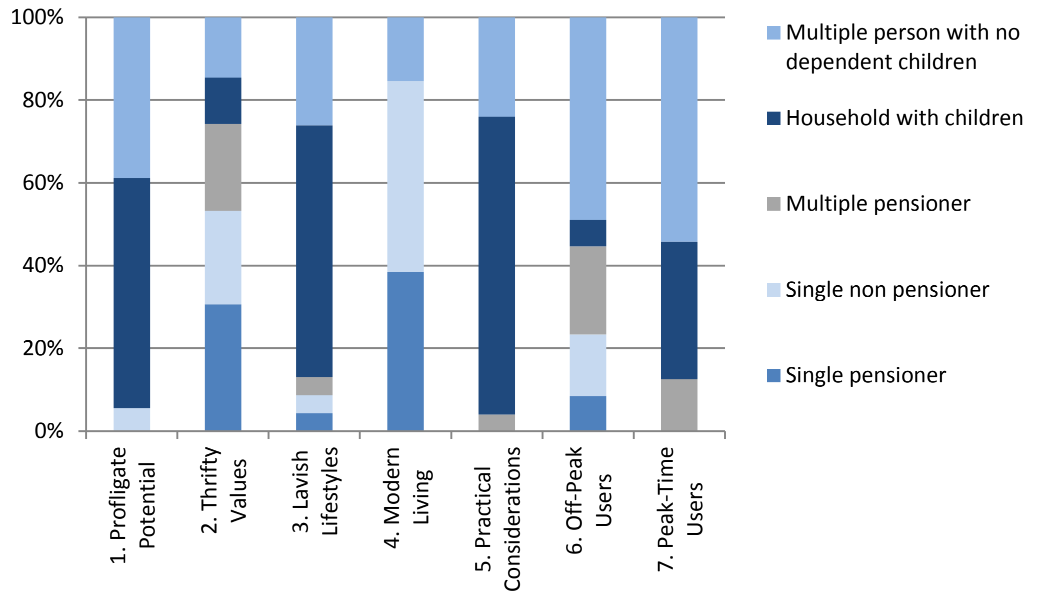

Figure 8: The distribution of household types for each cluster.

4.2.5 Respondents' Age, Gender and Working Status

As discussed above, the respondent variables are of limited relevance in this analysis since they reflect the specific characteristics of the single household member who completed the questionnaire rather than the average for that household. Therefore, for aspects such as age, gender and working status, the answers could vary significantly depending on which household member completed the survey. Nonetheless, we include these variables here as they provide a useful indication in these areas where more accurate household information is not available.

Age

Most clusters exhibited a broad distribution of age ranges (Figure 9), though the Profligate Potential cluster had over 50% of respondents in the 45-54 age range and the Off-Peak Users cluster showed a strong bias to older age ranges with 83% of respondents 55 years or older and no respondents under 35 years of age. The Thrifty Values cluster also exhibited a bias towards older age groups with 69% of respondents being at least 55 years old. A generally low representation of the youngest 19-24 age band across all households may be indicative of the low owner-occupier characteristics of this age range.

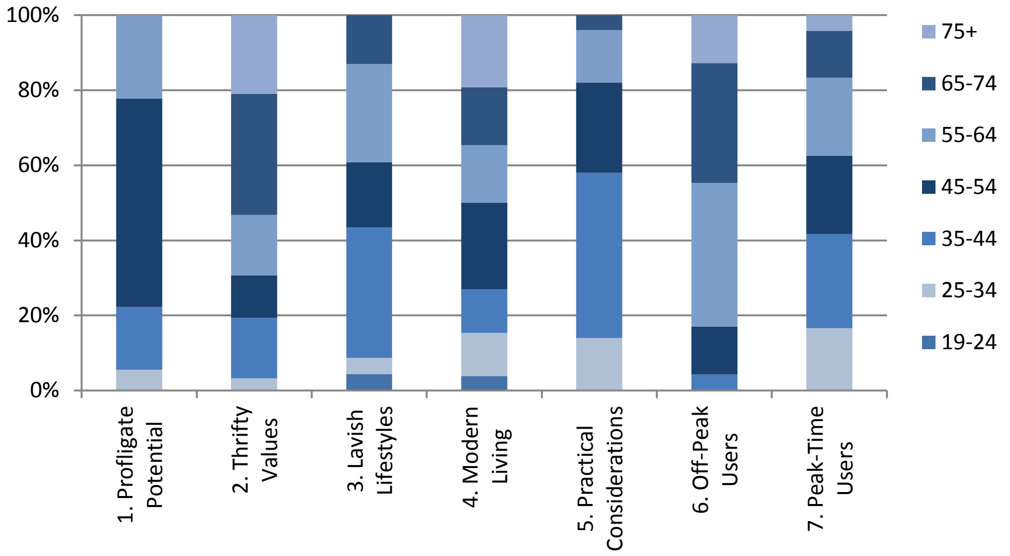

Figure 9: The distribution of respondents' age for each cluster.

Gender

The findings around respondent gender indicate that the survey responses were broadly mixed with some biases for several clusters (Figure 10) relative to the study average of 53% female respondents. It is impossible to tell if these biases between clusters were due to gender biases within the households or simply the household member that completed the survey. In any case, they are not likely to have significant ramifications for the purposes of the clustering analysis.

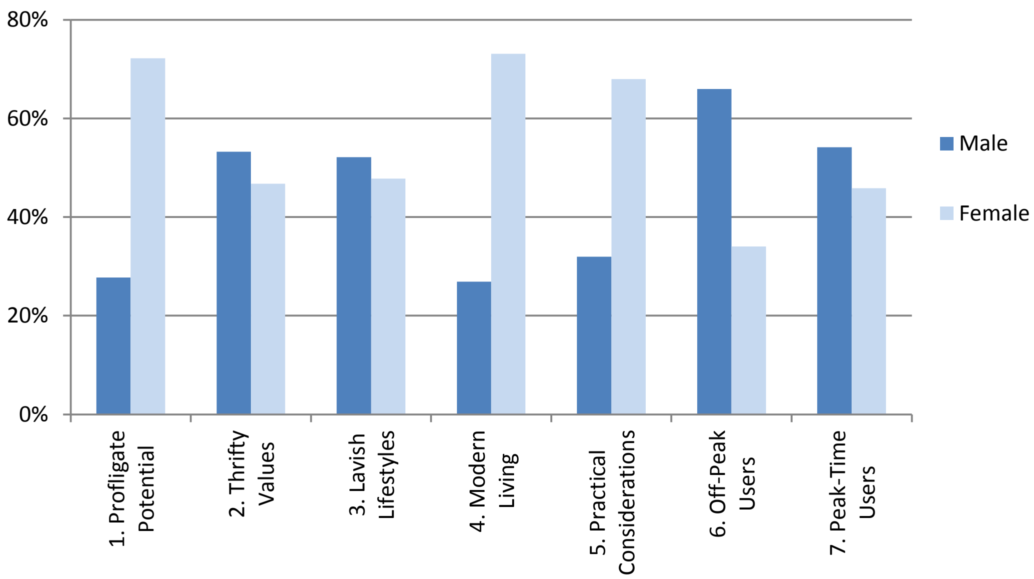

Figure 10: The distribution of respondents' gender for each cluster.

Working Status

The working status responses for each cluster were diversely distributed (Figure 11). It is worth noting that the Off-Peak Users, Thrifty Values and Modern Living clusters exhibited high proportions of retired respondents (64%, 56% and 50% respectively).

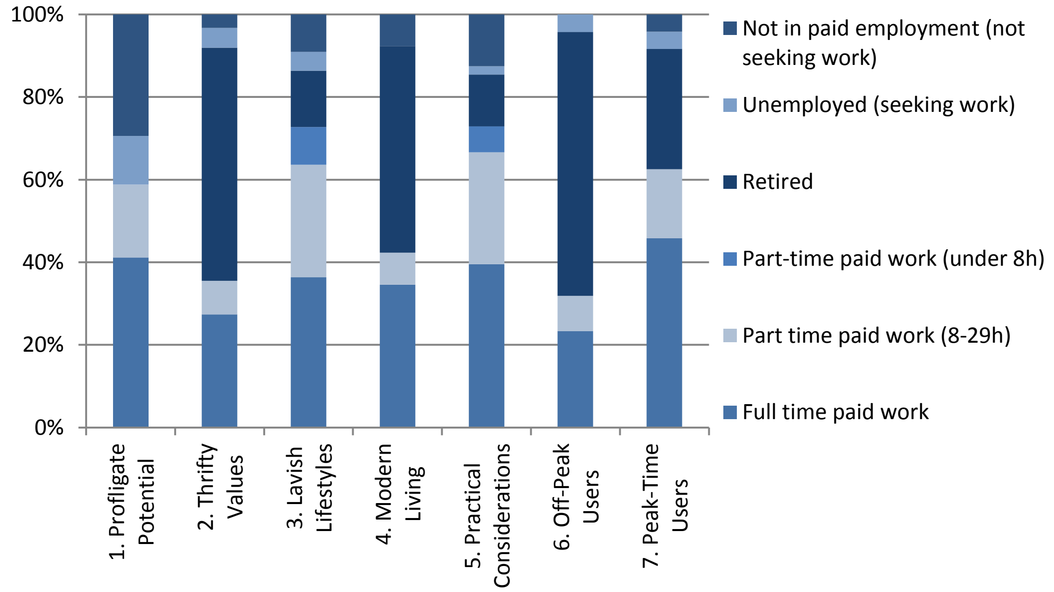

Figure 11: The distribution of respondents' working status for each cluster.

4.3 Building Details

In this section, the 2 clustering variables on building details (building age and floor area) are supplemented with 3 additional variables characterising the type of property, the terrain and heating fuel.

4.3.1 Building Age

Most of the clusters encompass a broad distribution of building ages (Figure 12) with the exception of the Modern Living cluster which was heavily weighted towards newer houses (68% of the homes in this cluster were built after 1983). In contrast, the homes in the Profligate Potential cluster tended towards older builds with 94% of the houses in this cluster built before 1966.

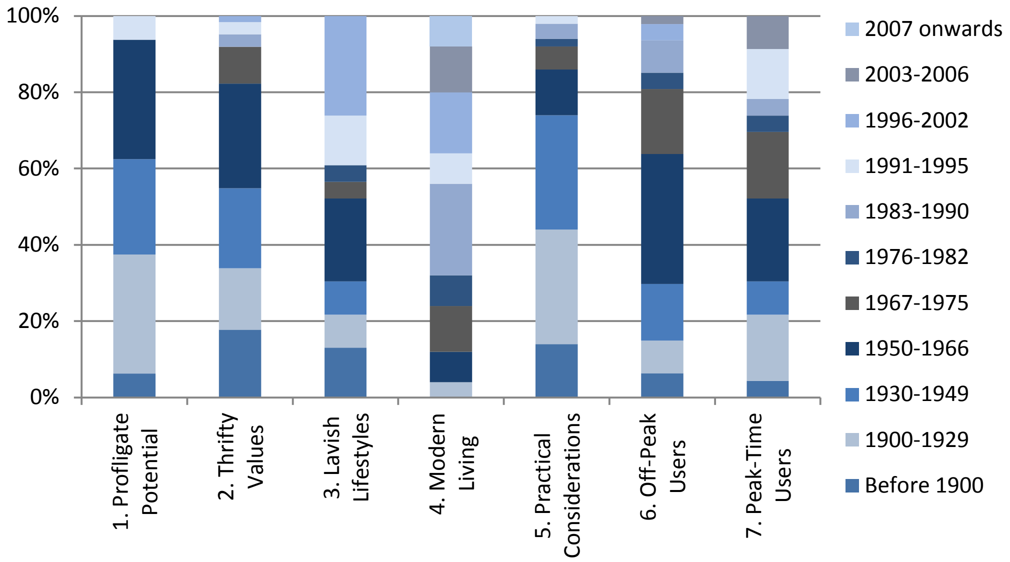

Figure 12: Building age distribution for each household cluster.

4.3.2 Building Floor Area

The average building floor area in the study was 102 m^2 and most clusters had values close to this amount, with the most notable exception being the high floor areas (169 m^2) of Lavish Lifestyles households (Figure 13). The Modern Living and Thrifty Values clusters had the lowest average floor areas (77 m^2 and 78 m^2, respectively).

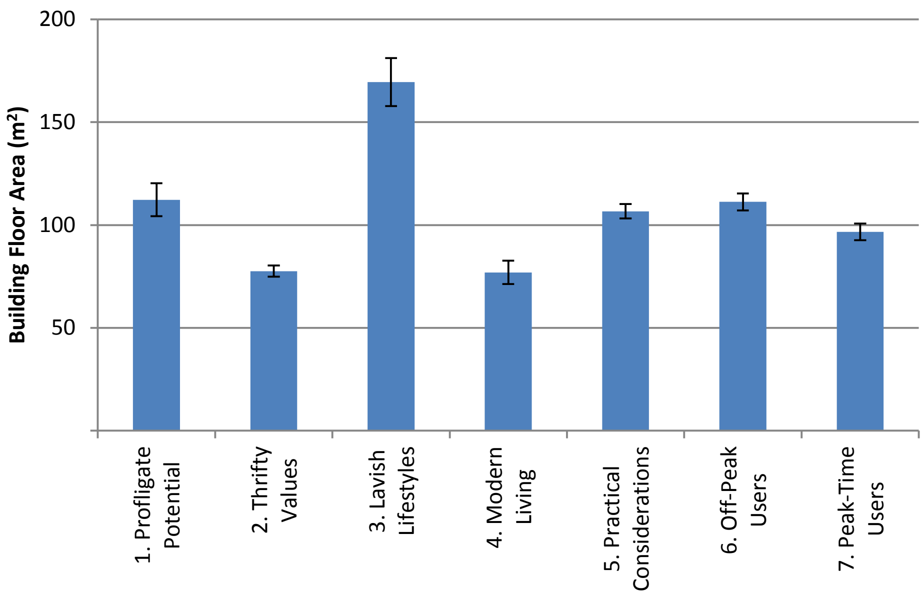

Figure 13: Average building floor area for each household cluster.

4.3.3 Property Type

As expected, the highest social grade household archetype, Lavish Lifestyles, had a high proportion of detached and semi-detached homes (Figure 14). 91% of the buildings in the Lavish Lifestyles cluster were either detached or semi-detached with the remaining 9% consisting of medium to large terrace houses.

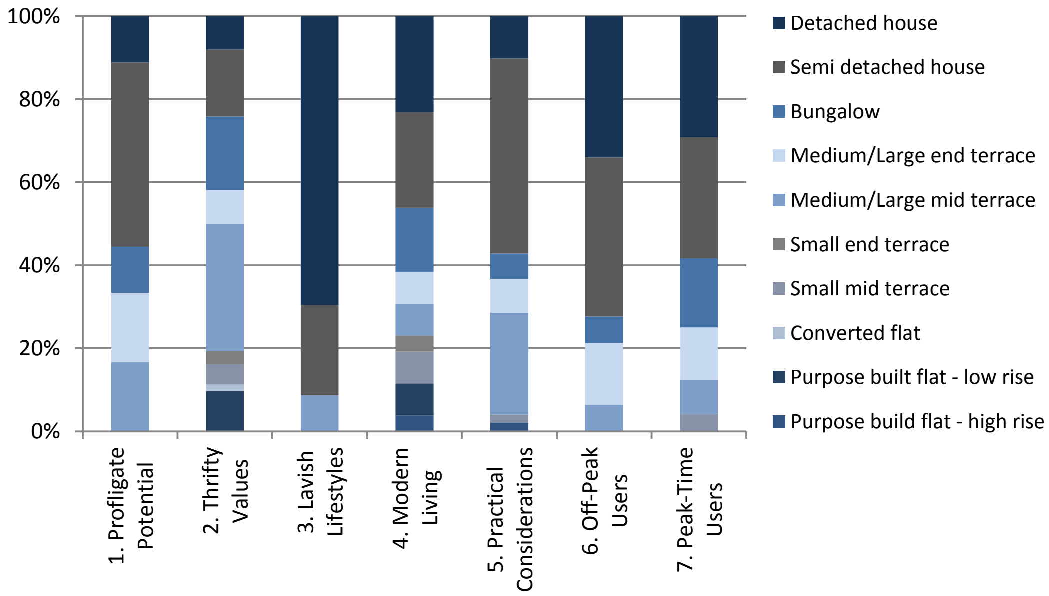

Figure 14: The distribution of dwelling types for each household cluster.

4.3.4 Terrain

The vast majority of households surveyed in the Household Electricity Usage Study were based in low rise urban/suburban regions (Figure 15). With this in mind, there is little cluster differentiation on the basis of terrain, though it is interesting to note that the highest proportion of houses in dense urban regions was observed for the Practical Considerations cluster, which also had the highest occupancy levels (3.6 people per household) and highest occupant density (29.6 m^2/person).

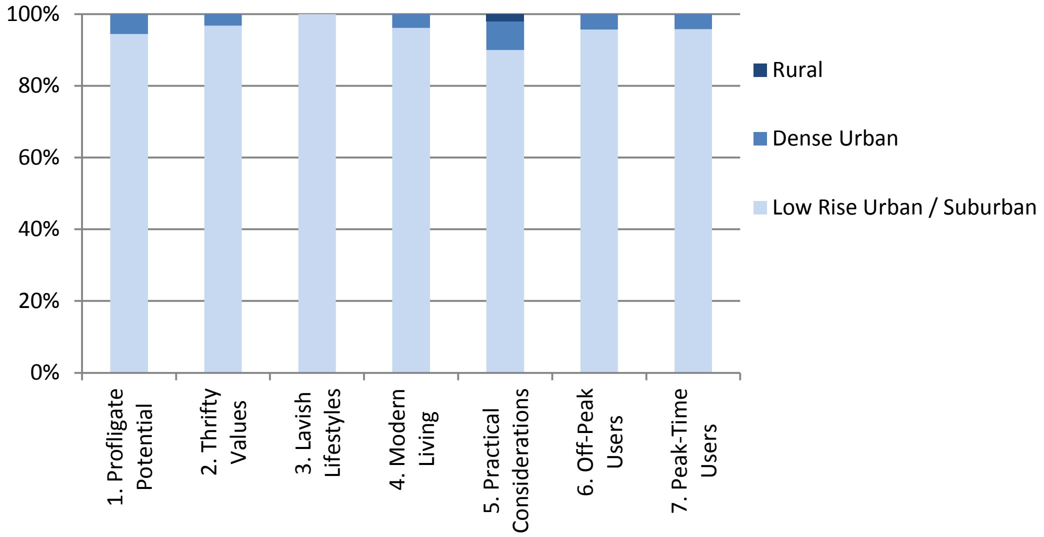

Figure 15: The distribution of terrain type for each household cluster.

4.3.5 Heating Fuel

Heating fuel in this context refers to the predominant fuel used for space and water heating. As can be seen in Figure 16, mains gas was the dominant heating fuel for all clusters, and represents the heating fuel of about 92% of the households monitored in the Household Electricity Usage Study. Therefore, the options available for statistically significant analyses of this characteristic between the different household archetypes are limited.

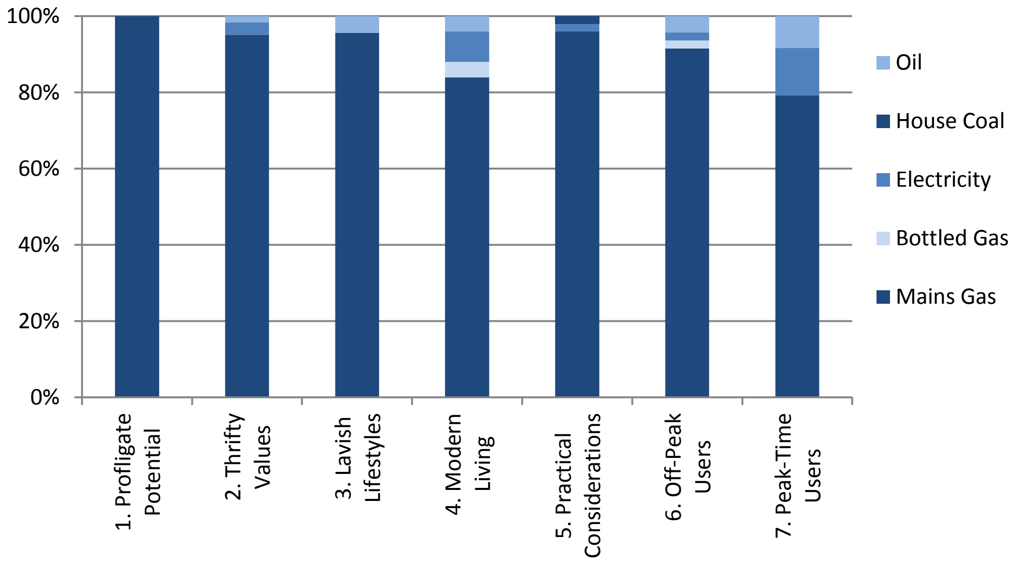

Figure 16: The distribution of heating fuel source for each household cluster.

4.4 Electricity Usage

4.4.1 Number of Electrical Appliances

The average number of electrical appliances across the seven clusters ranged between 27 and 53 (Figure 17). As might be expected, these values demonstrated some correlation with the number of occupants in the house, the building floor area and total electricity use per annum (Appendix B).

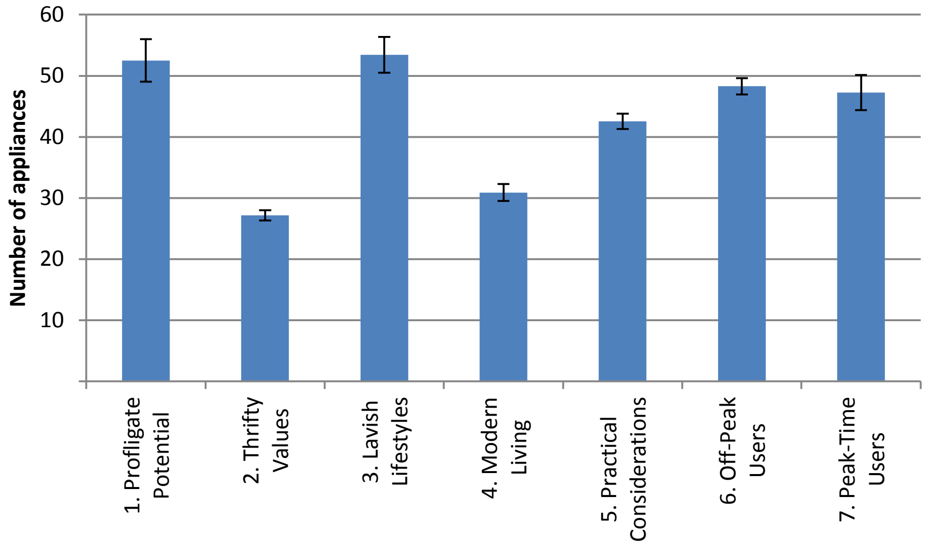

Figure 17: The average number of electrical appliances for each household cluster.

4.4.2 Total Electricity Use Per Annum

Over the entire 250 surveyed households, the average annual household electricity use was 3,867 kWh/year[23]. As can be seen in Figure 18, the variation in electricity use between clusters was considerable. Three clusters (Profligate Potential, Lavish Lifestyles and Peak-Time Users) accounted for 42% of the total electricity used with only 26% of the surveyed households. Of these high use archetypes, Profligate Potential households had, by far, the highest annual electricity usage levels at 7,840 kWh/year, more than double the survey average. Conversely, the Modern Living cluster, which encompassed 10% of the monitored households, had the lowest annual electricity usage levels of 1,869 kWh/year, consuming only 5% of the total annual electricity used across all households.

[23] Electricity use for space heating was not included in the total since many households were monitored outside of the colder months (November to March) in which space heating would typically be used.

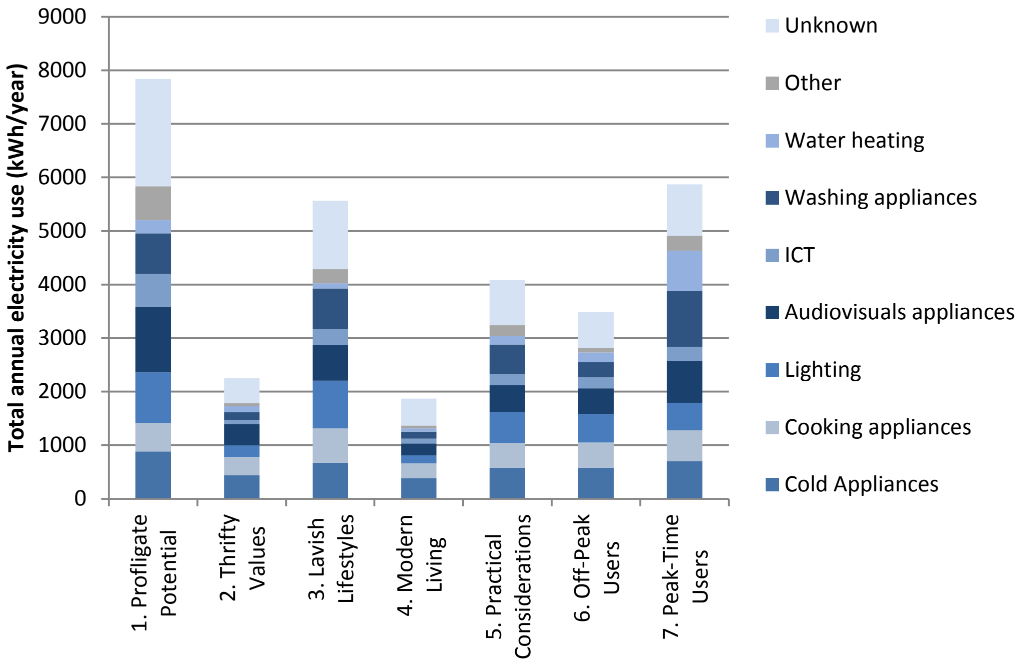

Figure 18: The average annual electricity used by appliance type for each household cluster.

It is worth noting that there was only minor correlation between total electricity use and the clustering variable for 'current actions' (Appendix B). This likely reflects the broad range of factors that contribute to total electricity use (including household occupancy, building floor area, number of appliances, etc.) without any showing a particularly strong correlation with the total amount of electricity consumed.

4.4.3 Percentage of Electricity Used in the 6-7pm Peak

In this study we have taken the peak load period as being between 6-7pm to maintain consistency with the "Further Analysis of the Household Electricity Use Survey" report[24]. Figure 19 indicates that the Peak-Time Users and Lavish Lifestyles clusters had the highest peak-time usage fractions (7.1% and 6.9%, respectively) with the Off-Peak Users cluster exhibiting the lowest level of peak-time consumption (5.5%).

[24] Palmer, J., Terry, N. and Kane, T. (2013), "Further Analysis of the Household Electricity Use Survey – Early Findings: Demand Side Management" for DECC and Defra.

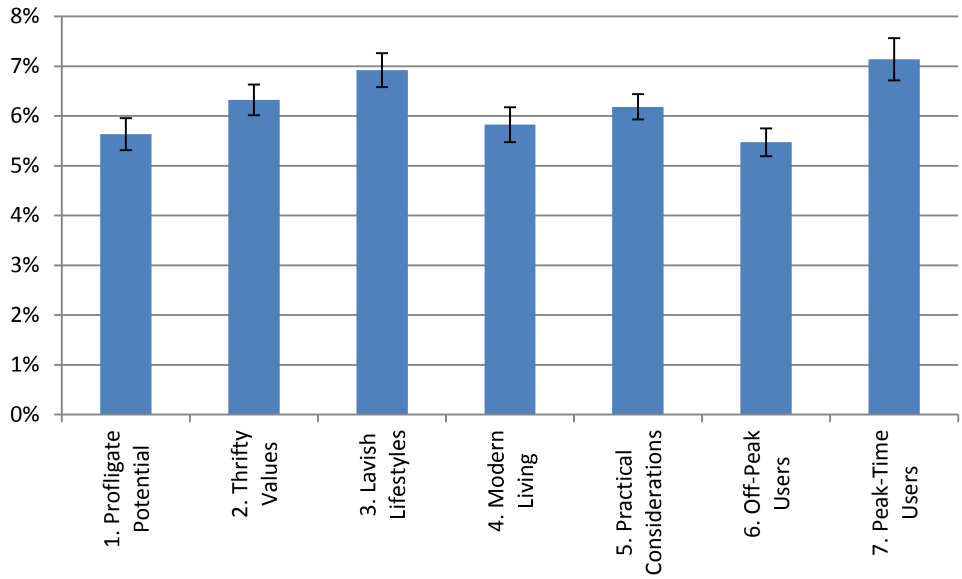

Figure 19: Percentage of electricity used in the 6-7pm peak for each household cluster.

4.5 Technical Potential

4.5.1 Appliance Efficiency Potential Savings

The technical potential for appliance efficiency savings for each household was obtained from the original Household Electricity Usage Study report[25] and measures the electricity that could be saved annually by:

- replacing all cold appliances with class A+ or A++ equipment;
- replacing all incandescent and halogen light bulbs with compact fluorescent lights;
- reducing all standby power for the audiovisual and computer sites;
- replacing existing washing machines, clothes dryers and dishwashers with energy efficient alternatives; and
- replacing desktop computers with laptops.

As can be seen in Figure 20, the potential savings from appliance efficiency improvements ranged between 1,546 kWh/year (for Profligate Potential households) and 323 kWh/year (for Modern Living households). As a fraction of total electricity use, these potential savings represent as much as 20% of the total amount of electricity used (in the case of Profligate Potential households).

[25] AEA Technology (2012), "Household Electricity Survey: A study of domestic electrical product usage" for DECC, Defra and the EST.

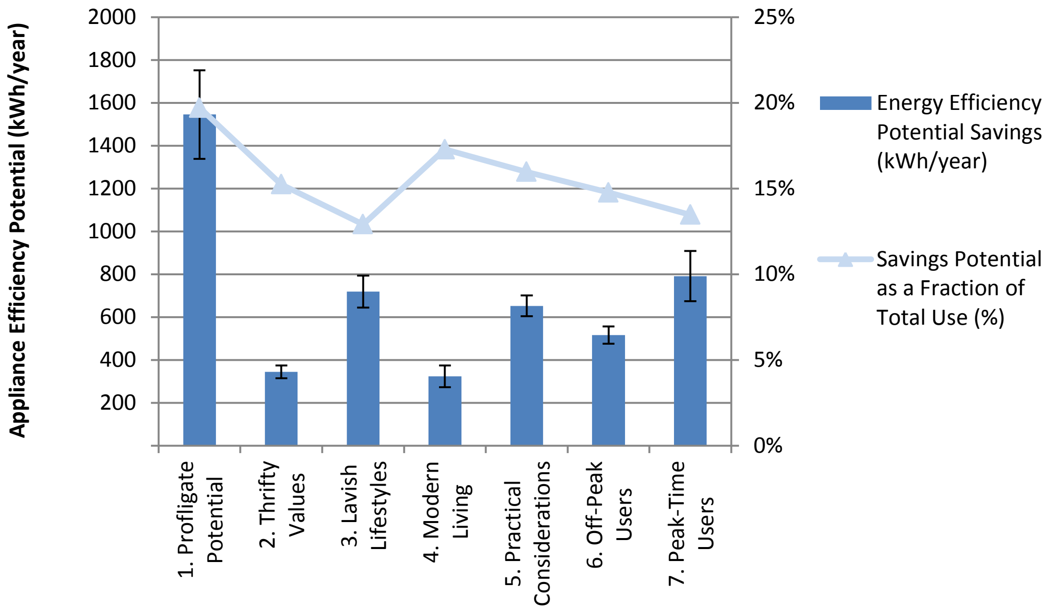

Figure 20: The appliance efficiency potential savings for each household cluster, expressed as total energy per annum and fraction of total electricity use.

4.5.2 Peak Shift Potential Savings

It is assumed that the electricity usage arising from certain appliance types can be shifted to varying degrees around peak usage periods. In line with the “Further Analysis of the Household Electricity Use Survey” report, we have focused on fully shiftable appliances (washing machines, tumble dryers, dishwashers and water heating) as well as partially shiftable appliances (cold appliances and space heating)[26]. Depending on the appliance type being considered, various fractions of the peak load (from 6-7pm) were assumed to be movable to lower demand periods. For the purposes of this analysis, load shifting from lights, TVs, audio equipment, computers, and cooking appliances have not been considered owing to the limited shifting potential offered by these appliance types.

Cold Appliances

Cold appliances make up approximately 10% of peak evening electricity demand (from 6-7pm) for the monitored households, the highest of all appliance groups. Previous studies for DECC and Defra on dynamic demand potential from cold appliances indicate that as much as 28 W in a

[26] Palmer, J., Terry, N. and Kane, T. (2013), “Further Analysis of the Household Electricity Use Survey – Early Findings: Demand Side Management” for DECC and Defra.

150 W rated appliance could be shifted for as long as 30 minutes with instant recovery of the operating temperature (while not taking any additional power to achieve this)[27,28]. Findings of the Smart-A project indicate that additional energy required in response to consumer behaviour (i.e. opening and closing the fridge or freezer) is at its peak around the 6-7pm period and accounts for approximately 42% of power demand at this time[29]. Adapting the Smart-A diurnal load profile to a 150 W rated appliance[30] and assuming that power requirements due to consumer behaviour cannot be shifted, yields a peak shift potential of 9% of the 6-7pm demand from cold appliances (i.e. an average of 6.3 W per household during the 6-7pm peak or 2.3 kWh/year) if these appliances are fitted with built-in controls to minimise peak load demand.

Washing Appliances

Washing appliances (including washing machines, tumble dryers and dishwashers) account for approximately 8% of peak evening demand for the monitored households. This class of appliances is considered to be particularly flexible and 100% of peak-time usage from this category is assumed to be switchable to non-peak periods.

Water Heating

Similarly, the demand characteristics of water heating appliances (e.g. household hot water and electric showers but not including kettles) are considered to be flexible enough to move 100% of their peak-time use to lower-demand periods. This is a best-case scenario and it is recognised that altering household showering habits may present additional challenges beyond those involved in changing automated household water heating times.

Space Heating

For the purposes of this study, peak-time electric space heating was only considered to be shiftable in the case of electric storage heaters. More disruptive interventions are possible, such as switching heating fuel, but these are captured in the next section on the technical potential from fuel switching.

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27 Aunedi, M., Enrique, J., Calderon, O., Silva, V., Mitcheson, P. and Strbac, G. (2008) “The Potential for Dynamic Demand - Economic and Environmental Impact of Dynamic Demand”, for DECC.

28 EA Technology (2011) “Delivering the Benefits of Smart Appliances” for Defra.

29 Stamminger, R. (2008), “Synergy Potential of Smart Appliances. D2.3 of WP2 from the Smart-A project”, for the European Commission.

30 Assuming that the cold appliance is “on” (cycling) for a third of the time.

It was found that only two households with storage heaters used electric space heating during the 6-7pm peak period[31]. Given the low statistical significance available from the 2 applicable households, space heating was excluded from the analysis of peak shifting potential.

Figure 21 illustrates the potential demand that could be shifted from the peak period for cold appliances, washing appliances and water heating. Peak-Time Users had the highest peak shift potential (124 kWh/year, equivalent to an average of 341 W per household during the 6-7pm peak) which was more than triple that of the next highest cluster, Lavish Lifestyles (36 kWh/year, i.e. 99 W per household during the 6-7pm peak). The large peak shifting potential offered by the Peak-Time Users cluster derives from their high usage of washing and water heating appliances during the peak period – these two appliance types account for 98% of the total peak shifting potential of this group.

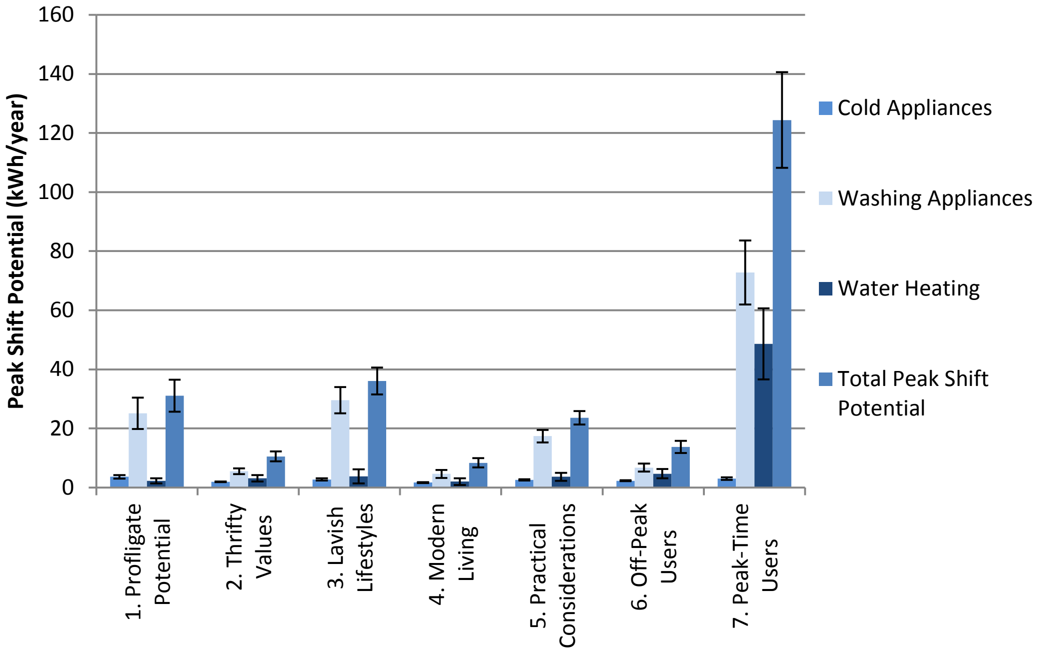

Figure 21: The peak shift potential savings, by appliance type, for each household cluster.

For most clusters, washing appliances accounted for much of the peak shift potential. Given the relative ease with which washing appliance loads can be shifted away from peak demand periods, this appliance category

31 This finding implies that there is scope for improving the setup and usage of existing storage-capable heating systems within some UK households to ensure they are operating at optimal times. Households with a dual tariff structure would make immediate financial benefits from such steps.

represents a promising target for demand-side response strategies. This finding is in close agreement with the "Further Analysis of the Household Electricity Use Survey" report[32].

4.5.3 Fuel Switch Potential Savings

Household electricity demands on the grid could also be significantly reduced by switching existing electric water and space heating systems (including both primary and auxiliary heating appliances) to an alternative fuel (e.g. natural gas, biogas, renewable hydrogen, microgenerated heat, district heat, etc.). Alternatively, part of this total saving potential could be achieved by switching to a more efficient electric heating system (e.g. a modern air source or ground source heat pump). While this represents a significant intervention in terms of installation costs and disruption, the impact on electricity use can be considerable (Figure 22). It is worth noting that many households were monitored outside of the November to March heating period and were, therefore, excluded from the calculation of the cluster averages for space heating. This accounts for the relatively large standard error values for space heating shown in Figure 22.

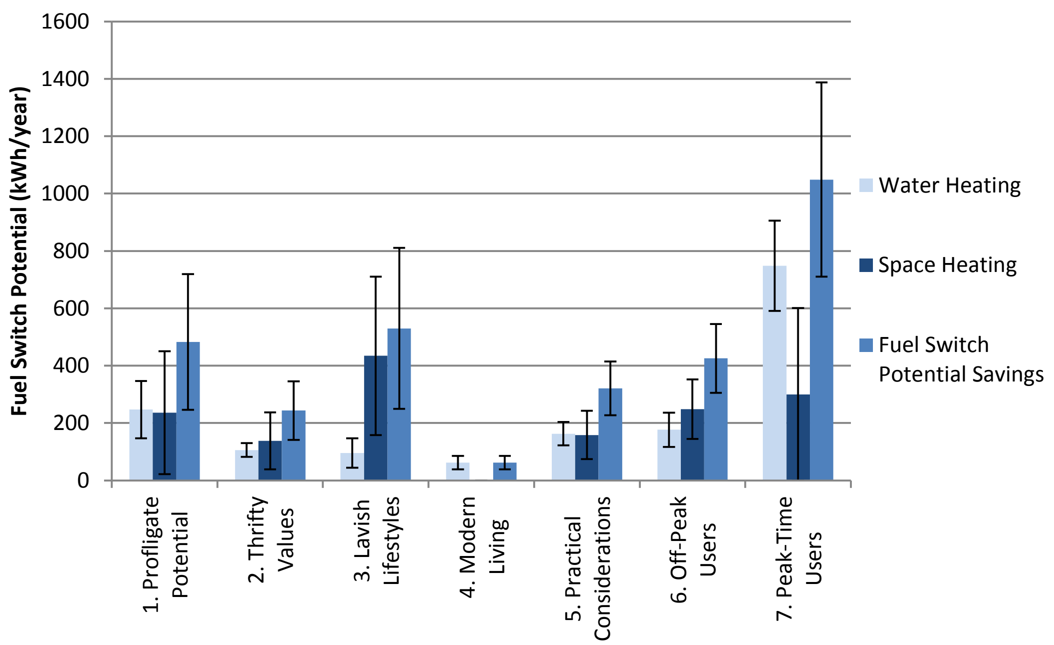

Figure 22: The fuel switch potential, by appliance type, for each household cluster.

32 Palmer, J., Terry, N. and Kane, T. (2013), "Further Analysis of the Household Electricity Use Survey – Early Findings: Demand Side Management" for DECC and Defra.

The Peak-Time Users cluster offers the greatest overall fuel switch potential (1049 kWh/year), followed by Lavish Lifestyles (530 kWh/year) and Profligate Potential (483 kWh/year). Interestingly, the fuel switch potential for Lavish Lifestyles households derives predominately from space heating (82%). Since no Lavish Lifestyle houses used electricity as the primary space heating fuel (Figure 16), this switching potential derives from auxiliary electric heating that could potentially be avoided by optimising use of the primary central heating system (predominately mains gas). Of the 116 households monitored during the November to March heating period, approximately 21% were observed to utilise secondary electric heating to support a non-electric primary heating system (e.g. natural gas, oil, etc.) whereas for Lavish Lifestyles households this figure was 30%.

5 Conclusions and Recommendations

- The 250 households included in this study were found to cluster into seven distinct household archetypes based on their attitudes to the environment, demographics, building details and electricity usage characteristics.

- It was observed that environmentally friendly beliefs within a household do not necessarily imply environmentally friendly actions due to the interplay of other lifestyle priorities (in some cases linked with social grade). This implies that green beliefs, in isolation, are an incomplete indicator of low-carbon policy traction, meriting the use of a cluster-based approach to market segmentation that is able to capture the nuances of these complex consumer priorities.

- In general terms, the clusters identified in this report offer the opportunity to better understand the electricity savings potentials offered by various consumer segments – in the specific context of UK electricity consumption – along with the demographic, building and attitudinal factors that underpin these opportunities. In this way, it is possible to ensure that future interventions (such as those aimed at optimising energy efficiency, peak load shifting and heating impacts on the electricity network) will encompass as much of the UK population as possible, and certainly those groups which offer the greatest potential for beneficial impact.

- The unique characteristics of each of the seven household clusters make it possible to identify the household groups where different interventions are likely to have the greatest impact. Of these characteristics, the metrics for household technical potential (in terms of electricity savings from energy efficiency, heating fuel switching or optimisation and peak shifting) are particularly important for identifying the capacity for targeted interventions. To add context on the size of the opportunity available, Table 8 below shows the technical potential in these areas for each cluster when scaled to the UK national level[33].

[33] The recruitment process used to determine the participants in the Household Electricity Usage Study resulted in a reasonably close match with the overall owner-occupier population across England, as examined in detail in the original Household Electricity Usage report: "Household Electricity Survey: A study of domestic electrical product usage". However, the Household Electricity Usage Study, which is limited to 250 households, does not contain specific data for Scotland, Wales and Northern Ireland or for non-owner-occupiers, so scaling this data to the UK national level represents an approximation and is for illustrative purposes only.

Table 8: Technical potentials for each household cluster scaled for the UK.

Cluster	Fraction of population (%)	Efficiency potential (TWh/year)	Fuel switch potential (TWh/year)	Peak shift potential (TWh/year)	Peak shift potential (GW)
1. Profligate Potential	7	2.9	0.9	0.06	0.16
2. Thrifty Values	25	2.3	1.6	0.07	0.19
3. Lavish Lifestyles	9	1.7	1.3	0.09	0.24
4. Modern Living	10	0.9	0.2	0.02	0.06
5. Practical Considerations	20	3.4	1.7	0.12	0.34
6. Off-Peak Users	19	2.6	2.1	0.07	0.19
7. Peak-Time Users	10	2.0	2.7	0.32	0.86
UK Total	**100**	**15.8**	**10.5**	**0.75**	**2.05**

- Profligate Potential households offer by far the greatest technical potential for appliance efficiency savings with an average opportunity of 1546 kWh/year per household (about double that of any other cluster) or approximately 2.9 TWh/year nationally. When considered alongside the very green current beliefs of Profligate Potential households, there appears to be scope for uptake of policies targeting this aspect of electricity use within this cluster.

  Recommendation: Use the characteristics identified in the cluster analysis to target awareness raising and other interventions to realise the energy efficiency potential of Profligate Potential households.

- The medium levels of appliance efficiency savings potential per household (652 kWh/year) of the Practical Considerations cluster, when combined with their strong representation in the population (20%), yields a large potential for efficiency savings at the national level (3.4 TWh/year). Practical Considerations households also have very green current beliefs that may favourably predispose them towards appliance efficiency interventions.

  Recommendation: Practical Considerations households should also be targeted for broader appliance efficiency strategies in conjunction with the Profligate Potential cluster.

- The Peak-Time Users cluster offers, by far, the highest technical potential for shifting electricity use out of the 6-7pm peak with a per household average capacity of 341 W during the 6-7pm peak (more than triple the next highest cluster) which equates to approximately

0.9 GW nationally. The Peak-Time Users cluster also offers the highest electricity savings for switching heating fuel (or to a more efficient electric heating system) – on average 1049 kWh/year per household and about 2.7 TWh/year nationally. However, these high technical potentials are combined with non-green current actions and only moderately green beliefs in this cluster indicating there may be limited willingness or motivation to address these areas at present.

> **Recommendation:** Further investigate the drivers and incentives that could motivate households in the Peak-Time Users cluster to realise the high technical potentials of this household archetype, particularly in the context of future demand-side response strategies.

- The Lavish Lifestyles cluster also offers high heating fuel switching potential per household (530 kWh/year, which scales to about 1.3 TWh/year for the UK), the majority of which (82%), was from secondary electric space heating devices supporting a non-electric central heating system (i.e. natural gas or heating oil). This indicates significant potential for electricity savings by optimising use of the primary central heating system in this cluster (approximately 1.1 TWh/year across the UK).

> **Recommendation:** Target awareness raising campaigns to improve the utilisation of primary central heating systems and reduce secondary electric space heating requirements, particularly in Lavish Lifestyles households. In the case of Lavish Lifestyles households, these campaigns will need to be mindful of the other lifestyle priorities (related to high social grades) that motivate this group and currently appear to hinder the adoption of environmentally friendly behaviours in this cluster.

- Finally, the well-defined clusters produced in this project offer excellent scope in future work for combining the household clusters with other low-carbon technology uptake, grid management and geographical mapping studies[34,35,36].

[34] Element Energy (2011) “Plug-in Vehicles Economics and Infrastructure: Quantifying Consumer Behaviour”, for the Energy Technologies Institute.
[35] Element Energy (2009), “Strategies for the uptake of electric vehicles and associated infrastructure implications”, for the Committee on Climate Change.
[36] Element Energy (2009), “Uptake of energy efficiency in buildings”, for the Committee on Climate Change.

Recommendation: Ensure future household studies examining low-carbon technology uptake, demand-side response strategies and policy impacts are structured so that they can be linked to the Household Electricity Usage Study clusters identified in this project, thereby revealing potential synergies with implications for policy development and grid management.

6 Appendix A

Table 9: Factor analysis results indicating the correlation (between -1 and 1) of each survey question with each of the 3 factors.

Household Electricity Usage Study Survey Question[37]	Factors 1: Current beliefs	 2: Current actions	 3: Beliefs about the future
3.14 To what extent do you agree or disagree that: The effects of climate change are too far in the future to really worry me	.732	.172	.107
3.16 To what extent do you agree or disagree that: It's not worth Britain trying to combat climate change, because other countries will just cancel out what we do	.716	.018	-.178
3.15 To what extent do you agree or disagree that: It's not worth me doing things to help the environment if others don't do the same	.653	.098	-.175
1 How concerned, if at all, are you about climate change, sometimes referred to as 'global warming'?	.647	.132	.291
4 Which of these statements describes how you feel about your current lifestyle and the environment?	.630	-.161	.080
3.13 To what extent do you agree or disagree that: It's only worth doing environmentally-friendly things if they save you money	.617	.267	-.161
3.9 To what extent do you agree or disagree that: The so-called 'environmental crisis' facing humanity has been greatly exaggerated	.616	.124	.439
3.11 To what extent do you agree or disagree that: Being green is an alternative lifestyle it's not for the majority	.561	-.097	.019
2 Thinking about the causes of climate change, which, if any, of the following best describes your opinion?	.480	.116	.225
3.10 To what extent do you agree or disagree that: It would embarrass me if my friends thought my lifestyle was purposefully environmentally friendly	.463	.176	-.165
3.4 To what extent do you agree or disagree that: I don't pay much attention to the amount of water I use at home	.089	.657	-.037
6.7 How often, if at all, do you do the following: Boil the kettle with more water than you are going to use	-.110	.655	.082
6.2 How often, if at all, do you do the following: Leave your TV or PC on at home when you are not using them	-.132	.591	.056
6.6 How often, if at all, do you do the following: Leave a mobile phone charger switched on at the socket when not in use	-.214	.583	.113
6.5 How often, if at all, do you do the following: Leave the lights on when you are not in the room	-.096	.537	.046
5 Which of these statements would you say best describes your current lifestyle?	.238	.518	.046
3.17 To what extent do you agree or disagree that: I don't really give much thought to saving energy in my home	.226	.509	-.173
6.3 *How often, if at all, do you do the following: Cut down on the use of hot water at home*	.189	.493	-.009
3.12 To what extent do you agree or disagree that: I find it hard to change my habits to be more environmentally-friendly	.243	.485	-.147
6.1 How often, if at all, do you do the following: Leave the heating on when you go out for a few hours	.116	.361	.104
3.5 *To what extent do you agree or disagree that: People have a duty to recycle*	.310	.339	.060
3.1 To what extent do you agree or disagree that: I would only travel by bus if I had no other choice	.107	.290	.037
6.4 *How often, if at all, do you do the following: Wash clothes at 40 degrees or less*	.069	.132	-.203
7 *Which of these statements applies to you personally at the moment with regard to buying energy efficient ('A' rated or better) appliances, excluding energy saving light bulbs.*	.101	.104	-.324
3.6 *To what extent do you agree or disagree that: We are close to the limit of the number of people the earth can support*	-.095	.198	.681
3.8 *To what extent do you agree or disagree that: If things continue on their current course, we will soon experience a major environmental disaster*	.284	.139	.643
3.7 *To what extent do you agree or disagree that: The Earth has very limited room and resources*	-.072	.151	.574
3.3 To what extent do you agree or disagree that: People who fly should bear the cost of the environmental damage that air travel causes	.234	.008	.470
3.2 *To what extent do you agree or disagree that: For the sake of the environment, car users should pay higher taxes*	.350	.072	.399

[37] Responses for questions shown in italics were inverted to align all answer scores from the least environmentally friendly response to the most environmentally friendly.

7 Appendix B

Table 10: Cluster variable correlation analysis showing that the correlations between variables are all within the maximum absolute correlation threshold of 0.9[38].

	Current beliefs	Current actions	Beliefs about the future	Building age	Household occupancy	Building floor area	Household social grade	Number of electrical appliances	Total electricity use per annum	Fraction of electricity used in peak	Peak Shift Potential	Appliance Efficiency Potential
Current beliefs		.000	.000	-.053	.326	.208	.219	.186	.212	-.089	.043	.168
Current actions	.000		.000	.024	-.205	-.222	-.168	-.221	-.257	-.110	-.141	-.147
Beliefs about the future	.000	.000		-.060	.023	-.098	-.023	-.079	.011	-.057	-.039	-.052
Building age	-.053	.024	-.060		-.153	-.068	.123	.055	-.047	-.013	.020	-.121
Household occupancy	.326	-.205	.023	-.153		.303	.041	.417	.498	.144	.282	.306
Building floor area	.208	-.222	-.098	-.068	.303		.282	.448	.344	.064	.070	.193
Household social grade	.219	-.168	-.023	.123	.041	.282		.220	.061	.046	.033	-.004
Number of electrical appliances	.186	-.221	-.079	.055	.417	.448	.220		.541	.014	.231	.293
Total electricity use per annum	.212	-.257	.011	-.047	.498	.344	.061	.541		.080	.475	.578
Fraction of electricity used in peak	-.089	-.110	-.057	-.013	.144	.064	.046	.014	.080		.176	.002
Peak shift potential savings	.043	-.141	-.039	.020	.282	.070	.033	.231	.475	.176		.286
Appliance efficiency potential savings	.168	-.147	-.052	-.121	.306	.193	-.004	.293	.578	.002	.286	

38 Mooi, E. and Sarstedt, M. (2011), “A concise Guide to Market Research”, Springer-Verlag, Berlin.