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BENCHMARKING DOMESTIC GAS AND ELECTRICITY CONSUMPTION TO AID LOCAL AUTHORITY CARBON REDUCTION POLICY

by

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A Doctoral Thesis

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ABSTRACT

As part of an effort to be a world leader in international efforts in reducing atmospheric carbon dioxide levels, the UK Government has set itself ambitious targets to reduce carbon dioxide emissions by 80% relative to 1990 levels by 2050. To meet this target, there is a strong emphasis in reducing carbon emissions from the domestic sector through the reduction of energy consumption in UK households by improving the energy efficiency of the housing stock, and the behaviours of the occupants. The Department of Energy and Climate Change have indicated that Local Authorities in England are potentially to work in partnership with businesses and community organizations to facilitate delivery; and as a promoter of domestic energy efficiency policies. Consultation with 11 Local Authorities across England confirmed that they are lacking a reliable mechanism that can detect areas within their administrative boundaries that are most in need of intervention to improve the energy efficiency of the housing stock. For the year 2008 the regression models demonstrate that geographical variations in the size of the house, median household income, and air temperature account for 64% of the variation in English domestic gas consumption, and that variations in the size of the house, median household income, and proportion of households connected to the national gas grid account for 73% of the variation in domestic electricity consumption. The predicted values from these regression models serve as benchmarks of domestic gas and electricity consumption in England having accounted for household income, house size, house type, tenure, and climatic differences and could be used to identify areas within Local Authorities with higher than expected energy consumption for energy efficiency interventions. These results contribute to the wider academic debate over how best to achieve the overall aims of household CO_2 reductions by moving beyond a purely technical or behavioural-based approach to reducing domestic energy consumption.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BERR	Department for Business, Enterprise and Regulatory Reform
CERT	Carbon Energy Reduction Target
CESP	Community Energy Saving Programme
CIBSE	Chartered Institute of Building Services Engineers
CO_2	Carbon Dioxide
CSE	Centre for Sustainable Energy
DCLG	Department of Communities and Local Government
DECC	Department of Energy and Climate Change
DEFRA	Department for Environment, Food and Rural Affairs
DTI	Department of Trade and Industry
ECI	Environmental Change Institute
ECO	Energy Company Obligation
EEA	European Environment Agency
EST	Energy Savings Trust
EU	European Union
GIS	Geographical Information Systems
HCA	Home and Communities Agency
HDD	Heating Degree Day
HECA	Home Energy Conservation Act
HEED	Home Energy Efficiency Database
IGEM	Institute of Gas Engineers and Managers
IPCC	Intergovernmental Panel on Climate Change
ISMIR	Income Support for Mortgage Interest Repayments
LA	Local Authority
LAA	Local Area Agreement
LDZ	Local Distribution Zone
LSOA	Lower Super Output Area
MET Office	UK Meteorological Office
MSOA	Middle Super Output Area
NEED	National Energy Efficiency Data-Framework
NI	National Indicator
OLS	Ordinary Least Squares
ONS	Office of National Statistics
SAP	Standard Assessment Procedure
SDC	Sustainable Development Commission
VOA	Valuation Office Agency

LIST OF VARIABLES

RGE	Ratio of Gas to Electricity Meters
HDD	Heating Degree Days
MHI	Median Household Income
ANR	Average Number of Rooms
BMG	Benchmark Gas Consumption
BME	Benchmark Electricity Consumption

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1. INTRODUCTION

The purpose of this thesis is to understand how residential energy consumption varies across England and the underlying reasons for this variation. By going beyond assessing the contributions of technical differences in the housing stock, or purely comparing raw energy figures, policy makers can better understand the reasons for variation in energy consumption. This original contribution to knowledge is essential for the ability of targeting areas for energy efficiency interventions, leading to the reduction in domestic energy consumption and aiding the UK Government in meeting ambitious carbon dioxide reduction targets. While it is widely understood in the academic community how to improve the thermal efficiency of the housing stock, it is difficult for organisations to determine those households that are most in need for intervention, given the variations in demographics, economics, climate, as well as behavioural and cultural factors.

This thesis identifies strengths and weakness of available data published by the UK Government, and indicates where improvements to these resources can be made. It is a necessary step since current Government policy emphasises the role of private finance in implementing energy efficiency improvements in the housing stock, and there is at present a lack of data on the energy efficiency measures installed, and a patchwork of policies to deal with energy inefficient housing. Encouraging private finance will require data that is seen to be accurate and precise in identifying the areas for work to be carried out. For Local Authorities, the role of enabling and directing capital for energy efficiency upgrades requires a mechanism that can be used to identify areas of inefficiency and relative over-consumption of domestic energy to provide assurances to third-party financers that they are making good investments.

The aim of this thesis is therefore **to identify the key factors that explain the variation in domestic gas and electricity consumption and, applying this knowledge, develop a**

model for Local Authorities to target areas of housing that is most likely to benefit from energy efficiency measures.

The study evaluates the extent to which local variations in energy consumption are dependent on social, demographic, technical, economic, and climatic factors and generates statistical models, utilising these inputs of variables to generate benchmarks of 'expected' consumption levels. This allows for:

- The identification of areas that have domestic energy consumption above the benchmark level and require intervention to reduce energy consumption, and also the highlighting of areas of low energy consumption that can serve as exemplars.
- Local Authorities to monitor the impacts of implementing energy efficiency policies over time through measuring energy consumption against benchmark figures.
- The production of a framework that will enable Local Authorities to compare their domestic energy efficiency against those of other Local Authorities across England.
- Contribution to the wider academic debate on how best to achieve reductions in energy consumption in the domestic sector.

To meet these aims, the following five objectives have been the foundation of this research:

1. The *Policy Objective* is to consult with Local Authorities (LAs) in order to (i) determine the form of the model, its outcomes, and scale of applicability, and (ii) develop a more detailed understanding of the priorities and pressures LAs face, in order to make the model as usable as possible. This objective is the foundation of the thesis.
2. The *Data Objective* is to (i) identify nationally publically available datasets under the categories of social, demographic, technical, economic, and climatic factors; (ii) explore the uncertainty, limitations and methodological processes in the data

collection, and (iii) generate descriptive statistics illustrating the spread, distribution and average values for each of these factors.

3. The *Analytical Objective* is to explore relationships between domestic energy consumption and identified datasets using statistical methods including correlation, regression and appropriate tests of significance.
4. The *Output Objective* is to use the datasets and findings from objectives 2 and 3 as significant indicators to develop a statistical model that produces benchmarks for domestic gas and electricity consumption.
5. The *Applicability Objective* is to test the model developed in objective 4 by i) illustrating the potential applications of the outputs for Local Authority energy policy, and ii) assessing the plausibility of the results through statistical testing using alternative data sources and a series of plausibility tests.

1.1 Meeting the Energy Challenge

The background and justification of this thesis is the UK Government's carbon dioxide (CO_2) emissions reduction target, as first proposed in the 2007 Energy White Paper *Meeting the Energy Challenge.* This White Paper initially set out legally binding plans to reduce the UK's CO_2 emissions by 60% from 1990 levels by 2050 (HM Government 2007), a target which was subsequently revised upwards to 80% in the 2008 Climate Change Act (HM Government 2008). In 2010 the European Commission set out a commitment to reducing EU (European Union)-wide carbon emissions by 20% (30% if there was global commitment) relative to 1990 levels by 2020 (European Commission 2010). These ambitious measures were introduced in response to the widely accepted belief in the scientific community that the build-up of CO_2 concentrations in the atmosphere are responsible for the observed increases in average global temperatures over the course of the 20th Century (HM Government 2007). In the international policy context, this scientific community is perhaps best represented by the Intergovernmental Panel on Climate Change (IPCC), which stated:

> 'Carbon dioxide is the most important anthropogenic greenhouse gas. The global atmospheric concentration has increased from a pre-industrial value of about

> 280ppmto 370ppm in 2005. The atmospheric concentration of carbon dioxide in 2005 exceeds by far the natural range over the last 650,000 years (180 to 300ppm) as determined from ice cores. The annual carbon dioxide growth rate was larger during the last 10 years (1995-2005 average: 1.9ppm per year) than it has been since the beginning of continuous direct atmospheric measurement (1960-2005 average: 1.4ppm per year) (IPCC 2007:2)

Following the 2010 UK General election, the Conservative-Liberal Democrat Coalition Government affirmed the UK's commitment to the 2050 target for CO_2 emissions. Indeed it was just two months after the Coalition Government was formed that it formally signalled its intention to reaffirm the UK's commitment to meeting the 2050 target in *Pathway to 2050,* stating that the new Government is 'committed to reducing greenhouse gas emissions in the UK by at least 80% relative to 1990 levels' (HM Government 2010:1). However, what this document does not set out are any concrete policies, measures or procedures to *meet* the 2050 target. Rather it sets out a series of strategies – with variations in the combinations of required energy supply changes and demand reduction which *could* reduce the UK's carbon footprint. Of note is how improvement in the energy efficiency of the housing stock and reducing the demand for electricity features prominently in five of the six suggested *pathways* to meeting the 2050 target. In the context of the UK this is a very important development with successive Governments committed to national carbon reduction targets, regardless of political orientation.

One of the major reasons for this commitment to addressing carbon emissions and energy consumption is that the UK is increasingly dependent on imported energy and its target is also partly in response to fears over its long-term energy security (Wicks 2009, HM Government 2010). Here, reducing CO_2 emissions through the reduction of energy demand is deemed necessary to alleviate the pressure on fossil fuel energy sources, which are finite in supply and will eventually run out or become too expensive to use economically (Weyman-Jones 1986, HM Government 2008, Howell and Nakhle 2008, Roberts 2008, MacKay 2009). As a net importer of these fuels there is both a desire and political and economic pressure for the UK to become less dependent on imported fuels (Department for Business, Enterprise and Regulatory Reform [BERR] 2008, MacKay 2009). For this reason alone, the UK is a pertinent national context within which to conduct research into domestic energy reduction.

1.2 Domestic Energy Reduction: The Key to Meeting the Energy Challenge

To be effective in reducing CO_2 emissions there must first be effective measurement of current emissions. The UK disaggregates its CO_2 emissions at the point of energy consumption. What this means is CO_2 emissions are attributed to the individual consumer rather than to the power station where the electricity is generated. With this accounting strategy, the domestic sector accounts for almost 25% of UK CO_2 emissions and 30% of total final energy use (Utley and Shorrock 2008, Kannan and Strachan 2009). Moreover, the energy demand in the domestic sector has risen by approximately 30% over the last 35 years (Utley and Shorrock 2008). Yet we know there is significant potential to reduce energy demand through improving the energy efficiency of the housing stock, and through the introduction of greater energy efficiency in electrical appliances (Firth and Lomas 2009). From previous research, we know that energy demand in the domestic sector is linked to two main factors: the demand for gas (primarily for space and water heating) and the demand for electricity (which is required for lighting, appliance use and electric heating functions) (Utley and Shorrock 2008, Brown *et al* 2009, Department of Energy and Climate change [DECC] 2010a). Space heating currently accounts for approximately 60% of total domestic energy consumption (Firth and Lomas 2009, Summerfield *et al* 2010a). One of the challenges facing the UK Government then is to reduce demand for gas and electricity in the domestic sector, an area where demand continues to rise. Central to this, as one area with potential for demand reduction, is improving the housing stock itself.

The turnover of the housing stock in the UK is approximately 1% per year (DECC 2010a), and the Sustainable Development Commission (SDC) estimates that 70% of the UK's 2050 housing stock has already been built (SDC 2007). So although much of the academic and policy focus is on designing housing stock which is fit for the twenty-first century (Boardman 2010, DECC 2010a), reducing CO_2 emissions in the domestic sector will in future years have to take into ever greater consideration the task of improving the energy efficiency of the *existing* housing stock. What we take from this is that to enact the improvement of energy efficiency in UK households, there is going to be a need for strong policy action to encourage mass uptake of energy efficiency improvements. Indeed, we can already see some recognition of this in recent publications by the UK Government.

DECC published *Warm Homes, Greener Homes* in 2010, a strategy document which underlined the UK Government's commitment to improving the energy efficiency of the existing housing stock, bringing the thermal properties of older buildings towards the level of energy efficiency of a new build house, and re-affirmed a commitment to reducing household energy consumption by 29% by 2020. The document goes on to state that 'by 2020, up to 7 million homes will have more substantial improvements such as solid wall insulation or renewable energy generating technologies, while millions more will benefit from access to advice, information and finance' (DECC 2010a:1). This has been developed further by the incoming Coalition Government who were quick to put in place plans to incentivise households to carry out the necessary upgrades to their properties through the Green Deal and Energy Company Obligation (ECO) schemes launched in 2012 (DECC 2011a/b). Alongside this, one of the most important developments in current political practice is the focus which is being put on Local Authorities to play an ever increasing role in implementing domestic energy reduction strategies (DECC 2010a, DECC 2011a/b).

1.3 Local Authorities: Meeting the Domestic Energy Consumption Challenge Head On?

Warm Homes, Greener Homes highlighted that Local Authorities were to be given an important role in the efforts to reduce CO_2 emissions from the domestic sector (DECC 2010a,b), recognising 'local authorities' important existing responsibilities for cutting carbon emissions and their unique abilities to bring the right people together, making it easier for individual householders' (DECC 2010a). As part of this drive towards sub-national approaches to reducing CO_2 emissions, DECC now publish data at sub-national level on energy consumption from commercial, domestic, and transport sectors to 'enable councils and others to monitor and target small areas for further interventions as part of their local energy strategies, and enhance implementation of energy efficiency programmes and thus reduce carbon dioxide emissions' (DECC 2010c:2). In doing so, DECC has built on the work conducted by the Department for Environment, Food and Rural Affairs (DEFRA), which stated back in 2008 that 'Local Authorities can make a significant impact on emissions reductions in residences, businesses and transport in their community' (DEFRA 2008:3). Data has been published at Lower Super Output Area (LSOA) level; these are census output areas of 500-700 households and based loosely on homogenous tenure and house types (Office of National Statistics [ONS] 2010a). The Coalition Government has alluded to the role of Local Authorities in orchestrating the Green Deal and ECO policies, suggesting that Local Authorities will be potentially placed on the front-line of incentivising households to participate in these schemes, or performing an advisory and enabling role for private sector companies, through the identification of areas for intervention (DECC 2011a/b).

It should be noted at this point that the focus of this research is on England, which is administered directly by the Central UK Government and its Local Authorities are not subject to devolved administrations as in Wales, Scotland and Northern Ireland. Devolution has implications for data availability, the spatial scale at which data is produced. Devolved administrations also have their own responsibilities and objectives for the housing stock which may differ from the UK Government's aims (DEFRA 2008). It is for this reason that this current research project looks at England, rather than the UK as a whole.

1.4 Outline of the Thesis

To address each objective and to meet the overall aim of this research, following this introduction the thesis is structured as follows:

Drawing on academic research and policy documents, **Chapter Two** offers some critical reflections on the previous work that has been carried out around domestic energy consumption reduction in the UK and elsewhere. An analysis of previous studies into the factors impacting on the levels of domestic energy consumption was carried out, and develops an understanding of the key driving factors in the geographical variation in domestic gas and electricity consumption. Academic discussions are related to the policy objectives of the UK Government with particular attention drawn to the role of Local Authorities in current policy prescriptions for reducing domestic energy consumption.

Following this **Chapter Three** outlines the methodology that was developed to generate the results necessary to address both the aim and the objectives for this thesis. The methodology section provides the justification of the methods used and how these methods have been used in previous academic research in the context of local energy policy. The chapter introduces how each objective of the thesis was met, detailing the data sources, methods, outputs, and applications involved in the study. The secondary data sources and methods for collection of primary data are introduced and how these relate to achieving the overall aim of the thesis.

Chapter Four presents the results from consultation with Local Authorities, in the form of semi-structured interviews. The results from these interviews are compared and contrasted to the findings from the literature review, with areas of consensus and contention examined in further depth. Attention is paid to discussions of analytical strategies and modelling of data to ensure the outcomes of the thesis have practical applications.

The domestic energy consumption statistics published by DECC are evaluated in **Chapter Five.** These data sources were produced specifically to aid Local Authorities in conducting local domestic energy reduction policies and they form the dependent variables in the statistical study in this thesis. The chapter outlines the steps taken to enable the use of the data in the study through processes of data cleaning and outlier checking, and presents the descriptive statistics that highlight the distributions of average household domestic gas and electricity consumption across LSOAs in England.

The independent variables used in the statistical study are introduced and evaluated in **Chapter Six.** These variables represent the influencing variables of domestic energy consumption. This chapter details the methodology behind their data collection and the strengths and weaknesses of the data. There is a description of how the data was cleaned in this study, followed by a presentation of the descriptive statistics that describe the distributions of each data source. The implications of these explorations into the data sources on the modelling process are discussed.

Chapter Seven describes the development of multiple regression models that use the independent variables to predict the gas and electricity consumption. The chapter details the steps taken to construct multiple regression models, and the rigorous analysis to ensure the assumptions of multiple regression were met. Tests of the regression model using data from 2009 and 2010 are used to ensure the models are not specific to one particular year. Following the tests of the modelling process and its results, the 'expected consumption' benchmarks are generated and this forms the basis for the outputs that would be disseminated to Local Authorities.

In **Chapter Eight** the recorded consumption values are compared with the benchmark figures for each area of housing. This 'energy consumption' index is intended to serve as a guide to Local Authorities as to whether an area of housing is consuming greater gas or electricity than would otherwise be expected. As with the modelling process, the outputs are tested, firstly by running the results over time over a three year period to test the stability of the results when making year-on-year comparisons. Secondly, the results were tested by applying filters on areas of housing where discrepancies exist between multiple data sources. This is to assess the potential impacts of an acknowledged limitation of the DECC statistics.

Chapter Nine describes the testing of energy consumption indices. Firstly locally specific results were generated for Local Authority representatives, and presented to them in feedback sessions. Particular attention is paid to the respondent validation of the method, data and practical uses for the results generated in this thesis. The chapter continues to test the results from the model by conducting site visits on case studies of LSOAs in Leicester and to ensure that the model can identify areas of known and theorised energy efficiency. The results are related back to current theories in the academic literature surrounding *tenure, house age,* and *fuel poverty*. There is an investigation into comparing the relative consumption indicators in rural and urban areas, and how the incidence of higher than expected consumption changes between Local Authorities containing new and expanded towns, and those which do not.

Chapter Ten brings together the key findings from this research, and how these findings address the objectives set in this chapter. The chapter goes on to evaluate the outputs of this research and sets out the suggested future work. Each of the objectives is evaluated in turn, describing the headline findings from the research and how these results link to the overall aim of the thesis. An evaluation of the methods employed, and data used to address each objective is presented, with the limitations clearly stated. Following from this, the chapter presents the overall findings from this thesis and establishes the key conclusions from the research. It is at this point that the overall contribution to knowledge is stated and the chapter finishes with a discussion of future work that can build on the findings and further questions arising from carrying out this research. The conclusions are then presented here.

1.5 Conclusion

This research will examine the role of Local Authorities in the context of reducing domestic gas and electricity consumption and develop an understanding of how this role benefitted by increasing understanding of domestic energy consumption. This is to be done by exploring the factors which account for the variation in domestic energy consumption across England, and the political and resource constraints that Local Governments face when attempting to design and implement energy efficiency policies. The thesis contributes to the on-going theoretical debate regarding the process of identifying energy inefficient households, and the appropriate scales for energy efficiency policies to be undertaken. This engages with the literature from energy policy, local governance studies, building engineers, and policy documents from the UK Government. This will be relevant for policymakers and political leaders, providing an evidence-based methodology for identifying subnational areas for energy efficiency interventions. It also provides a cross-disciplinary connection for academics between building engineering and economic and political studies.

2. LITERATURE REVIEW

This chapter explores the theories presented in the academic literature, and the political developments that have shaped current UK Government policy concerning improving energy efficiency in the domestic sector. Firstly, the chapter investigates the theories about what drives energy consumption in the domestic sector, evaluating the theories from the academic literature and paying particular attention to the demographic, social, technical, economic and climatic variations across England and how these impact on residential energy consumption. Secondly, the chapter outlines current knowledge about methods of reducing energy consumption in the housing stock, particularly focusing on the technical interventions currently applied to improving energy efficiency in the domestic sector. Thirdly, there is a discussion of previous and current policies enacted by the UK Government for encouraging and prescribing local level domestic energy efficiency. Finally, the chapter presents the need for benchmarking, and the methods in which Local Authorities can target areas that might most benefit from energy efficiency improvements. The original contribution to knowledge of the thesis, is presenting the need for, and proposing a strategy for the development of, benchmarks for domestic sector gas and electricity consumption.

2.1 Drivers of Domestic Energy Consumption

The Department of Environment, Food and Rural Affairs (DEFRA) commissioned work to understand the magnitude and spatial variability of carbon emissions in UK Local Authorities (DEFRA 2008). On taking over responsibility for this issue, DECC has acknowledged, and continued to research into the factors which drive energy consumption in UK households (see DECC 2011c). Morley and Hazas (2011) state that studies of household energy use show a large degree of variability that cannot be entirely explained by infrastructural differences alone. Yao and Steemers (2005) suggest the energy use pattern in the domestic sector varies depending on factors such as climate, household composition, family income, cultural background and a human behavioural factor. This is supported by studies by Weber and Perrels (2000), Druckman and Jackson

(2008), Olonscheck *et al* (2011) and Wiesmann *et al* (2011). In attempting to account for these socio-technical differences, DECC has developed the National Energy Efficiency Data-Framework (NEED), to 'develop a wider understanding of energy use and energy efficiency', which has identified the average number of rooms, household income, tenure type and type of dwelling as the most important factors influencing the level of gas consumption from a sample of four million dwellings (DECC 2011c). The updated Home Energy Conservation Act (HECA) from 2012 pushes this analysis as a tool for Local Authorities to identify potential energy inefficiencies in their housing stock, but only utilises floor area and house type as producing variations in household energy use, ignoring demographic, economic and climatic factors (DECC 2012a). Building on the framework of this analysis for NEED at individual household level, this project analyses the impacts of the demographic, social, economic, and technical variations on average electricity and gas consumption in lower super output areas (LSOAs) – areas of 500-700 houses based on house type and tenure (ONS 2010a) and considers the impacts of geographical climatic variations across England, as had been subsequently identified in the academic literature.

2.1.1 Demographic Drivers

Between 1801 and 2000 the population of England and Wales grew from 8 million to 48 million whilst over the same period the average household size fell from 7 people per house to less than 3 (Lowe 2007). This has led to an increase in the number of houses from 1.2 million to 26 million (Boardman 2010). Over the past 30 years there has been a large increase in the number of single person households, with the proportion almost doubling from 17% in 1971 to 32% in 2000. This is partly explained by increases in life expectancy, as 50% of people aged over 75 live alone compared to 12% of 25-44 year olds (Department of Trade and Industry (DTI) 2002). An important consequence of the trend towards individualistic living is that it reduces the benefit of 'heat sharing' as greater numbers of single person households each have their own heating demands (Yao and Steemers 2005, Druckman and Jackson 2008), and critically, households require a minimum level of consumption to run the house which is independent of household size (Utley and Shorrock 2008).

O'Neil and Chen (2002) modelled the energy use of households in a cross-sectional study based on a series of residential surveys between 1978 and 1994 in the USA, analysing the following factors as inputs: age of dwellings, household size and age of occupants. Their findings suggest that a larger household (defined by number of residents) will have a higher absolute energy use, but per person this is lower than a household with a smaller number of residents. O'Neil and Chen's findings suggest that a two person household will use 17% less energy per capita than a one person household. This is an expected finding which confirms the hypothesis of the benefits of heat-sharing through multiple occupants in housing. What we can take from this is that for domestic energy consumption to reduce, energy efficiency of the housing stock would have to increase at a rate greater than expansions to both the population and to the housing stock. The key demographic driver of domestic energy consumption is therefore the number of people per household.

2.1.2 Social Drivers

Tenure influences the energy demands of housing and by implication the strategies which can be implemented to reduce energy consumption. There are two major divisions in tenure types (with several sub-divisions thereafter) between the owner-occupier households and the rented sector. Owner-occupier households are also further split in the UK Census classifications between 'owned outright', 'owned with a mortgage' and the less common 'shared ownership'. In owner-occupier housing the owners are responsible for initiating any of the insulation measures outlined in section 2.2 and would gain all of the financial and comfort benefits from lower bills and warmer housing following their investments into their properties (DECC 2010a). However, despite owner-occupiers directly benefiting from energy efficiency interventions, private owners of properties may be resistant to change that 'imposed' by Local or National Government in their private spaces (Lomas 2009, Williams *et al* 2012). Lomas (2009:190) presents reasons for this resistance, including: 'uncertainty over the final cost [of the intervention], the exposure to 'strangers' around the house, downstream teething troubles, the potential effect on property value, the possible aesthetic consequences, the up-front preparation and residual mess'. These potential resisting factors are important for the UK, where owner-occupation is the dominant tenure type and at higher proportion than in most of continental Europe. The proportion of owner-occupiers in the UK was approximately 68% in 2008 (DECC 2010a). This is a rise from 10% in 1914 (Griffiths and Wall 1998). The 'right-to-buy' policy of the 1980s led to a large number of social housing being bought by tenants at a discount (Boardman 2010), transferring ownership, control of the upkeep, and maintenance of almost two million properties from Local Authority control into private ownership (House of Commons Library 2012).

The rented sector is split in two distinct sectors; private rented and social rented (comprised of council rented and housing association). The private rented sector accounts for 14% of the housing stock, the social rented sector accounts for 18% of the housing stock (DECC 2010a). In the social rented sector, Local Authorities have direct control over the housing stock which they own, and some degree of control over the housing stock that they regulate through housing associations registered with them, and the social renting sector is approximately equally split between these two sections (DECC 2010a, Reeves *et al* 2010). Central Government directly regulates social housing although there is geographical variation in the percentage of social housing between Local Authorities (Reeves *et al* 2010). Local Authorities dedicated to reducing CO_2 emissions from the domestic sector have the ability to carry out mandatory renovations to improve the thermal efficiencies of their own dwellings (DECC 2010a). The *Warm Homes, Greener Homes* (DECC 2010a) document states that social housing has the potential to make a significant contribution towards reducing carbon emission, due to the proportion of the housing stock that is classified as social housing and the level of control Local Government has over them. DECC (2010a) note the traditionally close proximity of social housing, either on large, dense housing estates or in apartment blocks, which gives the ability to stimulate a large market for insulation materials and processes. Active attempts to improve the efficiency of social housing became prominent when the Decent Homes Standard (DHS) was introduced in 2001. The DHS was a strategy of the previous Labour Government as part of their fuel poverty reduction policy, requiring social housing to meet energy efficiency requirements (at least 50mm loft insulation and cavity wall insulation where applicable) by 2010 (Home and Communities Agency [HCA] 2012). However at the end of 2011, 7% of the four million social housing stock did not meet the DHS, with a lack of funding as a major reason for the relative lack of progress in renovating and insulating the social housing stock (Cooper and Jones 2007, HCA 2012). Whilst the social housing stock has relatively high Standard Assessment Procedure (SAP) ratings (averaging over 60), these only account for 18% of the housing stock, and is still some way below the average SAP ratings of new homes (of 80) (CCC 2012). SAP is the Government's methodology for assessing and comparing the energy and environmental performance of dwellings, of any sector.

The private rented sector of the UK housing stock differs from the social housing stock as private landlords are generally more profit oriented (Cooper and Johnson 2007). Private landlords are unlikely to undertake energy efficiency measures since it is the tenants who gain the financial rewards and improved heating conditions, while the landlords must pay the upfront costs of such installations (DECC 2010a). This is an example of the principle-agent problem in economics and referred to as the 'tenant-landlord problem' in this scenario (Griffiths and Wall 1998, Druckman and Jackson 2008). Druckman and Jackson (2008) concluded that houses in the private rented sector have on average relatively low levels of insulation as a direct result of the tenant-landlord problem. The Institution of Gas Engineers and Managers (IGEM, 2011) suggest that houses rented from private landlords have by far the worst SAP ratings. The private rented sector had average SAP ratings of 51 in 2009 compared to 61 of social housing (IGEM 2011).

Interventions to improve the UK housing stock have been focused on reducing fuel poverty, first defined by Boardman (see Boardman 2010), and subsequently used as the Government definition, as ‘a household in the UK that needs to spend more than 10% of its income on fuel to maintain a satisfactory heating regime’ (Boardman 2007, 2010, Fahmy and Gordon 2007). The majority of the ‘fuel poor’ are in the private rented sector (Boardman 2010). Any policies which attempt to improve the building fabric of the rented sector must devise strategies that take into account the tenant-landlord problem in the private rented sector. DECC’s 2010 document *Warm Homes, Greener Homes* outlines a number of plans, such as minimum efficiency standards and making cavity wall and loft insulation mandatory on rented properties by 2015 (DECC 2010a), to meet the aims of reducing fuel poverty, and to put pressure on private landlords to improve the energy efficiency of the private-rented sector. The key social driver of domestic energy consumption therefore is the tenure of the occupants, and also the prevalence of fuel poverty in the area.

2.1.3 Economic Drivers

Energy demand in the domestic sector is influenced by economic factors, primarily household income and energy prices. Economic theory suggests that an increase in the price of a good would lead to a corresponding decrease in its consumption (Griffiths and Wall 1998). The impact of price rises on demand reduction is measured by calculating the price elasticity of demand for energy consumption (Griffiths and Wall 1998), and work carried out by Summerfield *et al* (2010a) suggest that a 50% increase in energy prices would produce a 10% decrease in energy consumption, giving a price elasticity of demand of -0.2 (calculated by dividing the percentage change in demand by the percentage change in price). Utley and Shorrock (2008) in their study for the domestic energy fact file conclude that energy prices are likely to have had a relatively small impact on domestic energy consumption over the past 30 years, supporting the inelastic (i.e. a price elasticity of demand figure of less than 1) figure given by Summerfield *et al* (2010a). Alberini *et al*’s (2011) study from reviewing a number of price elasticity studies further concurs with Summerfield’s findings, suggesting that price elasticity is inelastic in the long-run across the US, but adding that it is more elastic in the short run. The conclusion from the study is that householders will immediately reduce consumption in response to price shocks but over a longer period of time they will modify their expenditure patterns to accommodate price rises and maintain similar levels of consumption. So while we can suggest it is well understood how energy prices impact energy consumption over time, it remains unclear how geographical differences in energy prices impact energy consumption across a country such as the UK.

Income affects dictate the affordability of energy consuming products, the ability to meet the costs of achieving higher internal temperatures, and the ability to have longer heating periods (Haas and Schipper 1998). Summerfield *et al* (2010b) recorded from a study of 36 low energy houses in Milton Keynes that the top 30% of households by income used more energy than the remaining 70% of households combined. This appears to support the recent findings from DECC (2011c), who found from their analysis in NEED that household income is the second largest factor behind the size of the house in influencing domestic electricity and gas consumption in the UK. Furthermore, studies from Wiesmann *et al* (2011) and Bianco *et al* (2009) determine that household income is a dominant factor in the level of electricity consumption in Portuguese and Italian households respectively, while Druckman and Jackson (2008) highlight the link between household income and heating energy in their study of UK domestic gas consumption patterns. What we can take from this is that there is unlikely to be a simple linear relationship between income, energy prices and energy consumption (Haas and Schipper 1998, DTI 2002). Alberini *et al* (2011) note that the impact of energy price increases become less influential on energy consumption as incomes rise, while Brown *et al* (2009) suggests there may be an 'inverted-U' relationship between energy consumption and income, with energy consumption reaching a peak as incomes rise and then beginning to decline. The key economic drivers of domestic energy consumption therefore are household income and energy prices.

2.1.4 Technical Drivers

Technical factors describe the condition, size and physical attributes of the building stock. These technical factors have a major impact on the level of energy demand in the domestic sector, especially concerning space heating. The Energy Saving Trust (EST) (2011:1) state that: 'understanding the energy performance of the housing stock is the first step towards developing a comprehensive and effective energy strategy'. The quality, age and construction of the housing stock vary geographically, and particularly the age and size of the housing stock has a big impact on the energy needed to achieve levels of thermal comfort. Houses built since 1990 are 40-50% more energy efficient than the national average, while housing built before 1919 is the most thermally inefficient (Lowe 2007, Boardman 2007). This is because older pre-war houses were built with solid walls which are less effective at retaining heat and are tougher to insulate than post-war cavity wall housing, and progressively stricter building regulations have been applied to modern house construction. Druckman and Jackson (2008) suggest that even after many older dwellings have had energy efficiency improvements installed there still remains a close correlation between age of property and its energy efficiency. Building regulations were enforced after 1976. These regulations set minimum insulation standards and so solid walls, un-filled cavity walls, single glazing and un-insulated roofs were common construction features prior to this (Dowson *et al* 2012). The improvement in thermal properties is a result of stricter building regulations, technical advances, and improved construction. Yet despite the UK Government's aspiration for housing built after 2016 to be *zero carbon* with regard to heating demands, the existing housing stock has a long lifespan with construction standards pre-dating modern energy and thermal comfort standards (defined as an internal temperature of 21°C) (HCA 2012, Wilkinson *et al* 2007). A recent study by DECC (2011a) has demonstrated that within a sample of 3.5 million houses that houses built between 1919 and 1945 have median gas consumptions 12% higher than the national median but also 7% higher than the median of pre-1919 houses. These findings suggest there are other factors that affect domestic energy consumption not just simply the age of the housing stock.

The size and type of house can have a major influence on the demand for heating energy as houses with a larger floor area, greater number of rooms, and a larger number of exposed walls are likely to require more heat to achieve thermal comfort (Boardman 2010). Baker and Rylatt (2007) discovered from a study of 148 dwellings across Leicester and Sheffield, using correlation and multiple regression analysis that the number of bedrooms appeared to be the strongest predictor of domestic energy consumption, accounting for almost 35% of the variation in household gas and electricity consumption in the study. There is expected to be a strong positive correlation between the number of bedrooms, the number of children, the number of occupants and the floor area of the house, which is supported by the findings from the Baker and Rylatt study. Detached housing is considered to have the highest energy demands due to the lack of shared walls and large floor areas (Yao and Steemers 2005, Utley and Shorrock 2008, DECC 2011a). Inner city blocks of flats are thought to be the most efficient since they allow for heat sharing with neighbouring residents and have relatively small floor areas (Druckman and Jackson 2008, Boardman 2010). Druckman and Jackson (2008) have modelled the average heat loss of the main dwelling types in the UK, stating the watts per °C (the rate of energy required to increase the average internal temperature by 1°C). This is presented in Table 2.1 below.

Table 2.1 Average Heat Loss in UK Dwellings (Source: Druckman and Jackson 2008)

Type of Dwelling	**Heat Loss (Watts/°C)**
Detached	365
Semi-Detached	276
Terrace	243
Bungalow	229
Flat	182
Average	259

This information is important for Local Authorities as the composition of their local housing stock will determine their feasible energy reduction targets and what action they can take to improve energy efficiency (Druckman and Jackson 2008). Boardman (2010:133) highlights the relationship between housing density and house types, suggesting that 'there is a relationship between built form and housing density: more detached homes in rural areas and more flats and terraced houses in city centres'.

For Local Authorities, knowledge of the primary heating fuel is important when implementing heating energy efficiency policies. All households are connected to the electricity grid, while the number of houses disconnected from the gas grid is quoted to be 4.3 million customers in Great Britain, 17% of the housing stock (Boardman 2010). Rural areas are more likely to lack a connection to the gas grid (Boardman 2010). A different set of interventions may be appropriate to households which are not connected to the gas grid. Knowledge of housing using electric heating is vital to calculate electricity consumption benchmarks (as electrically heated homes would be expected to have higher electricity demands). The key technical drivers of domestic energy consumption therefore are: the age of the house, the size of the house, the type of house, and whether or not the primary heating fuel is domestic gas.

2.1.5 Climatic Drivers

External air temperature is generally accepted as a driver of demand for internal space heating and cooling energy (Chartered Institute of Building Services Engineers [CIBSE] 2006, Utley and Shorrock 2008). IGEM (2011) demonstrate that winter temperature correlates strongly with gas use, citing weather as a key factor in fuel poverty rates across the country, and demonstrating that the external air temperature (through heating degree days) has a direct relationship with the level of gas consumption in English housing. This is in agreement with the work of Summerfield *et al* (2010a), who in their study of benchmarking UK domestic energy; model the impact of average heating season air temperature on heating energy over time. This was done using a multiple regression model to measure energy consumption changes as a result of efficiency improvements as opposed to changes in weather. From their research they observed that a 1°C increase in temperature leads to an approximate 5% decrease in energy demands. This is an attempt to quantify the relationship between external climate and domestic energy consumption.

The approaches taken by Summerfield *et al* (2010a) and Weismann *et al* (2011) use Heating Degree Days (HDD) as a proxy for external air temperature. Heating Degree Days are a function of the length of time the external air temperature is below a specified base temperature, and how far below the base temperature the air temperature is (CIBSE 2006, Layberry 2008), giving a linear relationship between temperatures below the base temperature and heating energy demands of buildings (Reiss and White 2005, CIBSE 2006, Environmental Change Institute [ECI] 2011). CIBSE (2006) give this example for heating degree-day calculated to a base of 14°C:

> "On day 1 a base temperature of 14°C and a mean outdoor temperature of 7.3°C will give 6.7 degree-days (or K-day) for that day. On day 2 the mean outdoor temperature is 9.4°C to give 4.6 K-day. For these two days there is a total of 6.7+4.6=11.3 K-day. It is usual to use degree-day sums over suitable periods, for example monthly, seasonally or annually".

15.5°C is the base temperature most consistent with academic work in the literature, based on the notion that 18°C is the 'comfort' level for internal temperature, and that the presence of heating gains from appliances and solar gains are adequate to achieve comfort internally when the external temperature is 15.5°C (CIBSE 2006, Layberry 2008, Meier and Redhanz 2010, ECI 2011). A well run building should have a heating energy use which is proportional to the number of degree days for the time period (ECI 2011), and a higher the number of heating degree-days indicates colder weather, while a lower number indicates milder weather (CIBSE 2006). Therefore, the key climatic driver of domestic energy consumption is the external air temperature (given by heating-degree days).

2.1.6 Personal Attitudes as Drivers

Ultimately, energy consumption within the house is dependent on the individual preferences and behaviours of the residents. Behavioural and personal characteristics are notoriously difficult to quantify, monitor and measure for policy makers (Owens and Driffill 2008). Household preferences impact on gas consumption primarily through the chosen heating periods and internal air temperatures for households but for electricity consumption this is more complicated (Fischer 2008). MacKay (2009) makes explicit note of the potential carbon savings from the domestic sector by householders reducing thermostat levels. Whilst there are financial savings to be made by reducing heating levels, internal temperatures of 23-25°C are reported (Roberts 2008, Dowson *et al* 2012), and this is above the thermal comfort definition of 21°C. Energy behaviours, particularly for heating regimes are guided by habitual behaviour and the influence of social norms rather than rationality (Caird *et al* 2008, Lopes *et al* 2012).

Electricity consumption is usually dependent on appliance use, based around many diverse activities from listening to music, working at a computer or washing clothes (Fischer 2008, Ravetz 2008). The past 30 years has seen a proliferation of electrical appliances, but also the level of electrical energy required to operate these devices, and the increasing lengths of time that these are used for. Ravetz (2008) gives examples of this increased 'appliance diversification', such as: air conditioning, patio heaters, wide screen televisions, clothes driers, walk-in refrigeration and advanced security systems. Electricity consumption is often not considered by consumers of these goods and there is a complex relationship between the level of technology and social norms (that influences the consumption of electricity) and the interpretation of energy information presented to consumers (Lopes *et al* 2012). Overall, energy efficient behaviours often lack lifestyle benefits (such as turning off stand-by functions) and therefore there is a lack of motivation to engage in them, particularly if the economic costs of 'inefficient' behaviour is small (Caird *et al* 2008, Lomas 2009).

2.2 Methods to Reduce Domestic Energy Consumption

There has been a growing recognition by the UK Government that the levels of thermal efficiency in UK dwellings need to be improved to meet overall climate change targets. This has been affirmed by DECC publications since 2010 which emphasise the need, and potential strategies for, reducing domestic energy consumption. According to Alfredsson (2004), there are two main methods put forward to reducing energy consumption from housing: technical changes and behavioural changes. Each of these will now be discussed in turn.

2.2.1 Technical Interventions

Given that the UK's housing stock is one of the oldest and least efficient in Western Europe, with millions of properties containing poorly performing solid walls, single glazing and un-insulated roofs and floors which are responsible for a significant amount of wasted heat (Boardman 2004, Dowson *et al* 2012), there is significant potential to improving the energy efficiency of the domestic sector by improving the condition of the existing stock. Johnston *et al* (2005) believe it is unlikely that the UK will be able to achieve significant savings from the domestic sector without achieving significant reductions in domestic energy demand, stating that achieving the UK's [now 80%] carbon dioxide emissions targets will likely require 'a significant increase in the rate at which fabric and end-use efficiency measures are currently being implemented into the UK housing stock' (Johnston *et al* (2005:16). Building regulations in the domestic sector have been strengthened, increasing the energy efficiency of new additions to the housing stock, and reducing the demands for gas required to reach the levels of thermal comfort. Improving the thermal efficiency of the existing housing stock should lead to reductions in the amount of energy required for space heating. Not only this, but electricity consumption is a growing phenomenon in the domestic sector, whilst the academic focus on technical interventions have primarily focused on reducing space heating demands (BERR 2008, Lomas 2010).

Methods of reducing domestic energy consumption are demonstrated by Firth and Lomas (2009) who noted in a study of housing in Leicester that a 40% reduction in domestic CO_2 emissions could be met by improving the thermal property of the housing stock and the introduction of appliances with greater levels of energy efficiency. In their account, Firth and Lomas go on to outline how this reduction would be achieved by insulating all solid and cavity walls, installing 300mm of loft insulation in all lofts, converting all boilers to condensing gas boilers, replacing all windows with double glazing, and gain 100% uptake of low energy cold appliances, low energy lighting and low standby power devices. If we were to take just one of these, DECC's analysis for NEED suggests installing cavity wall insulation produces 15-17% efficiency savings in gas consumption, though it should be noted this is dependent on the house type. Taking this one stage further, IGEM's (2011) strategy for reducing fuel poverty in the UK, through improving levels of energy efficiency, suggests that a reduction of 45-55% in the energy needed for heating can be achieved by adding loft, wall and floor insulation.

One note of caution is that increasing the energy efficiency in the housing stock does not always lead to expected reductions in energy consumption. Where energy efficiency interventions do not generate the estimated reductions in energy consumption it is termed *rebound.* Improving the energy efficiency of the housing stock may actually have the effect of householders increasing their heating periods, increase their internal temperatures, or to heat rooms that could not previously be heated (Greening *et al* 2000, Sorrell 2007, Madlener and Alcott 2009). Rebound is defined as where 'some or all of the expected reductions in energy efficiency improvements are offset by an increasing demand for energy services' (Barker *et al* 2007:4935). To illustrate one example of how the rebound effect can occur in the domestic sector, the European Energy Agency (EEA) (2008) have noted that the level of thermal comfort (i.e. the temperature of, and length of time in the heating period) has increased over time, negating some of the efficiency gains from insulation measures and improved heating systems. More specifically, we can see how, with the advent of central heating and double glazing in the UK the average internal room temperature is estimated to have risen from 13°C in 1970 to almost 19°C in 2001 (Lowe 2007, Allen and Hammond 2010). This is an important concept to consider when measuring energy efficiency improvements in the domestic sector, since there is likely to be a discrepancy between the energy efficiency measures installed in housing (and their theoretical energy consumption reductions) and the actual reductions in domestic energy consumption. Added to this, there are problems with practically applying theoretical measures to improving the technical efficiency of the housing stock. For example solid wall insulations are hindered by restrictions on modifying the external walls of housing, e.g. because of conservation areas and the need for planning permission (Dowson *et al* 2012). There are also factors which hinder the uptake of technical interventions due to the disruption to everyday life of the occupants of the households (Caird *et al* 2008). Downson *et al* (2012) cite under-floor heating, which is often only installed during a larger scale refurbishment of the flooring of the house due to the disruption that the installation would cause to the occupiers. It is not just the knowledge of technical interventions that will reduce energy demand in the domestic sector, but also a mechanism to encourage uptake that is important. Not only this, there is often a reluctance, or resistance to the uptake of technical interventions. In the Williams *et al* (2012:139) study of suburban England, it is stated: 'suburbs are also often places where residents feel and value a sense of propriety and control. In this context proposed changes to homes and neighbourhoods are often viewed as direct threats to resident rights'. Focusing solely on technical knowledge will not bring about the required energy savings without also addressing occupant behaviour, and this behavioural and attitudinal aspect is important when the proposed technical interventions involve a degree of invasion into people's personal spaces.

2.2.2 Behavioural Change

Unlike with technical interventions to improve energy efficiency, behavioural change actively requires changing householders' activities and living environments to achieve reductions in energy consumption (Alfredsson 2004). One immediate consequence of this is the outcomes of these methods are more difficult to predict than technical energy efficiency interventions. One starting point that might be considered for behavioural change policies is MacKay's (2009) suggestion that energy efficiencies in space heating can be best achieved by adjusting the thermostat to be closer to the external air temperature or by only heating rooms that are being used by the residents. But alongside this, and in the context of this study, is the Government's launching of a scheme to enable residents to directly monitor their energy consumption through smart metering. This is clearly indicative of a move towards energy reduction demands through behavioural change (Wilks 2009).

Behavioural change is clearly an important step change in the approach to meeting energy reduction targets because prior to smart meters, and indeed still the case for the majority of householders, are only made aware of their energy consumption when they receive a utility bill. There has been a recent trend from energy companies to display comparisons of consumption levels over time and against neighbours on energy bills, but this is still in its infancy. One way of both quantifying, and potentially inducing change in energy behaviours is through the introduction of smart meters. Smart meters are an example of consequence strategies, which aim to change the consequences of energy consumption behaviour (Steg and Vlek 2008, CCC 2012). Wood and Newborough (2007) and Fischer (2008) are both sceptical of the role smart meters can play in reducing domestic energy consumption, suggesting that providing information about energy consumption from appliance use could provide too much complex information and create confusion. From a policy perspective, the energy savings that result from behavioural change and identification of exactly what led to them is difficult. The precise nature of these difficulties is addressed in chapter 4 following consultation with Local Authority representatives.

In contrast to consequence strategies; there are also numerous *antecedent* behavioural strategies, which aim to change the factors that precede behaviour through education and information provision. Here the EU have been an important institutional actor, implementing policies to display energy efficiency certificates on many large appliances such as televisions and fridges (EEA 2008). Critically these energy efficiency certificates also highlight the differences between energy efficiency and energy consumption because a fridge that is more energy efficient may still use more overall energy than an alternative, less efficient but smaller fridge. In 2011 the UK phased out the sale of incandescent light bulbs, following the EU verdict that the sales of these light bulbs should be banned from 2010 onwards (EEA 2008). Upgrading the light bulb stock should prove to be relatively easy due to the short product life-span and the relatively low replacement cost of light bulbs. However even this measure was met with some opposition within the UK with some residents being unhappy with perceived government intrusion in their lives, perhaps best summarised by an article in the British newspaper *The Independent* (2009). The complexities of householder behaviour in the context of energy is best summed up by Allcott and Mullainathan (2010:1), who state: 'Historically, energy efficiency has been a leading example of the difficulties in inducing people to change behaviours and adopt new technologies, even when it appears to be in their own financial interest'. This phenomenon is exacerbated by the UK Government's focus on heating and renewable energy whilst the 'burgeoning' electricity consumption and behavioural change strategies have been overlooked (Leaman *et al* 2010).

2.2.3 Current Applications for Interventions

The UK has one of the worst energy efficiency levels in Western Europe (Boardman *et al* 2005). By 2016 it is envisaged by the Government that new build housing will be designed and constructed to be *zero carbon*, as set out in the 2006 document *Code for Sustainable Homes* (Department for Communities and Local Government [DCLG] 2006a). The *Code For Sustainable Homes* states there will be interim progress towards this *zero carbon* target through changes to part L of the Building Regulations (conserving heat and power) by making technical improvements to energy efficiency a legal requirement in the construction of new houses (Boardman 2007, DCLG 2006a, DCLG 2010a).

The current domestic energy efficiency policy in the UK is the Green Deal. The Green Deal is designed to allow households to cover the upfront costs of energy efficiency installations to their house through a loan which is secured on the property and paid back through the reductions in householder's energy bills (HM Government 2011a, DECC 2011a). Interventions under the Green Deal must meet the Government's *Golden Rule* target, where the costs to pay for the Green Deal measures is less than the energy cost savings that result from the interventions (DECC 2011a, HCA 2011, IGEM 2011). This ensures that the estimated savings on energy bills are equal to or greater than the payback costs of the loan which are added to consumer energy bills (DECC 2011b, Dowson *et al* 2012). Alongside the Green Deal, the Energy Company Obligation (ECO) obliges energy companies to cover the costs of energy efficiency measures for lower income households. The ECO is primarily aimed at stimulating installations of solid wall insulation (DECC 2011a/b, CCC 2012). The measures listed in Table 2.2 are available under the Green Deal (DECC 2012b), for each one an indicator is given of the ECO scheme under which it can be installed. As can be seen from these measures, the primary focus of the Green Deal is to improve the technical efficiency in the housing stock, with little focus on behavioural aspects. The biggest barriers to providing energy efficiency interventions under the Green Deal are the inability to accurately determine potential energy savings given occupant behaviour, and potential errors in predicting energy consumption from building energy models (Lomas 2009, Dowson *et al* 2012). Added to this, the Green Deal does not take into account the non-monetary factors that reduce the desire for energy efficiency interventions highlighted by Lomas (2009) such as the disruption to lifestyle, impact on house prices and changes to aesthetics. What are needed are policy guidelines, and monitoring frameworks that are flexible enough to recognise the differing strategies available to reduce domestic energy consumption and not solely to focus on improving the physical properties of the housing stock.

Table 2.2 Interventions Available Under the Green Deal (Source: DECC 2012b)

Measures	**ECO Scheme Availability**
Air Source Heat Pumps	Affordable Warmth
Biomass Boilers	Affordable Warmth
Biomass Room Heaters	Affordable Warmth
Cavity Wall Insulation	Affordable Warmth
Cylinder Thermostats	Affordable Warmth
District Heating	Affordable Warmth, Carbon Saving Communities
Draught Proofing	Affordable Warmth, Carbon Saving Communities
Hot Water Showers	Affordable Warmth
Hot Water Systems	Affordable Warmth
Hot Water Taps	Affordable Warmth
External Wall Insulation	Affordable Warmth, Carbon Reduction, Carbon Saving Communities
Fan-Assisted Replacement Storage Heating	Affordable Warmth
Flue Gas Heat Recovery Devices	Affordable Warmth
Ground Source Heat Pumps	Affordable Warmth
Heat Controls (for wet central heating system and warm air system)	Affordable Warmth
Heating Ventilation and Air-Conditioning Controls	Affordable Warmth
High Performance External Doors	Affordable Warmth
Hot Water Controls (including timer and temperature controls)	Affordable Warmth
Hot Water Cylinder Insulation	Affordable Warmth
Internal Wall Insulation (of external walls) Systems	Affordable Warmth, Carbon Reduction, Carbon Saving Communities
Lighting Systems, Fittings and Controls	None
Loft or Rafter Insulation	Affordable Warmth, Carbon Saving Communities
Mechanical Ventilation and Heat Recovery	None
Micro Combined Heat and Power	Affordable Warmth
Pipe-Work Insulation	Affordable Warmth
Photovoltaics	None
Chillers	None
Gas-Fired Condensing Boilers	Affordable Warmth
Replacement Glazing	Affordable Warmth, Carbon Saving Communities
Oil-Fired Condensing Boilers	Affordable Warmth
Warm-Air Units	Affordable Warmth
Radiant Heating	Affordable Warmth
Roof Insulation	Affordable Warmth, Carbon Saving Communities
Room in Roof Insulation	Affordable Warmth, Carbon Saving Communities
Sealing Improvements	None
Secondary Glazing	Affordable Warmth, Carbon Saving Communities
Solar Water Heating	Affordable Warmth
Solar Blinds, Shutters and Shading Devices	None
Transpired Solar Collectors	None
Under-Floor Heating	Affordable Warmth
Under-Floor Insulation	Affordable Warmth, Carbon Saving Communities
Variable Speed Drives for Fans and Pumps	None
Waste Water Heat Recovery Devices Attached to Showers	None
Water Source Heat Pumps	Affordable Warmth

2.3 Policy Context in the UK

In 206 academic papers published in the *Energy Policy* journal Keirstead and Schulz (2010) found that less than 10% of articles focused on sub-national energy policies. This is important in the context of this present study because it suggests research at the subnational level is an often overlooked component of the academic literature on energy policy in general, and from this, energy *reduction* policy in particular. The need for more detailed research in this area becomes obvious when considering the arguments recently put forward in the work of Keirstead and Schulz (2010) and Sovacool and Brown (2009), who recommend a blending of centrally prescribed 'top-down' policies and locally developed community 'bottom-up' schemes as the optimum approaches to energy policy.

This argument can be seen to develop from Schruers (2008), who concludes that successful bottom-up policies developed at the local level can feed-up to the national scale to meet Central Government targets. The importance attached to this view is it suggests there is a necessity to move away from the 'one-size-fits-all' policies imposed by Central Government (Leach and Percy-Smith 2001, Stoker 2004). In principle, what the former approach offers is an opportunity for local communities to modify national policies and for national policy to be shaped by innovative community schemes (Leach and Percy-Smith 2001). On paper, the Localism Bill, launched in 2011 by the UK's Coalition Government (see: Department of Communities and Local Government [DCLG] 2011) is seen as giving communities and individual citizens 'more direct information about how their local public services are run, and have more direct powers to influence and hold to account public services' (Lowndes and Pratchett 2012:8), but as is always the case with localist approaches, it remains to be seen if the reality matches the rhetoric (Harrison 2008).

2.3.1 Organisation of Local Government in England

Local Government in England is a mix of single and two-tier councils. Local Authorities in England mainly differ between rural and urban areas. A single-tier of Local Government commonly exists in urban areas, with the local council responsible for delivering education, social care, land use planning, housing, waste management and the running of libraries and leisure services. In rural areas, there are predominantly two-tier set ups, with the larger county councils administering education and social services, and the smaller district councils providing environmental, welfare and regulatory functions (Stoker 2004, Walker and Boyne 2006). Crucially in the present context it is the district councils that have responsibility for energy policy in two tier-councils.

The John Major-led Conservative Government of the early 1990s sought to implement a single tier of unitary authorities in non-metropolitan counties (metropolitan counties underwent this shift in the 1970s); however county councils were able to fight a successful campaign against this motion (Stoker 2004). The result is that while many Metropolitan authorities are now free of county council control, with their own finance and budgets - district councils remain as smaller units and have their power and finance constrained by their county councils (Stoker 2004). The consequence of this is the housing sector is currently the responsibility of the district councils, and Local Authorities are expected to direct resources and implement energy efficiency schemes within their boundaries in partnership with communities and private enterprise (DECC 2011a,b). Green and Orton (2012) question if the fragmentation of Local Government in England renders an effective localised public policy impossible. Given the complex nature of Local Government in England, the enquiry in this project and the generation of benchmarks took place using census units. These are free from political and administrative pressures, but provide the building blocks of larger administrative authority units.

2.3.2 Relationship between National and Local Government in England: Agreements and Target Setting

Traditionally, UK energy policy has been heavily centralised and devolution of energy policy to sub-national authorities would be seen as a dramatic change in attitudes (Smith 2007). This conforms to the wider UK political culture, which is seen as one of the most centrally controlled states in Western Europe (Leach and Percy-Smith 2001, Bulkeley and Kern 2006). In the late 1990's, the then Labour Government introduced a series of reforms to Local Government, devolving certain decision making-powers to sub-national authorities to operate within a framework set out by Central Government (Leach and Percy-Smith 2001, Stoker 2004, Smith 2007, Roberts 2008). Transferring power and responsibility from Central Government to Local Authorities can lead to friction between the two levels of Government. This is particularly acute with target setting and monitoring which is a way of Central Government to maintain control over Local Government – a situation particularly acute in the UK under previous Labour Governments where a target-setting culture set in. Specifically with regard to energy policy, Keirstead and Schulz (2010) highlight how Local Authorities garnered little support from National Government due to financial constraints and also ideological differences especially where the Local Authority was led by a party other than that which was nationally elected. Under Labour, Local Authorities were increasingly expected to carry out energy efficiency schemes in conjunction with other organisations and take on the 'enabling' role that would facilitate voluntary and private sector activity (Bulkeley and Kern 2006). One of the major difficulties of this 'enabling' role was that it became increasingly difficult to point to deliverables, when these were dependent on other organisations. In-spite of this, Labour remained steadfast measuring Local Authority performance through an array of nationally set targets.

The previous Labour Government was regularly described by political commentators as having a 'strong preference for targets, performance indicators and regulation' (Stoker 2004:225). A leading governance expert in the UK, Stoker (2004) explains that the attitude of the Government at the time was on performance measurement and identification of 'best practice', accompanied by top down regulation. For Local Governments, this target and performance indicator culture was highlighted when DCLG implemented the Local Area Agreements (LAA), the most recent of which ran from 2008-2011. The LAAs consisted of 198 National Indicators (NI) which Local Authorities would choose 35 to have their performance monitored against (DCLG 2009).

DCLG conducted feedback sessions with ten Local Authorities (Bournemouth, Cornwall, Hammersmith and Fulham, Norfolk, Nottingham, Reading, Rochdale, Sheffield, South Tyneside, and Wolverhampton) to discover the steps these local authorities had taken to promote local development and which NIs were chosen to achieve this (DCLG 2009). DCLG identified five key areas which were significant in influencing the selection of NIs within the LAA: capacity and deliverability, types of indicators available, data availability and analysis, funding, macroeconomic conditions. One crucial finding to emerge from DCLG's 2009 report was that although there had been a growing interest in the relationship between economic development and environmental sustainability by Local Authorities, there was little interest in pursuing the primary CO_2 emissions indicator, NI 186 (per capita CO_2 emissions in Local Authority Area). This apathy towards NI 186 was primarily as a result of concerns over data availability appropriate to the local economy and the lack of funding available to deliver beneficial outcomes (DCLG 2009). But it also suggests a more fundamental concern with target setting for energy efficiency policy interventions, specifically the ability to calculate the CO_2 emission reductions that are a direct result of Local Authority policy action.

Howell and Nakhle (2008), commentating on energy policy in the UK, are critical of the politics behind target setting, and criticise Governments and organisations for setting aspirational or overly demanding targets well into the future. They argue that these future targets are set and raised without making enough short-term progress towards achieving them, and that politicians being elected on short terms have little incentive of risking short-term hardship in pursuit of a long term target. While this criticism is primarily aimed at National Government, it is also applicable to Local Government. Local Councillors seeking re-election are likely to be unwilling to jeopardise their chances of winning by implementing policies that offer little short-term gain, or even cause short term disadvantage, especially for a scheme that is not mandatory (Howell and Nakhle 2008). Related to this, Local Authorities may feel the need to be seen to be 'doing something' rather than implementing a longer term policy that doesn't grant immediate results (Keirstead and Schulz 2010). Jefferson (2008) was critical of the UK's energy policy, citing Local Authorities as facing no accountability or penalty and called for the abolition of targets, deriding them as 'unrealistic' and 'irritating'. While some may be in agreement with the sentiments of Jefferson, the UK has to meet its energy reduction targets irrespective of the political environment within which Local Authorities have to work.

2.3.3 Energy Policy under the Previous Labour Governments (1997-2010)

Under the LAA, Local Authorities were required to select 35 indicators against which their performance would be measured over a three year period (DCLG 2007, 2009). Of the national indicators listed, it was the aforementioned NI 186 which is of most relevance to this project. A related indicator was NI 187 (tackling fuel poverty - people receiving income based benefits living in homes with a low energy efficiency rating) (DCLG 2007). As highlighted in the previous section, the NIs relating to energy efficiency were not compulsory for Local Authorities, and Local Authorities were responsible for setting their own per capita CO_2 targets. One suggestion is that Local Authorities pursuing NI 186 may have set targets that lacked ambition, which were easy to obtain but did not make any meaningful contribution towards reducing domestic energy consumption and therefore national CO_2 emissions (DCLG 2009). One consequence of this perception was that DECC moved quickly to introduce a Local Carbon Framework to build on the national indicators, whereby Local Authorities were required to set themselves 'stretching' targets to reduce CO_2 emissions within their boundaries and develop a framework for achieving them (DECC 2010a). This framework did not set out clear guidelines on what constituted a 'stretching target', or guidance on how to monitor progress towards these targets. These are key objectives if a localised approach to reducing domestic energy consumption is to be successful. Allowing Local Authorities to set their own targets based on their own local knowledge of their areas and communities is seen as a positive step, and deciding what is successful does require *local judgement* (Leach and Percy-Smith 2001, Stoker 2004). Further statements of the role in Local Authorities in conducting energy policy was highlighted by the 2010 DECC release of *Warm Homes, Greener Homes*, which indicated that Local Authorities were to become the front line in efforts to reduce domestic sector energy consumption and CO_2 emissions (DECC 2010a, Sunikka-Blank *et al* 2012).

Despite emphasising the roles of Local Authorities in conducting local energy policy, the previous Labour Government's strategies to improve the energy efficiency of the domestic sector remained heavily centralised. One of the flagship schemes of this era was the *Warm Front* strategy, which was primarily aimed at meeting the target of eliminating fuel poverty by 2012 through installing energy efficiency measures in housing. It was developed in 1999 to address the main causes of fuel poverty: poor energy efficiency of the home, the price of energy, and low household incomes. Under the scheme it was energy efficiency that had the biggest priority (Boardman 2010, DECC 2011b). As well as being a symptom of an energy inefficient house, fuel poverty is seen as a major implication for health problems (both physically and mentally) and therefore reducing fuel poverty through Warm Front was a headline policy of the Labour Government (Critchley *et al* 2007, Boardman 2010). Warm Front enabled low income householders to apply for £2500 for home energy efficiency improvements if they met eligibility criteria (Gilbertson *et al* 2006). Conducting interviews with recipients of the Warm Front scheme, Gilbertson *et al* (2006) found that having Government-funded intervention to improve household energy efficiency was a more effective method in improving the housing stock than providing tax-breaks or other monetary incentives. In their research they showed how 80% of the respondents stated that given the money themselves outright, they would have 'spent it on heating' rather than on the long term energy efficiency improvements to their house. This was supported by the UK Government's own analysis, with the National Audit Office estimating that Warm Front saved householders on average £360-£400 (IGEM 2011).

A second important strategy implemented by the post-1997 UK Government was the Energy Efficiency Commitment (EEC), which placed the emphasis for energy efficiency on energy supply companies with more than 50,000 domestic consumers (DEFRA 2008, CCC 2012). The extension of the scheme to 2012, under the Carbon Emissions Reduction Target (CERT) label introduced a higher target for CO_2 emissions with greater emphasis on insulation measures (see HCA 2012). CERT did not have a specific objective to reduce fuel poverty and so it was the Community Energy Saving Programme (CESP) which ran in conjunction with CERT and placed a priority on the bottom 10% of LSOAs ranked by the income section of the Index of Multiple deprivation (Druckman and Jackson 2008, HCA 2012). The CESP 'community approach' arose out of the belief that interventions which are targeted at groups of homes in an area should improve efficiency and lower costs for contractors as well as helping to build a sense of community action (IGEM 2011). The main limitations of CESP were the geographical constraints, as Local Authorities found that LSOAs did not always correspond to neighbourhoods or housing estates, and the narrow definition of deprivation derived by income (HCA 2012). Both the CERT and CESP strategies were developed at the national Government level, with Local Authorities playing the role of identifying eligible households with little power to modify the eligibility criteria for targeting areas for intervention. As discussed in chapter 4, it was the prescriptive criteria of CESP, sticking rigidly to LSOA boundaries that impacted on the success of the scheme.

2.3.4 Energy Policy under the Conservative - Liberal Democrat Coalition Government (2010-Present)

The Conservative-Liberal Democrat Coalition Government has wasted little time in producing new policies, strategies, and acts in energy policy. Most notably, the 2011 Energy Act sets out plans detailing the roll out of the Green Deal and ECO schemes (HM

Government 2011a). The current 2012-13 Energy Bill, which is to undergo its third reading in the House of Commons, highlights a proposed ‘decarbonisation target range’. This ‘decarbonisation range’ would be a range for the carbon intensity of electricity generation based on economic and fiscal conditions, social considerations (specifically the effects on fuel poverty), and technological development (UK Parliament 2013). These strategies are proposed for a national scale but do not actively target reducing household energy consumption. In terms of domestic energy reduction, DECC has placed emphasis on Local Authorities to have a major role in energy reduction policies. This is based on the belief that Local Authorities have an advantage over centralized government in being able to adapt policies to best suit the needs of their communities and residents (DECC 2010a, 2012a). The Green Deal consultation emphasises Local Authorities roles in promoting the scheme due to the *trust* that Local Authorities have from their residents (DECC 2012a, IGEM 2011). Local Authorities are expected to play the role of provider; partner and promoter of the Green Deal, directing private companies to areas which would experience the most benefit from energy efficiency schemes, providing their own finance to improve the standard of the housing stock and galvanising community support to participate in the scheme (DECC 2011c/d). Under this scenario, Local Authorities are expected to continue with the strategy of the previous Government’s plans and undertake energy efficiency measures in partnership with other organisations. This strategy blurs the distinction between autonomous changes (e.g. owner-occupiers undertaking schemes for their own benefit) and planned changes (e.g. Local Authorities carrying out retrofits for the public good), which is highlighted by Williams *et al* (2012). But returning to a key point emerging from these debates is that while the Coalition have been strong on the aspiration for these policies and initiatives, the success will almost certainly be dependent on the monitoring and targeting frameworks which are established alongside them.

There have been moves towards greater local involvement in energy efficiency programmes. CCC produced a report in 2012 entitled *How Local Authorities can reduce emissions and manage climate risk* which set out two aims:

1. "How Local Authorities can be encouraged to show strong leadership and responsibility in cutting carbon emissions both from their own estates and operations and those arising within their areas; and
2. Benchmark levels for the scale of ambition that Local authorities might appropriately set themselves, possible approaches to deliver that ambition and how this would contribute to the national carbon budgets" (CCC 2012:8).

However with funding cuts to Local Authorities of up to 26% in real terms between 2010 and 2015, and the abolishment of Local Area Agreements and National Indicators, it is unclear how this localised energy policy and benchmarking strategy will materialise at a local scale, and the 2012 update to Home Energy Conservation Act (HECA) indicates that in the short-term at least, it is a national benchmarking system that will be used (DECC 2012a). Fudge *et al* (2012) believe that despite the abolition of the NI186 performance indicator, the continuation of data publications still enables Local Authorities the opportunity to implement and measure progress in reducing energy consumption in their boundaries.

2.4 A Justification for Energy Consumption Benchmarks

The ECO publications of 2011 outlined plans to research ways in 'which Government might be able to help energy companies find households' for uptake in the ECO scheme (DECC 2011b). DECC (2012a) have since indicated that they will provide resources to Local Authorities that will enable them to meet their local energy consumption obligations such as tracking emissions over time and helping identify particular areas to target. Since 2007 DECC has been publishing residential gas and electricity consumption statistics below Local Authority level 'to allow LAs and other interested bodies to more easily target specific areas as part of the implementation and monitoring of local energy strategies' (DECC 2010c:1), and a catalogue of data from 2005 has been published on the DECC website (DECC 2012b). Prior to the creation of DECC, it was DEFRA which had the responsibility for domestic energy consumption, and in 2008, DEFRA stated that Local Authorities will benefit from publications on emissions on an end-user basis (i.e. at household level) as this will aid in more accurately targeting efficiency measures. The DECC publications from 2011 and 2012 concerning NEED and HECA indicate a commitment towards a quantitative approach towards benchmarking energy efficiency in local areas. This is an approach favoured by Leaman *et al* (2010:570) who state that 'benchmarking against empirically derived yardsticks is now a standard requirement for energy and occupants'. DECC themselves have acknowledged potential ways in which their data could be analysed, stating:

> "DECC has developed a means to use this data and compare it with modelled levels of domestic gas consumption below Local Authority level. Having taken into account local conditions, this data gives authorities the ability to identify where gas consumption in residential accommodation is higher than would normally be predicted – implying lower levels of efficiency in homes in the area' (DECC 2012a:10)

2.4.1 Using Raw Data

Simply using the raw consumption data published by DECC may have the effects of masking benefits that certain areas may gain through their economic structure, climatic factors and other external circumstances which influence domestic energy consumption (Keirstead and Schulz 2010). As discussed in section 2.2.2, there is a difference between absolute energy consumption, and the level of energy efficiency. A large house may have higher annual gas consumption than a smaller house, but the larger house may be more energy efficient to meet thermal comfort levels. Using statistics on existing insulation measures can be misleading due to deterioration in pre-war retrofits (Dowson *et al* 2012). In theory data on the relative efficiency levels of the housing stock is collected by the Energy Saving Trust through the Home Energy Efficiency Database (HEED), described as a 'key source information to assist local, regional and central government, in monitoring and reporting on their housing duties, including the Home Energy Conservation Act' (EST 2012:3). However as a resource, the HEED database is too limited in its scope to be of any meaningful use to Local Authorities in conducting large scale improvements to the thermal efficiency of the housing stock. DECC (2012a) and EST (2012) both state that HEED has coverage of just 50% of the UK housing stock, and under-represents the private sector. HEED's coverage of housing focuses on Government sponsored schemes such as CERT and Warm Front and excluded DIY-installations that were not through a Government-backed energy-efficiency measure (DECC 2012a).

Therefore there is a need to go beyond using the HEED database to identify houses in need of energy efficiency installations. Another alternative source of information on the theoretical energy efficiency is the Energy Performance Certificate (EPC) requirement which since 2008 has assigned an energy efficiency rating based on the theoretical thermal efficiency of the dwelling. Similar to HEED this suffers from poor coverage as it is currently only a requirement of houses that are sold or rented and therefore does not take into consideration houses owner-occupied since 2008 that have not changed occupancy (Watts *et al* 2011). This lack of data, or poor quality data had previously been identified as a barrier of CESP implementation, and the use of theoretical consumption based on levels of insulation and age of construction hide behavioural factors, as well as incorrect use of heating systems, appliances, and poor installation of energy efficiency measures leading to a gap between theoretical and actual energy demands (Watts *et al* 2011). Alongside these limitations in potential energy efficiency indicators, these are focused on space heating and do not take into consideration appliance use.

2.4.2 Developing Benchmarks

What is required is for Local Authorities to be able to track how the energy reduction policies that they implement are affecting the energy consumption levels in their housing having accounted for variation in energy consumption. Currently there is no mechanism which allows Local Authorities to do this. What is proposed for the remainder of this thesis is the development of a benchmark for Local Authority domestic energy consumption that accounts for the specific circumstances of their area and distinguishes between high consumers and inefficient consumers of domestic energy. The actual consumption can be compared against the benchmark, and these benchmarks would be updated year on year to enable the monitoring of energy efficiency policies. A reduction in energy consumption would be reflected in the ratio of recorded energy consumption against benchmark consumption (hereafter termed 'consumption index'). A robust benchmarking process would also aid in attracting Green Deal partners, who would be unwilling to commit the finances to starting-up Green Deal schemes, or risk their reputation on schemes that did not have adequate data to support actions (CCC 2012). The rest of this thesis is builds on data focused at LSOA level, but crucially, and unlike the CESP scheme would not set qualifying criteria or limit Local Authorities to only providing assistance in specified areas and would encompass owner occupiers, private renters and social renters. The results are intended to guide as opposed to prescribe policy interventions.

Mulder (2006:147) emphasises key considerations when attempting to measure sustainability, and these can be applied to the residential energy efficiency agenda. These considerations are:

- An appropriate methodological framework
- Contrasting and trustworthy data
- A strategy of appropriate communication
- A system of permanent evaluation

Mulder's approach builds on the Bellagio principals, developed by the Rockefeller Foundation in 1996. The principles guide the assessment, development and interpretation of indicators for measuring sustainable development. The indicators followed for this project are:

- Standardising measurement wherever possible to permit comparisons;
- Designed to address the needs of the audience and users;
- Develop a capacity for repeated measurement to determine trends; and
- Provide openness in the methods used, and uncertainties in the data collected

The development of the benchmarks in this thesis follows these principles; ensuring comparisons of Local Authority performance can be made. Consultation will be made with Local Authorities to ensure the benchmarks and their applications meet the needs of Local Authority users and that the methods used to generate the benchmarks are understood by them. The results and analytical process were re-run incorporating time-series data to evaluate how the results can be used over-time.

2.5 Conclusion

There are arrays of well understood strategies that can improve the energy efficiency of England's domestic sector that would lead to houses requiring less heating energy to reach comfortable levels. However improving energy efficiency does not cause energy conservation to occur, and the Government must encourage householders to practice energy efficient behaviours, and to purchase energy efficient replacements of electrical appliances. Local Authorities are expected to act in a way that identifies areas which are most in need of energy efficiency improvements, and devise schemes which encourage energy efficiency behaviour whilst meeting the needs of their local residents. The 2010 general election in the UK has led to a change in approach from the national government, with less emphasis on meeting energy and carbon reduction targets by Local Authorities, but with more emphasis on encouraging the uptake of national energy efficiency schemes such as the Green Deal and the ECO. One of the main points to emerge from the literature is that policies aimed at improving the energy efficiency of the housing stock often overlap with those aimed at addressing fuel poverty, but may result in different outcomes in terms of domestic energy reduction. There are also instances where behavioural change leads to outcomes that would not be expected from modelling the impacts of energy efficiency interventions. These outcomes often lead to rebound effects and are difficult to accurately quantify. The implication of political change is also discussed with Local Authority respondents to assess the relationship between local government, national government and the electorate. These political changes include the role of private sector organisations to provide local housing services, collaboration between Local Authorities, National Government policies and the re-organisation of Local Authorities themselves.

While the rationale behind these schemes is relatively well understood, there is a lack of work to provide Local Authorities with practical tools to effectively identify areas with higher than expected domestic energy consumption. This makes it difficult to justify interventions and energy efficiency improvements. The review of the academic literature identifies the factors that account for variation in household energy use, and this is vital knowledge for monitoring changes in energy consumption across England. The main factors are demographic, social, economic, technical, and climatic and these are the key in understanding variations in household energy consumption.

This thesis is an original contribution to the academic debate and this knowledge is essential to enact policies to address areas in need of intervention, and implement domestic energy reduction policies. What is proposed for the remainder of this thesis is the development of a benchmark level of Local Authority domestic energy consumption, given the specific circumstances of their area, against which the areas actual consumption can be compared. This would highlight areas that have higher than expected consumption levels and therefore may benefit from energy efficiency interventions. A robust benchmarking process would also aid in attracting Green Deal partners, who would be unwilling to commit the finances to start Green Deal schemes, or risk their reputation on schemes that did not have adequate data to support actions.

Particular attention is drawn to the role of Local Authorities in current policy prescriptions for reducing domestic energy consumption. What emerges from this chapter is Local Authorities are becoming key agents in domestic energy reduction strategies. Nevertheless, the way Local Authorities are, for example, evaluated by centrally-imposed targets in relation to energy policy suggests there are both strengths and weaknesses of this approach. Analysing both the opportunities and barriers to reducing domestic energy consumption, it becomes clear is that for Local Authorities to achieve the ambitious aims imposed on them by central government, they will need, first, an understanding of the key factors driving variation in domestic gas and electricity consumption, and a model which enables them to target areas for implementing policies which ultimately leads to the successful reduction of domestic sector energy consumption.

3. MATERIALS AND METHODS

This thesis follows a mixed-methods approach, utilising statistical modelling techniques and conducting qualitative research with Local Authorities to ensure the models developed have practical applications for policy makers. This chapter firstly examines the philosophical positioning of this project, establishing the epistemological and ontological approaches taken in data collection and analysis in this thesis. The main portion of this chapter presents the research focus in the context each of the objectives in turn, setting out the methodology used to address the objective for data collection and analysis. These sections describe the theoretical and practical justifications of the qualitative and quantitative methods chosen, and highlight the strengths and weaknesses of these methods. Finally, the concluding section outlines how this methodology has served to produce the data and results which both underpin and inform the research findings presented, and how addressing each objective meets the overall research aim of the thesis.

3.1 Positionality

Positionality is the context in which data is collected and analysed and shapes the approach to theory and methods which researchers use (Furlong and Marsh 2010). Understanding the positionality of any particular piece of research, and therefore the preconceptions about the nature of the world and data collection, is vital to interpret the method and the results from research projects. Positionality is made up of epistemology (a branch of philosophy concerning origins, nature, method, and limits of human knowledge) and ontology (concerning assumptions in conceptual reality and questions of existence) (Burnham *et al* 2004, Fellows and Liu 2008, Furlong and Marsh 2010). The most notable division in positionality is between research that attempts to establish cause and effect, and research which seeks interpretations and meanings (Gomm 2004). This research is primarily focused on establishing cause and effect, focusing on the factors which influence variation in domestic energy consumption. However some attention is paid to the underlying interpretation of the results, and how these results are interpreted by policy makers.

3.1.1 Ontology

Ontology is concerned with whether there is a ‘real world’ that exists independent of our knowledge about it (Furlong and Marsh 2010). There are two broad ontological positions: objectivism and constructivism. The aim of objective research is that the same inputs under the same circumstances would yield the same outputs and results (the principle of replication), which is associated the philosophy of positivism. Quantitative approaches and results are seen as a language of scientific credibility (Fellows and Liu 2008, Dorling 2010). This is in contrast with constructivism, where experiences of the world are shaped by the observations and perceptions of the people involved, and are more commonly associated with qualitative analysis (Fellows and Liu 2008). The methods employed here attempt to produce objective results for determining the levels of household energy efficiency in English LSOAs, with a method that is replicable. The qualitative aspects in this research are to guide the methodological process, and the presentation of the results, and serve as a validation exercise, as opposed to a constructivist study. This research follows an objective ontology.

3.1.2 Epistemology

Epistemology is the theory of knowledge, concerning whether a researcher can identify ‘real’ or ‘objective’ relations between social phenomenon (Walliman 2006, Bryman 2008). Within objectivism are two positions: positivism and realism. Researchers who follow positivism usually express a preference for quantitative methods, where under a given set of conditions there will be regular and predictable outcomes. This epistemology is primarily associated with the natural and physical sciences (Bryman 2008, Furlong and Marsh 2010). The role of research is to test theories and provide materials for the development of laws (Bryman 2008). This was the dominant paradigm in the social sciences from the 1930s through to the 1960s; however social science criticism of positivism became prominent in the 1970s, seeing the application of ‘objective’ scientific methods to human behaviour as inappropriate (Gray 2009, Clifford *et al* 2010). Positivism does however remain the dominant philosophy for many of the natural sciences and engineering disciplines which seek to establish universal laws based on objective observations.

The second objectivist epistemology is Realism. Realism shares objectivist ontology, but is also concerned with interpretations and meanings more in common with constructivism. Gray (2009:24) describes Realism as believing 'that there is an external reality out there that can be measured but achieving this can be difficult' and describes how Realism begins from the position that science, and the scientific method, is true and accurate but that some observable 'facts' may in fact be illusions, and are open to interpretation. Carrying out research under Realist epistemology therefore may utilise both quantitative and qualitative methods (Furlong and Marsh 2010). Whilst Positivists believe that the observations from research directly reflect reality, Realists believe observations from research is a way of knowing reality (Bryman 2008).

Interpretivist epistemology suggests that no researcher could be objective, because they view the world as being socially constructed. The scientific method is rejected, since results, and the interpretation of these results are affected by the researcher's pre-existing views on the world. The position is therefore more commonly associated with qualitative methodologies. The relationship between ontology, epistemology and methodology are summarised by Furlong and Marsh (2010) and reproduced in Figure 3.1.

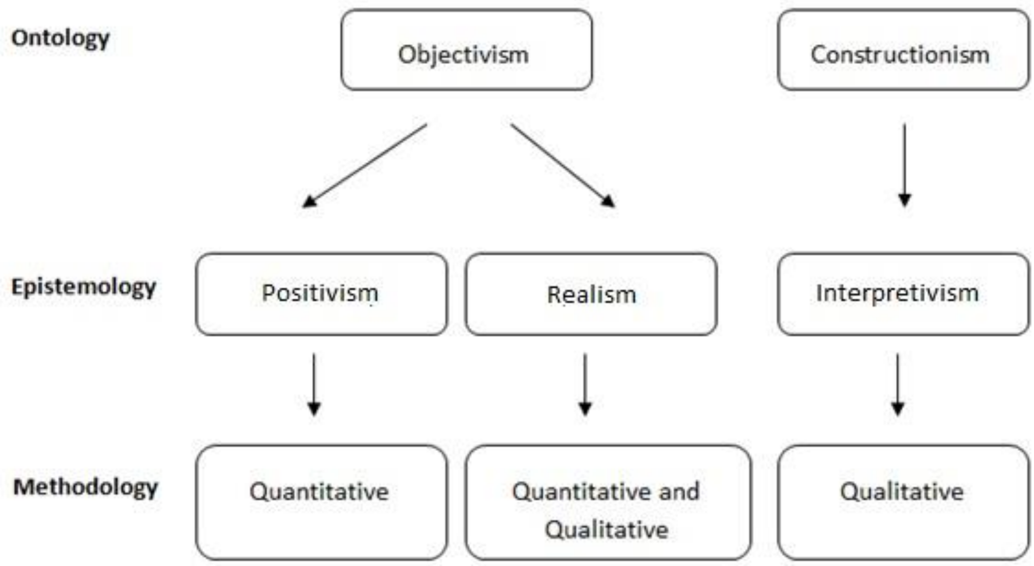


Figure 3.1 Connections between Ontology, Epistemology and Methodology (Source: Furlong and Marsh 2010)

3.1.3 Positionality of this Project and Methodology

As highlighted in the preceding section, this thesis follows objectivist ontology, and a realist epistemology. The aim of the thesis is to generate a replicable set of numerical indicators, using quantitative data and methods. Quantitative research and data serves many uses in research, seen by positivist and many realist researchers as the only way to conduct purely objective research. Theories and hypothesis can be developed and tested using quantitative data (Bryman 2008). Quantitative methods are used in social science research to explain, predict and model human behaviour and decision making (Clifford *et al* 2010). However, this is supplemented by a qualitative study to develop a grounded understanding of the challenges facing Local Authorities, and to ensure the indicators produced have practical applications. One of the criticisms of qualitative research is the lack of generalisation that can be drawn from results, and that the results may be so personal to the researcher that another investigator may come to a radically different conclusion following the same method (Gray 2009).

However, applying the principles of the scientific method to all phenomena of research is seen as 'turning a blind eye' to the differences between the social and natural world (Bryman 2008:15). Clifford *et al* (2010) highlight the limitations of positivist research in human geography, where the application of 'objective' scientific methods conceptualise people as rational decision makers, an assumption which does not always hold true in the real world. It can also been seen to be easier to demonstrate an empirical relationship between two variables than to provide convincing theoretical arguments as to why these relationships arise (White 2010). To avoid the incorrect claims of spurious statistical results, the analysis of secondary data has been related to the literature and collected alongside Local Authority representatives to ensure the findings had theoretical and practical justifications.

Therefore the research methods used in this thesis are a mixture of qualitative and quantitative methods. The mixed-methods approach utilised triangulation where multiple research methods confirm, develop and modify analytical processes. This follows the approaches the theoretical approaches advocated by Gomm (2004) and Fellows and Liu (2008) and building on the ideas highlighted by DECC (2012a) as a way of utilising their sub-national energy consumption data. The method of ensuring that the research findings can be of us to, and have practical applications for Local Authorities is described by Bryman (2006:106) as 'utility triangulation'. This approach provides a more elaborate understanding and greater confidence in the conclusions of the model's results than using a purely statistical approach which may yield spurious and implausible results as well as findings with unworkable applications.

3.2 Achieving the Policy Objective

The policy objective involved consulting with Local Authorities to determine the form of the model and ensuring its applicability as well as enabling local respondents to identify data sources as well as presenting the opportunities and limitations of sub-national domestic energy consumption policies. To establish this, one-hour semi-structured interviews were carried out with 11 Local Authority representatives employed in the field of carbon reduction and domestic energy policy. Findings were compared and contrasted to the academic and policy literature and the process of developing statistical models in subsequent objectives were designed to meet the needs of Local Authorities as indicated by the findings from this chapter. The results from this objective are presented in Chapter 4.

3.2.1 Theoretical Justification

The method used to achieve the policy objective was semi-structured interviews. This was seen as an appropriate method for exploring Local Authority roles in developing and implementing energy-efficiency policies, and the financial and political pressures that Local Government face. Semi-structured interviews are based on flexible question orders, with a list of themes or topics to be addressed, with the aim to develop a conversational structure (Gibson and Brown 2009) and responses can therefore be related to themes emergent from the literature review and to results from the statistical study. Semi-structured interviews offer a greater depth in responses, which is seen as a bigger advantage than a larger number of responses, a view advocated by Burnham *et al* (2004). Building rapport with interviewees develops trust between the participants in the interview and enables the probing of answers to gain a better understanding of the financial and resource constraints faced by Local Authorities and their roles within the context of local domestic energy policy. Qualitative research tends to emphasise multiple meanings, emotions, intentions, values and interpretations rather than seeking to impose any one ‘dominant’ or ‘correct’ interpretation (Winchester 2005, Clifford *et al* 2010). In this thesis, the qualitative semi-structured interviews supplement the quantitative research, providing context for the statistical results and outputs generated by the quantitative method. Semi-structured interviews were seen as the most appropriate method to achieve this.

Alternatives to semi-structured interviews were considered, and these methods have their own advantages and disadvantages. Questionnaires produce categorical and numerical data which can be useful for discovering people's attitudes and opinions about social, political and environmental issues (McLafferty 2010). This method is beneficial for obtaining large number of responses at a relatively low cost and these results can be relatively easily compared from case to case due to the structured nature of the method. However the main limitation of questionnaires is the potential for ambiguous responses, misinterpretation of questions, and non-response bias (where those who do respond are not representative of the original sample). The voluntary nature of answering open-ended questions and measuring opinions through categorical 'tick boxes' leads to a loss of information that could be better obtained through face-to-face interviews and the standardised nature of questionnaires can often reduce the explanatory power of results (Valentine 2005, McLafferty 2010). Structured interviews could overcome some of these limitations by clarifying the ambiguity of questioning and reducing non-response bias however organising structured interviews in face-to-face settings adds to the time and costs required to conduct the research. Telephone interviews can overcome this to an extent but this is an impersonal method and adds to the problem with technological issues such as poor quality phone lines and disconnection. Structured methods suffer from a lack of depth in the interviews by instead focusing on gaining a range of respondents. Unstructured interviews give complete freedom to explore 'interesting' lines of enquiry and each interview is unique and are directed by the informant's responses (Dunn 2005) and themes not previously considered are likely to arise from this lack of formal direction from the interviewer (Gomm 2004, Dunn 2005). However the main limitations of unstructured interviews are the potential to lose focus from the original research questions, and the difficulties in comparing multiple interview responses.

3.2.2 Data Collection

Prior to consultation with any human participants ethical guidelines were adhered to, ensuring that this study was conducted in accordance with the guidelines on ethics set out by Loughborough University's ethical code (see Loughborough University 2011). As with any research project there are ethical responsibilities towards human participants in research interviews concerning consent, confidentiality and courtesy. In particular this requires the researcher to ensure there is: the avoidance of harm, the avoidance of deception, the right to privacy, the right to confidentiality, and a need for informed consent (Burnham *et al* 2004, Walliman 2006, Gray 2009). Ethical behaviour is essential to protect the rights of individuals involved in research, and maintaining public trust (Hay 2010). Providing anonymity is a key process to enable respondents to be honest and truthful in their responses, without these comments to being taken to reflect the views of the organisation as a whole, or to be traced back to the individual respondent which could cause any professional or personal harm. It can be difficult for researchers to fully grant anonymity. Gibson and Brown (2009) outline some of the main ways identification can occur:

- Identifiability from quotes (by the way people talk)
- Difficult to know which features of the data would be recognised by others, especially when anonymising the names of respondents (i.e. by job title)
- Anecdotes told in interviews may be widely known by others and the citation of these in analysis may reveal identify to others

To meet the ethical criteria, all interviewees were sent an email outlining the aims of the project, the process of recording the meeting and the proposal of anonymity and confidentiality. This was important so that informed consent can be obtained from the respondents (Walliman 2006). Obtaining informed consent satisfied the ethical criteria, but also gives participants more confidence in the research, and therefore will be more likely to be open and honest in their responses to the research questions (Gray 2009). By meeting interviewees in their place of work, and by anonymising the records of the interviews it ensured minimal risk was placed on interviewees (Burnham *et al* 2004, Walliman 2006, Silverman 2010). Care was taken not to disseminate sensitive material (i.e. physical documents received during the interview). All transcripts were sent to the interviewees for respondent validation, with the interviewees given the opportunity to correct errors and omit potentially sensitive information.

Interviewees were recruited using sequential snowball sampling following initial contact with a gatekeeper employed at a regional statistics authority. Initially the focus was on one Government Office region. The major difficulty of interview research is obtaining a high response rate, especially from methods such as cold calling (Longhurst 2010). Snowball sampling was seen as preferable to cold calling because it is specific respondents that were sought for interview (Burnham *et al* 2004) and given the nature of Local Government; it is likely that there would be connections between people in the sample job positions across different organisations. There are also barriers to interview research, and using an initial gatekeeper was vital in discovering the key local workers in the fields of domestic energy and carbon reduction. However there are concerns about gatekeepers directing only towards a narrow range of respondents (Valentine 2005). This was overcome by using snowball sampling with respondents in the study, and by gaining access to further respondents at networking events.

Initial requests to 10 Local Authorities from the Gatekeeper led to the recruitment of 5 respondents, a response rate of 50% which is considered a good response rate for interview research (Fellows and Liu 2008). Those five respondents covered: one county council, once city council, and three borough councils. This gave a sample of one upper tier council, three lower tier councils and one unitary authority. Networking events led to contact with 6 further councils from further afield across England, taking in a mix of unitary and lower tier Authorities, as well as rural and urban councils. This is essential because different regions and different types of councils will have different priorities, pressures, finance and political beliefs. After 11 interviews it was felt that theoretical saturation was met and that it was unlikely new information could be obtained by expanding the scope of respondents further, an approach following from the work of Burnham *et al* (2004), Bradshaw and Stratford (2005), and Neuman (2007). The recruitment strategy for the Local Authority respondents is shown in Figure 3.2, and details on the respondents documented in Table 3.1.

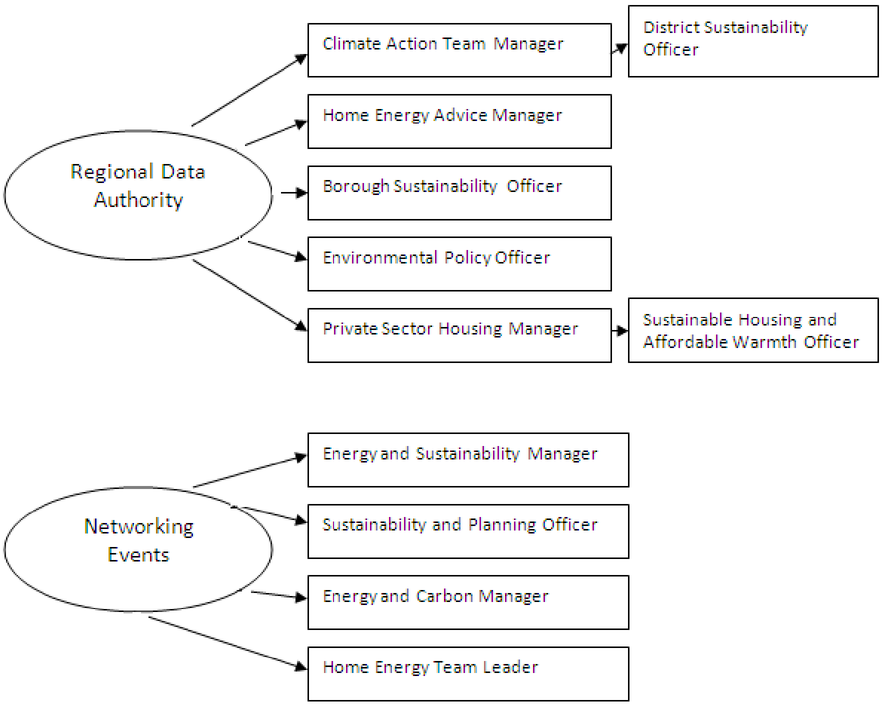


Figure 3.2 Strategy for Recruiting Local Authority Respondents

Table 3.1 Participants in Study

Position	Type of Authority	Tier of Authority
Climate Action Team Manager	County Council	Upper
Home Energy Advice Manager	City Council	Unitary
Borough Sustainability Officer	Borough Council	Lower
Environmental Policy Officer	Borough Council	Lower
Private Sector Housing Manager	Borough Council	Lower
Sustainable Housing and Affordable Warmth Officer	City Council	Unitary/Metropolitan
Energy and Sustainability Manager	Borough Council	Lower
Sustainability and Planning Officer	District Council	Lower
District Sustainability Officer	District Council	Lower
Energy and Carbon Manager	City Council	Lower
Home Energy Team Leader	City Council	Unitary

The audio of the interviews were recorded and partially transcribed. Audio recording of the data allowed for the focus on conducting the interview instead of having to take hand-written notes. Audio recording gave a complete recording of each interview which could be replayed overcoming the problems of note-taking mainly that missed sections cannot be recovered at a subsequent date, and sections cannot be reviewed for accuracy checking. Partial transcription was chosen because full transcriptions are time consuming (6-10 hours to transcribe 1 hour of text) and there was only the need for the content of interviewee speech to be analysed. False starts and changes in speech and body language were seen as irrelevant (Gray 2009). Partial transcriptions focus on the basic meaning of speech without attempting to represent its detailed contextual or interactional characteristics (Gibson and Brown 2009).

3.2.3 Analysis

Having recorded and transcribed the interview, the completed transcripts were then coded. Coding reduces the volume of data and categorises the text into themes which allows for comparisons between interview texts (Cope 2005). The coding strategy also aids in overcoming a common criticism of semi-structured interviews that the open-ended nature of the research makes answers highly specific to the individuals questioned (Cope 2010). By applying a constant coding method to transcripts, comparisons between responses become possible and explanation can be developed, and act as a spot check for accuracy as a form of quality control (Gorard 2003). Unusual responses can be referenced against other responses, the literature review and statistical results. Unclear responses can be addressed directly through establishment with the relevant respondent.

Thematic coding was used to ensure there was a rigorous analysis of the interview transcripts (Robson 2011) and ensuring that there was an avoidance of selecting quotations that back up pre-existing beliefs despite contrary evidence from the data (Walliman 2006). The thematic analysis method is based on analysing data according to commonalities, relationships, and differences across a dataset (Gomm 2004, Gibson and Brown 2009). It is a method advocated by Cope (2005), and Fellows and Liu (2008) for producing results more oriented to quantitative data. The alternative method was using the linguistic method of coding. Linguistic analysis focuses on developing a greater depth in the interpretations of the text. This is a response to the criticisms of thematic analysis, which is focused on description and exploration (Robson 2011). Thematic analysis is more suited to this project which focuses on descriptions and exploration to aid developing tools for Local Authorities in implementing policy. Thematic analysis allows a comparison of the content of the interview responses, and detects outlier responses which differ from the general consensus and set against the prevailing views in the academic and policy literature. Silverman (2006) warns against overly focusing on outliers, highlighting that general consensus issues are often more important. With that in mind, responses of overwhelming consensus were considered for the method of developing the statistical analysis process, and the outputs generated.

Initial codes in the analysis were developed from the research questions, background literature and initial quantitative results. These gave nine broad themes, sub-divided into thirty specific *apriori* codes. From reviewing the transcripts, three further themes were identified and adding six specific *empirical* codes across the previous nine themes. This coding process is shown below in Table 3.2.

Table 3.2 Coding Themes of Interview Transcriptions

Primary Code	Secondary Code(s)	Pre/Post Analysis
1. Rationale for Energy Efficiency and Carbon Reduction	a. Desire to be a seen as a leading authority b. Legislative requirements c. Tackling fuel poverty d. Meeting 'Decent Homes' requirement e. Save money for the council f. Fit with other schemes g. Social benefits	Pre Analysis Post Analysis
2. Policies	a. National Policy b. Regional Policy c. County Policy d. District/City Policy	Pre Analysis
3. Collaboration	a. Active collaboration b. Benefits of collaboration c. Collaborative funding d. Shared services	Pre Analysis Post Analysis
4. Interaction with Community	a. Promotional campaigns b. Involving community c. Community support d. Belief in climate change	Pre Analysis
5. Monitoring Policy Success	a. Use of national statistics b. Use of self-collected statistics c. Use of regional statistics d. Measuring instalments/renovations/activities e. Qualitative monitoring f. Scale g.Expertise	Pre Analysis Post Analysis
6. Target Setting	a. National targets b. Local targets c. Installation targets d. No formal targets	Pre Analysis
7. Comparing Against Other Authorities	a. Usefulness b. Aspirations	Pre Analysis
8. Resources	a. Level of resources b. Government resources c. Private resources d. CERT	Pre Analysis
9. Politics	a. Changes to schemes b. Political support c. Political Hierarchy	Pre Analysis Post Analysis
10. Tenure	a. Social housing b. Private sector c. off-gas	Post Analysis
11. Behavioural Change	a. Attitudes b. Financial	Post Analysis
12. Role of the Council	a. Reputation b. Knowledge c. Outsourcing d. Advice	Post Analysis

Following the coding of the data the text corresponding to each of the specific codes in the interviews were drawn together. These sections were then matched to the academic and policy literature, the secondary data, and the relevant research questions to identify linkages between the research methods and results, as well as providing direction for the statistical analysis.

3.3 Achieving the Data Objective

Nationally available datasets were found by exploring the data publishing by UK Government Departments, specifically DECC and ONS as well as non-Governmental (but extensively used by Government Departments) sources including Experian and the MET Office. The DECC LSOA per meter gas and electricity consumption statistics are the dependent variables. The independent variables from ONS, DECC, Experian and MET Office are the independent variables and classified into demographic, social, economic, technical and climatic variables. At the commencement of the study the DECC data was only available for 2008 and therefore this was the year of study. As the project developed, DECC's sub-national energy consumption data became available for 2009 and 2010 and these data were used for testing purposes. The results of this work are presented in chapters 5 and 6.

3.3.1 Theoretical Justification

Theories and hypothesis can be developed and tested using quantitative data (Bryman 2008). Quantitative methods are used in social science research to explain, predict and model human behaviour and decision making (Clifford *et al* 2010). The quantitative study in this thesis used secondary data sources from Government departments, and commercial organisations. A high proportion of research projects use secondary data and its main advantages over primary data are its speed and costs (Gorard 2003). This frees up time for research to be directed at analysing data as opposed to collecting it, and the depth and extent of secondary data that can be obtained allows for analysis of various sophistication; from simple description through to causal modelling (White 2010). Not only this, but Governmental, and particularly certified Official Statistics carry a certain authority, and is usually higher than could be collected through primary study (Gorard 2003). In many circumstances it would be almost impossible for the data to be collected by primary methods due to time and financial constraints (White 2010). While secondary data has advantages of scope and depth to what can be collected and analysed, there are also limitations which must be considered before conclusions are made. In the case of this thesis, it is the potentially high levels of misclassification of commercial properties as households, something that is addressed in Chapter 8.

3.3.2 Data Sources

All of the data sources used in this project are currently freely available online to academics (and in the case of DECC and ONS are free to all) and cover the whole of England. These datasets are published at lower layer super output area (LSOA) level, which are census geography areas organised for the boundary commission for the UK Census (ONS 2010a). LSOAs are defined by the ONS (2010a) as 'socially homogenous' with regards to house and tenure types, and represent approximately 1500 residents, in at least 400 households. Both Middle Super Output Areas (MSOA) and LSOAs fit within the boundaries of Local Authority areas. LSOAs are the smallest spatial scale for which DECC publish domestic energy consumption statistics and therefore the decision was made to use LSOA level as the spatial scale for this study. In the data release for sub-national energy consumption statistics DECC also included demographic variables from the 2001 Census. More up-to-date data was sought from ONS, which does publish population estimates at LSOA level. Following the method of DECC (from the NEED analysis), household income data was obtained from Experian. The Meteorological (MET) Office published heating degree day data at 5x5km grid squares from 1961 to 2006 under the UKCP09 directive. This directive was to provide data to 'encourage and facilitate research into climate change impacts and adaptation.' (MET Office 2013). To match the heating degree data to correspond to the 'base year', for which DECC's sub-national gas consumption data are weather corrected to. The average of 17 years of data from 1988-

2004 were obtained and assigned to LSOAs using GIS spatial tools. This assignment was done by overlaying LSOA boundaries to the grid squares and taking a weighted average based on the total LSOA area. Data sources as published are described in Table 3.3 and those which were derived from combining multiple data sources are noted in Table 3.4. In-depth discussions of the procedures used to clean and organise the data sources are highlighted in chapters 5 and 6.

Table 3.3 Secondary Data Sources as Published

Data Source	Organisation	Published Variables (Year Described)	Years Published	Driver Type	Published at LSOA	Official Statistics	Frequency of Update	Measured or Modelled
DECC (2012a)	DECC	Total Electricity Consumption	2008, 2009, 2010	Dependent Variables	✓	×	Annual	Measured
		Total Gas Consumption			✓	×	Annual	Measured
		Per Meter Electricity Consumption			✓	×	Annual	Measured
		Per Meter Gas Consumption			✓	×	Annual	Measured
		Number of Gas Meters	2008, 2009, 2010	Demographic	✓	×	Annual	Measured
		Number of Electricity Meters			✓	×	Annual	Measured
DECC (2012b)	DECC	Per Unit Cost of Gas	2008, 2009, 2010	Economic	✓	×	Annual	Measured
		Per Unit Cost of Electricity			✓	×	Annual	Measured
Census Dissemination Unit (2012a)	Experian	Median Household Income	2008, 2009, 2010	Economic	✓	×	Annual	Modelled
EDINA(2011)	EDINA	Area of LSOA (km)	Constant	Spatial	✓	×	Constant	Measured
					✓	×	Constant	Measured
ONS (2012a)	ONS	Total Population	2008, 2009, 2010	Demographic	✓	✓	Annual	Modelled
Census Dissemination Unit (2012b)	ONS	Average Number of Rooms Per House	2001	Technical	✓	✓	10 Years	Measured
		Proportion of Tenure Types	2001	Social	✓	✓	10 Years	Measured
		Proportion of House Types	2001	Technical	✓	✓	10 Years	Measured
MET Office (2012)	MET Office	Heating Degree Days 1988-2006	2008, 2009, 2010	Climatic	×	×	Constant	Modelled

Table 3.4 Derived Data Sources

Variable	Derived By	Driver Type
Number of People per House	Total Population/Total Number of Electricity Meters	Demographic
Population Density	Total Population/Area of LSOA	Demographic
Housing Density	Total Number of Electricity Meters/Area of LSOA	Demographic
Proportion of Gas Meters to Electricity Meters	(Number of Gas Meters/Number of Electricity Meters)*100	Technical

Having obtained these datasets, spread sheets were built at LSOA level in England using Microsoft Access. The advantages of using these data are: they cover the whole of England using consistent methodologies, and are published at LSOA level, with the exception of the heating degree day figures which were assigned to LSOA level using the overlay feature in ArcGIS.

3.3.3 Analysis

In interpreting the data, and subsequent results, it was important not to commit the *ecological fallacy* and assume that findings for LSOA level apply to all the individual households that reside within the area (Bryman 2008, White 2010, Robson 2011). The limitations of the DECC, ONS, Experian and MET Office data were taken into account with the implications of these limitations on the final results of the thesis discussed. Analysis of the descriptive statistics looked for kurtosis values >|3| and skew values >|1| that might indicate a non-normal distribution (Miles and Shevlin 2001). Prior to analysis on the dependent variables all LSOAs with zero gas consumption were removed as these areas heavily distorted the distribution of the LSOAs and it is not practical to predict gas consumption levels for areas disconnected from the gas grid. LSOAs with missing or negative electricity consumption were also removed from the analysis. Square root transformations were applied to reduce the skew of the dependent variables, a transformation advocated by Moore *et al* (2009). Analysis was then applied to both the untransformed and transformed variables.

3.4 Achieving the Analytical Objective

The data sources from objective two were then analysed exploring the relationship between the dependent variables (gas and electricity consumption) and the independent variables (the demographic, social, economic, technical and climatic drivers). Firstly, a correlation analysis was carried out between independent and dependent variables. This was done to reduce the number of variables for consideration for entry into Ordinary Least Squares (OLS) Multiple Linear Regression models by setting statistical criteria for entry into the model based on correlation co-efficients between independent and dependent variables. These regression models produced generalisations of the nature of geographical variation in domestic gas and electricity consumption. Two multiple regression models, one for gas, and one for electricity consumption were developed, with tests on the residuals to ensure the models met the assumptions of OLS multiple linear regression. The models were then tested using data for 2009 and 2010. The results of the statistical modelling are in Chapter 7.

3.4.1 Theoretical Justification

Lee and Lee (2009) discuss the options for constructing performance indicators for building management, stating that the two major methods are: using a simulation method, or a statistical analysis method. The simulation method is appropriate for modelling individual domestic properties' energy consumption where factors specific to individual buildings can be obtained (Lee and Lee 2009). Many of the studies analysed in the literature review use the simulation method to assess potential energy savings using engineering and mathematical modelling. However for policy evaluation, it is not necessarily the impacts on individual buildings that Local Authorities are measuring, but the aggregated performance of groups of housing. OLS multiple linear regression is considered to be the most widely used statistical technique in the social sciences, with applications in the physical sciences and engineering (Allison 1999, Miles and Shelvin 2001) and was chosen as the primary modelling method in this study. The relative simplicity of regression techniques was seen to appeal to non-statistical audiences (i.e. Local Authorities). Makridakis and Wheelwright (1989:30) highlight the need for simplicity when applying statistical analysis to real-world audiences with non-statistical audiences, stating:

> 'If a manager can use a more straight forward and less expensive forecasting method (as opposed to a more sophisticated and expensive one) and still achieve the required level of accuracy, he or she generally should do so'

This view is shared by Bianco *et al* (2009:1):

> 'It is common that complex models, even though they provide accurate predictions, are difficult to manage and often a less accurate model, but much simpler, is appreciated especially if the forecasting module is just part of a more complex planning tool, as is often the case'

Since the purpose of the statistical modelling is to identify factors that account for geographical variations in domestic gas and electricity consumption, there is justification for using a relatively simpler method (e.g. regression) and presenting the results, and the method to Local Authorities for review. Modifications could then be performed if necessary. This fits with the views presented by Makridakis and Wheelwright (1989:30), who add:

> '…generally it is much wiser to apply a straight forward, simple approach initially and to upgrade gradually to more sophisticated methods if this proves beneficial and necessary'

3.4.2 Selecting Inputs

Correlation analysis to determine the strength of the relationships between independent variables and the dependent variables was carried out to reduce the number of input variables into the model, alongside hierarchical methods (in this thesis the stepwise entry method). There is no one single variable responsible for driving household energy consumption. Correlation analysis provides an empirical measure of the association between two variables, which can then be subsequently used to develop statistical models (Gorard 2003, Lane 2010). Stevens (2009:73) states that the ideal scenario is:

> 'To have each of the predictors significantly correlated with the dependent variable and for the predictors to be uncorrelated with each other, so that they measure the different constructs and are able to predict different parts of the variance on y'

This rarely occurs in reality but serves as a guide when selecting inputs for regression analysis, where a good situation 'in practice is then would be one in which most of our predictors correlate significantly with y and the predictors have relatively low correlations among themselves' (Stevens 2009:73). Therefore there were two phases to the correlation analysis. Phase 1 involved assessing the strength of the relationships between independent variables and the dependent variables. cut-off of $|r|>0.2$ was chosen as a 'practical significance value' for correlation coefficient as the high sample size was likely to give statistical significance to almost all non-zero results (Miles and Shevlin 2001). In the second phase, correlation analysis was used to prevent excessive collinearity in the model. Collinearity exists when the independent variables are closely related to each other. The effects of high correlation between pairs of two independent variables increases the variance of the regression co-efficients, reducing the accuracy and precision of the outputs of the model, which reduces the stability of the prediction equation (Stevens 2009). As a rule of thumb presented by Allison (1999) and Miles and Shelvin (2003) pairs of independent variables should not have a correlation co-efficient of $|r|>0.7$.

The models for gas and electricity were then developed using a hierarchical method, stepwise. Stepwise entry combines the techniques of the two other hierarchical methods, (forward and backwards). Stevens (2009:76) outlines how the stepwise regression method determines variable entry:

1. The variable with the strongest correlation co-efficient against the dependent variable is entered into the model if its impact on the model is statistically significant.
2. Partial correlations with the dependent variable are calculated for all other potential variables, holding constant for the variable already entered into the model.
3. Following step 2, the variable with the highest partial correlation with the dependent variable is entered into the model, providing its impact on the model is statistically significant.
4. The 'least useful predictor' is re-assessed for statistical significance and removed from the model if it no longer meets significance criteria. This is because the effect of a variable entered in the model may be better explained by a combination of variables entered later in the model.
5. Steps 2, 3 and 4 are repeated until inputting additional variables no longer produces statistically significant changes to the model.

Using hierarchical variable entry methods for regression enables the relative effects of each independent variable on the strength of the statistical model, and has been used by Summerfield *et al* (2010a) to produce their time series benchmarking model. Hierarchical entry methods allow for a balance between simplicity of the model, and the strength of the predictions, where a large number of variables in a model can become redundant and unnecessary (Montgomery *et al* 1998, Abraham and Ledolter 2006, Stevens 2009). This is because the relatively large size of the data points (of over 30000 LSOAs) means that most effects will be declared statistically significant at the 0.5 level (Miles and Shevlin 2001, Stevens 2009). Therefore judgements are needed to ensure that the results are of practical significance (Stevens 2009). A cut-off point that a change in r^2 must be greater than 0.01 was chosen for this study, satisfying the concerns raised by Montgomery *et al* (1998) that the increase in r^2 must be large enough to justify adding an extra variable, and that adding an unimportant variable can actually cause the fit of the model to become poorer. Where pairs of independent variables were too strongly correlated, the strongest predictor (i.e. the one entered first by the stepwise method) in the model was kept in the model with the others excluded.

3.4.3 Assumption Checking and Testing

The assumptions of regression are: linearity, independence, normality of residuals and homoscedasticity. Linearity was tested by examining correlation between independent variables and the dependent variable, producing scatter plots to check for non-linear relationships. As stated in the section on selecting inputs, the level of independence between variables was attained by not including two (or more independent variables) with a correlation between them of $|r|>0.7$. Normality of residuals and homoscedasticity were checked by plotting the residuals from the regression modelling. Residuals should be normally distributed with a mean of 0, and display a constant variance when plotted against the predicted values of the model (i.e. there is no correlation). Non-normal residuals were dealt with by applying a square root transformation to the dependent variables, as advocated by Moore *et al* (2009) and Stevens (2009). Testing the models was done by using data for the independent variables from 2009 and 2010 to; firstly, predict gas and electricity consumption using the 2008 model and comparing these 'predicted' values against the recorded consumption figures. Secondly, multiple regression models were developed for 2009 and 2010 and comparing the r^2 values which should be within 10% of the 2008 original models, as advocated by Stevens (2009). These tests ensure the relationships identified for 2008 are consistent for 2009 and 2010 and give a sense of plausibility to the models generated in this thesis with the opportunity for models to be used over time to monitor policy success.

3.5 Achieving the Output Objective

The predicted values generated by the statistical models were then used as benchmarks to develop indicators which could guide Local Authority policy. To assess the relative consumption of each LSOAs, a consumption index was then calculated by dividing the recorded consumption figure from DECC by the benchmark figure, and multiplying this by 100 (for ease of viewing). It is expected that the mean for this index would be 100 (i.e. actual consumption = benchmark). Visual representations of these outputs were produced by generating GIS maps of Local Authority areas using a colour scheme based on the display energy certificates used for energy efficiency levels in buildings. Those with large deviations from 100 would be tested to assess the accuracy and applicability of the modelling results. In particular, maps of locally specific results were developed for the Local Authority respondents that agreed to follow-up interviews. The practicalities for these outputs is that those with a high consumption index might indicate potential energy inefficiency and therefore for energy consumption reduction policy intervention. Those LSOAs with a low consumption index may serve as exemplars for energy consumption practices. The results from this objective are described fully in chapter 8.

3.5.1 Testing Outputs over Time

The outputs were tested to ensure that the outputs for subsequent years were consistent with the outputs of 2008 to ensure that outputs do not vary significantly from year-to-year as a result of spurious statistical effects. The consumption indices from the model were tested by generating gas and electricity consumption indices using the 2009 and 2010 regression models. It was expected there would be a strong correlation between the indices in each LSOA between the years 2008, 2009 and 2010 to indicate that the consumption indicators do not experience large fluctuations from year to year which would undermine the plausibility of the modelling method. Changes in the indices over time should be as a result of behavioural and efficiency changes rather than due to statistical discrepancies. Deviations in the value of the consumption indices between 2008 and 2009, and 2009 and 2010 were tallied, assessing how the extent of consumption index deviations varies across the country and understand underlying reasons for these deviations.

3.5.2 Effects of Data Limitations

The second test of the outputs were to assess the potential impacts that the discrepancies in the DECC energy consumption data may have on the modelling process. By filtering out LSOAs where the number of meters for both fuels deviates from the number of houses as reported by the council tax bands and re-running the regression analysis, it is possible to identify LSOAs that experience significant changes to their recorded efficiency levels as a result of removing LSOAs that have potentially high levels of misclassification of non-domestic properties, addressing the limitations of the underlying data. This test was to ensure the results are indicating levels of higher and lower than expected consumption rather than arising as a result of data errors.

3.6 Achieving the Applicability Objective

The applicability objective tested a) the practical applications for use by Local Authorities and National Government, and b) the plausibility of the consumption indices through a series of plausibility tests. These plausibility tests were:

- Follow up studies with Local Authority representatives who agreed to remain engaged in the research to identify limitation in the statistical modelling method, the data used in the study, and the presentation of the results from the study
- A walk by survey of areas in the city of Leicester
- An investigation of the effect of tenure on gas and electricity consumption indices
- Testing the ability of the model to identify Milton Keynes as an area of ‘known’ energy efficiency
- An exploration of Local Authorities ranked by proportion of lower than expected consuming LSOAs by gas and electricity consumption, identifying classifications by new town urban development, and urban and rural classifications.

Detailed results of these plausibility tests are given in chapter 9.

3.6.1 Local Authority Feedback

Local Authorities were extensively involved in the feedback and validation stages of the project. A sub-sample of five Local Authorities (those Local Authorities who agreed to remain part of the research process following the initial consultation) were consulted and presented with locally specific results for their region in the form of two maps and a summary of the methodology. The Local Authorities included are listed in Table 3.5.

Table 3.5 Local Authorities in Feedback Study

Council	Council Type	Job Title
City Council	Unitary Authority	Home Energy Advice Manager
City Council	Unitary Authority	Home Energy Team Leader
City Council	Lower Tier	Energy and Climate Change Team Leader
City Council	Metropolitan Authority	Fuel Poverty and Affordable Warmth Officer
District Council	Lower Tier	Planning and Sustainability Officer

Councils were asked for their views on the methodology used to generate consumption indices, the data sets used as part of the study, feedback on the accuracy of the results generated by the model (do they appear sensible given their local knowledge), and how Local Authorities felt they could apply the results generated from the models. In contrast to the initial consultation, these feedback sessions took the form of 30 minute surveys, taking notes on open-ended questions.

3.6.2 Plausibility Test 1: Walk by Surveys in Leicester

The final validation test of the outcomes and applications of the thesis involved carrying out walk-by surveys in the City of Leicester. Five LSOAs were chosen: the highest relative gas consuming LSOA, the highest relative electricity consuming LSOA, the lowest relative gas consuming LSOA, the lowest relative electricity consuming LSOA and an LSOA with average figures for both. These surveys aimed to determine if the results produced by the statistical model were an accurate reflection of reality, as well as to test the accuracy of the underlying data used in the study. The questions posed in this plausibility test included:

- What visual indicators exist to highlight potential efficiency and inefficiency in gas and electricity consumption?
- What geographical areas are associated with energy efficient behaviours?
- Do the models overlook factors which may explain energy consuming behaviours that are immediately obvious from visiting the areas (and therefore impact on the predictions the model makes)?

Table 3.6 outlines the visual indicators looked for when using the site visits to assess the model's capability at identifying energy efficient behaviour in the domestic sector.

Table 3.6 Site Visit Assessment

Indicator	Potential Impact
Double Glazing	Absence of measure may indicate lack of other energy efficiency measures
Energy Efficiency Marketing	Attempts to encourage energy efficiency measures
Solar Panels, Micro-Wind	Less energy consumed from national gas and electricity grid
Estimated Age of House	Older Housing likely to have lower insulation levels
High number of cars, lights on, windows open during working hours	Home working, unemployment, students with different to expected energy consumption patterns
Discrepancies in House type from 2001 Census and Reality	Underlying data unreliable

The assessment of these walk-by surveys were to search for evidence which directly contradicts the model's outputs (such as an area which the model deems to have a high energy efficient rating yet is made up of old buildings with single glazing and no evidence of renewables or energy efficiency campaigning).

3.6.3 Plausibility Test 2: Investigating the Effects of Tenure

As well as site visits, the statistical results were theorised to be energy efficient and energy inefficient based on tenure types and the housing stock from the academic literature. The main findings from the academic and policy literature is that social housing would be expected to have higher levels of thermal efficiency (since the Authority either directly owns, or provides the housing stock and therefore has the ability to implement energy efficiency measures) whilst private renting has the lowest levels of thermal efficiency (due to the differences in preferences and incentives between landlord and tenant). The LSOAs were split into 5 bands based on tenure types (0-20, 20-40, 40-60, 60-80, and 80+) to give different mixes of tenure proportions. The mean, median, interquartile range and 95% confidence intervals were calculated for these groups to determine if there were significant differences in average energy consumption indices between LSOAs with differing proportions of social rented housing.

3.6.4 Plausibility Test 3: Identifying Milton Keynes as an area of Newer Housing

The academic and policy literature also concluded that newer housing (particularly houses built since 1960) should be energy efficient (with regards to heating demands). The town of Milton Keynes provides a unique example of this (having already been studied as a low energy housing case study by Summerfield *et al* 2010b) and therefore the model developed should identify LSOAs in Milton Keynes as relatively energy efficient by highlighting the Local Authority as having lower than expected energy consumption. This can be compared to the results from Leicester, which has developed in an incremental patchwork fashion and therefore has a mix of pre-1960 and post-1960 housing in its authority. The number of LSOAs identified as consuming higher than expected in Milton Keynes was compared to other similar sized-cities across England, as it was expected that Milton Keynes will have a greater proportion of lower than expected energy consuming LSOAs.

3.6.5 Plausibility Test 4: Classification of Local Authorities

Local Authorities were split into Local Authorities containing new and expanded towns (as described below), with those that do not (termed 'pre-existing'). A second division was by whether the Local Authority was classified as 'rural' or 'urban'. Statistical tests were performed on the differences in the Means to determine if a statistical significant relationship exists. It was expected that 'New Town' Local Authorities would have lower proportions of LSOAs with higher than expected gas consumption, and this would be a further test of the plausibility of the statistical results. Local Authorities were classified as 'New or Expanded' if they were featured on policy documents detailing the experiences of New Towns by the Department of Communities and Local Government (2010c), or appeared in the list of expanded towns in Hansard (1973). Local Authorities were also split between rural and urban using classifications by DEFRA (2009) to explore the ways in which the LSOA consumption indices vary between rural and urban Local Authorities.

Testing the statistical differences between the means from the divisions of new and old towns and rural and urban areas was done using t-tests and analysis of variance. These tests are the most appropriate for this type of analysis as advocate by Wright 2002, Kottegoda and Rosso 2008, and Moore *et al* 2009. Following on from the work on consumer group electricity consumption by Gaspar and Antunes (2011), and from the information from statisticians Moore *et al* (2009), Bonferroni post-hoc tests were carried out where the one-way Analysis of Variance (ANOVA) test indicated that the mean values between groups showed a statistically significant difference to determine which groups had statistically significant differences in their mean values. As consistent with all the other statistical tests, at the 0.05 statistical significance level as advocated by Moore *et al* (2009).

3.7 Conclusion

The methodology described for this research will use statistical methods on secondary data sources to determine the nature of the geographical variations in English domestic sector gas and electricity consumption. Taking a statistical approach will enable results to be generated nationally, using a consistent methodology allowing for comparisons between areas from different parts of the country. Regression analysis enables the identification of variables which account for differences in domestic gas and electricity use, which are key findings for academics and policy makers alike. However this research also draws upon qualitative studies from interviews of Local Authorities, placing statistical results into the context of the pressures Local Authorities face, and how the patterns suggested by quantitative studies can be of use to local policy makers and political actors. This builds on the work already established by DECC as part of their 2011 NEED study, and from the 2012 Update to the HECA act. Where this research presents a new and original contribution to research is to work closely with Local Authorities in demonstrating a clear statistical application that can be used to guide local energy demand reduction policy.

Ultimately this research is shaped to meet the needs of local actors, whilst maintaining academic rigour and therefore followed a mixed-methods approach to testing the suitability of the method, and the plausibility of the results. The regression models were tested using data from different data sources. The results from the models were tested using follow-up feedback sessions with Local Authorities to ensure that Local Authorities were comfortable with the methodology followed, and had confidence in the accuracy and applicability of the results. Walk-by surveys of case study LSOAs were a further step to ensure the models were not generating erroneous results when compared to the reality ‘on the ground’. Plausibility tests of tenure, house age as well as new town and rural/urban Local Authorities were carried out to demonstrate the plausibility of the results.

4. CONSULTATION WITH LOCAL AUTHORITIES

This chapter investigates the role of Local Authorities in energy policy, the policies which are currently being implemented and future implementation of policies, the collaboration with other organisations, the data resources available to local authorities, financial pressures, comparisons between local authorities, dealing with behavioural change, and the impact of the political system on Local Authority activity. This was done through conducting interviews with Local Authorities and comparing and contrasting the results against findings from the academic and policy literature. By addressing these themes the confidence that the statistical models are correctly specified for Local Authority operation is increased, and the models have practical applications. The question schedule can be found in Appendix 1. The recording of data produced 475 minutes of audio recording equated to 52,000 words of text once transcribed. The rest of the chapter presents the results organised into the categories listed in Table 4.1 and the associated analytical codes (for a full list of coding applied see Appendix 2).

Table 4.1 Organisation of Codes into Analytical Sections

Section Theme	**Codes Covered**
Energy Efficiency and the Council	1a,1b,1c,1d,1e,1f,1g,12a,12b,12c,12d
Policy Developments in Local Government Energy Policy	2a,2b,2c,2d,10b
Local Government Co-Operation	3a,3b,3c,3d
Energy Policy Monitoring, Targeting and Resource Availability	5a,5b,5c,5d,5e,5f,5g
Financial Pressures	8a,8b,8c,8d
Comparisons and Competition Between Local Authorities	7a,7b,10a,10b,10c
Behavioural Change	11a,11b,11c
Political Issues	9a,9b,9c

4.1 Energy Efficiency and the Council

As highlighted in the Warm Homes, Greener Homes document produced by DECC, it is Local Authorities who are seen as the front line for implementing domestic energy policy to meet national carbon reduction targets, recognising 'Local Authorities' important existing responsibilities for cutting carbon emissions and their unique abilities to bring the right people together, making it easier for individual householders' (DECC 2010a). From an overview of the initial findings from the eleven Authorities questioned in this study:

- All eleven made explicit the connection between implementing domestic energy policy and policies aimed at reducing fuel poverty, with three reinforcing the wider socioeconomic benefits of energy efficiency policies;
- Seven mentioned legislative requirements as a decisive driver for their role in implementing domestic energy policy;
- Seven are looking to meet the 'decent homes' standard in their authority's housing stock; and
- Four expressed a political desire to lead the community in implementing domestic energy policy

These initial broad results suggest that reducing energy consumption in the housing stock is not necessarily the main priority for Local Authorities when implementing domestic energy efficiency policies in their housing. Authorities are also concerned about social issues, and see the benefit of improving their houses for social benefits. Local Authorities are also keen to set an example to the community that they serve. This leadership role serves as a motivation for local councils, and a method to coerce behavioural change from their communities. This quote from the Climate Action Team manager illustrates this:

> 'It's not very good if we can't demonstrate that we've done something, we've invested and had some success'.

This can be important if, for example, Local Authorities are able to improve the quality of their social housing stock, which in turn drives demand for insulation measures in the private sector stock (both rented and owner occupied).

4.1.1 Legislative Requirements

While there is a need to meet legislative requirements, the Home Energy Advice Manager at one of the City Council's stated in interview how their organisation's rational is 'primarily Government targets, but there's a political desire as well'. This is indicative of a target-culture of central governments, which was particularly apparent under the post-1997 Labour Government, as discussed in the literature review (Parry 2007). This political requirement to achieve certain centrally prescribed targets is highlighted further by the Sustainability and Planning Officer at a District Council, who stated in interview how the council body 'won't do it unless it's legislated for...they may turn round and say 'we're not doing that''. Legislative requirements can be seen as important for driving Local Authority, but can also be a hindrance because Local Authorities are driven more by the central target than what is necessarily best of the local area and its people. There is a clear desire to help the community from the majority of the Local Authorities interviewed in this study, suggesting that energy efficiency policies can provide multiple benefits to the community, an area which is discussed in more detail in further sections and the conflicts with the Central Government.

From an interview with a Sustainability and Planning Officer, there is insight into when councils have little interest in promoting energy efficiency, and no formal legislative requirements to do anything, stating:

> 'There's no political desire…[the politicians] don't believe there is an energy issue or a climate change issue here. The politicians block every single move'

In this instance there is a lack of interest in the energy efficiency agenda, with the local leaders seeing it as a low priority for the council, with greater emphasis on jobs, growth and frontline services such as health and education. While this experience is an anomaly of this study, if the council does not see the benefit of implementing energy efficiency policy, and there is little community action to put it more forcefully on the council's agenda, then there is little incentive to intervene and attempt to promote behavioural change. With the focus directed to other priorities, such as economic development, health and education, more resources are likely to be diverted into these than into energy efficiency. It is perhaps a recognition of this that has led to central government to increase the pressure on Local Authorities to ensure energy efficiency is on the agenda for all local authorities, a legal requirement is seen as essential for there to be any chance for the UK reduce its domestic energy consumption and reduce overall carbon emissions.

There are signs that Central Government is eager to place greater legislative requirements and emphasis on Local Authority energy efficiency. DECC's publications surrounding the Green Deal, and the *Warm Homes, Greener Homes* document is clearly indicative of the wider literature which suggests that Authorities governing small-scale units are best positioned to galvanise popular support (DECC 2010a, 2011c). However Local Authorities paradoxically have little financial support to collect data and implement their own strategies. However both Central Government and Local Authorities see themselves as 'trusted' organisations, implied by all the Local Authorities interviewed but explicitly stated by the Energy and Sustainability Manager in the quote:

> 'I think Local Authorities are generally trusted a bit more than a private sector organisation with an agenda to flog them the latest technology'.

DECC reinforce this view in their literature concerning the Green Deal, and outline the commitment from National Government to give accreditation to companies to carry out energy efficiency installations in the domestic sector (DECC 2011c). This is highlighted in the 2012 HECA document (DECC 2012a). Therefore it is anticipated that Local Authorities will be given increasing data and financial resources to improve domestic sector energy efficiency to reduce domestic energy demands.

The role of Local Authorities in implementing national government policy was a key aspect of the previous Labour Government's pursuit of a decentralised policy implementation in England. However as alluded to in the literature review, the UK is one of the most centralised states in Western Europe, and there is a degree of scepticism around public sector organisations at all scales spending money effectively. The coalition Government has been quick to promote the need for decentralised policy implementation in England but in contrast to the labour Government who pursued a regionalist agenda, the Coalition are pursuing a more localist agenda, significantly the Coalition have already abolished regional authorities and the regional tier of governance established under Tony Blair's Labour Government in England, instead prioritising the establishment of Local Enterprise Partnerships – joint local authority-business bodies to support local area development. This showcases how the Coalition is placing local authorities through their 'new localism' agenda, at the heart of public service delivery, not just in energy reduction policies but in other key service delivery areas. This localism has greater impetus on public-private partnerships with the intended aim of improving public sector efficiency, which is discussed in further depth in future sections.

4.1.2 Priorities of Local Authorities and Energy Policy

Policies designed to reduce carbon emission from the domestic sector are often inter-linked with energy efficiency drives to reduce fuel poverty. DECC (2011c/d) acknowledge this in their consultation document surrounding the Green Deal and the Energy Company Obligation (ECO), with energy companies contributing through the ECO to meet the shortfall in energy savings where householders were living in under-heated houses. Targeting fuel poverty is seen as a vital social policy for Local Authorities. Interestingly the District Sustainability Officer states that an energy efficient property is one with 'a much reduced risk of fuel poverty for the occupants'. Fuel poverty and the associated social benefits were seen as a strong driver in promoting energy efficiency drives within their authorities, and this is where the rebound effect discussed in Chapter 2 becomes an important factor when considering the outcome of energy efficiency programmes. There is a perception from within Local Authorities that improving the energy efficiency of the housing stock does not represent success to their local residents in the same way as being able to demonstrate reductions in fuel poverty and improvements in the health of the residents.

Interventions to reduce fuel poverty are relatively easier to measure than domestic demand reductions as a result of local energy efficiency policies, and areas of fuel poverty relatively easier to identify than inefficient or overheated homes through currently available statistics (Fahmy and Gordon 2007). Fuel poverty is often prioritised ahead of straight forward energy reduction policies, and most Local Authorities have stated that this is due to the wider social benefits of taking residents out of fuel poverty. Fuel poverty is also a good political measure, since announcing reductions in fuel poverty captures voter interest far greater than announcing increases in energy efficiency. From interviewing Local Authority representatives, there was a consensus that there is a trade-off between reducing fuel poverty and lowering domestic energy consumption. A County Council Climate Action Team Manager in interview talked of a ‘slight irony’ where focusing efforts on reducing fuel poverty by increasing the energy efficiency of those homes will ‘probably drive carbon up rather than down’. This is as a result of the rebound effect discussed in chapter 2. This apparent ‘conflict’ is reinforced from an interview with a District Sustainability Officer who claimed that: ‘part of the problem is that the policies confuse fuel poverty reduction with carbon saving reduction. It’s a big, big overlap but it’s not necessarily the same thing’. Incorporating fuel poverty into the modelling process is important to ensure these potentially differing outcomes (increased energy efficiency against reduced fuel poverty) are accounted for when judging Local Authority performance.

The impacts of fuel poverty are not to be understated. Improving the energy efficiency of the housing stock will likely reduce fuel poverty and improve the standards of housing in low income areas, but this may not lead to the expected results of reducing energy consumption if energy conservation was not the sole or main priority of Local Government energy policy action. By assessing local authorities through measuring the reduction in domestic energy consumption, this will penalise Authorities which increase the energy efficiency of houses of residents in fuel poverty, while rewarding authorities which focus their efforts on more affluent residents (who are less likely to be in fuel poverty and therefore less likely to experience direct rebound effects).

Much of the literature on domestic energy efficiency addresses the benefits of pursuing a Warm Front/Fuel Poverty reduction policy for reasons other than reducing consumption, citing the increased health and social benefits of enabling low income residents to adequately heat their homes. The Borough Sustainability Officer gives an insight into the role of this particular council in achieving both reducing fuel poverty, and in meeting energy consumption reduction targets, explaining that:

> 'Clearly we are concerned about reducing fuel poverty and I'm making sure all our residents are safe and warm and healthy'.

In a separate interview the Energy and Sustainability Manager picked up on this theme, stating from their perspective 'I'm not necessarily focused on domestic energy but more focused on the fuel poor and the vulnerable'. Reducing fuel poverty appears to be a major policy driver for most local authorities, whereas reducing domestic energy consumption is only on the agenda for some authorities. For Local Authorities, fuel poverty is an important factor to consider, and therefore fuel poverty indicators must be included in any further analysis of energy efficiency reductions to fit Local Authorities priorities supporting the literature on the rebound effect. Fuel poverty strategies link into wider social objectives of Local Authorities, with the example of collaboration with the NGS on improving living environments and the overall health of the residents cited by the Home Energy Team Leader in interview, stating that it is important 'from a health aspect to keep heat in the home'. The NHS guidelines suggest that the priority demographic for maintaining a warm home includes pensioners and the young (NHS 2012). This interlinking relationship between fuel poverty and energy efficiency raises the need for a targeting model for Local Authority use to consider fuel poverty, or the relative incomes of households when directing energy efficiency policies. Whether Local Authorities intervene to reduce energy consumption or to reduce fuel poverty would be the decision of the Local Authority based on their local knowledge and the local objectives that they wish to achieve under the new localism agenda promoted by the Coalition Government.

4.2 Policy Developments in Local Government Energy Policy

For the communities which benefited from certain Government schemes such as Warm Front, the changing of schemes is seen as a big blow, highlighted by the Home Energy Advice Manager who points out that Warm Front going is 'unfortunate because although there were problems with it, it was pretty successful' and highlights the wider benefits for the council in general, adding 'in the City last year we had 1500 jobs carried out under Warm Front, almost £2million spent in the City'. The average spend nationally across Local Authorities on Warm Front schemes was £1.3million, although four councils spent less than £200,000 and one council spent just £205 on Warm Front in 2010/11 (DECC 2011e). While Warm Front is aimed more at alleviating fuel poverty than necessarily reducing energy consumption, these figures highlight the differing levels of resources being committed to these schemes between councils. The Private Sector Housing Manager believes there is 'clearly an on-going need for Warm Front' but from interviews, and examination of DECC's 2011 publications, it appears that the Energy Company Obligation (ECO) will become the replacement for Warm Front, albeit with more emphasis on energy company finance rather than public expenditure. Warm Front expired in 2011 and ECO only came into operation in October 2012. Six councils had at the time expressed uncertainty surrounding the replacement for Warm Front, and this uncertainty is reducing their abilities to devise schemes to reduce fuel poverty.

The flagship energy efficiency policy of the current coalition Government is the Green Deal, and there is scepticism expressed by five Local Authorities, especially regarding how those on low incomes can take part in the scheme. The Private Sector Housing Manager states that it is difficult to know how the green deal will impact on low-income households, and that low income people are ‘not what [the green] deal is designed for’. The Home Energy Advice Manager emphasised that the Green Deal is for the people ‘that are able to pay’. DECC (2011d) believe that those on low-incomes will be supported the ECO scheme, the role of the ECO scheme would overcome some of the fear expressed by the Private Sector Housing Manager in interview, who stated:

> ‘If you’re not adequately heating your house now you’ll only get pay-back if you continue not to adequately heat your home’.

The findings from these interviews, surrounding the topic of the Green Deal further emphasise the importance Local Authorities place on reducing fuel poverty, and reinforce the difficulty in separating the impacts of fuel poverty and energy efficiency policies. The transitory phase that Local Authorities find themselves in at present makes long term planning difficult. The interview with the Home Energy Team Leader outlines this best, stating:

> ‘We’re all sitting, waiting, we’ve got the big broad brush strokes but we need the details to see how we can implement it’.

Uncertainties over the implementation of new schemes, and the changing in mechanisms for implementing energy efficiency, and related fuel poverty reduction schemes strongly indicate that there is a need for the design of guidance models for Local Authorities that are not too-closely aligned to a specific government policy, and that there is insulation from policy changes, which is explored in greater depth later in this chapter. The model’s construction should be flexible enough to adapt to policy change, and should not ‘punish’ Local Authorities who pursue fuel poverty reduction policies at the expense of overall energy reduction. Identification of inefficient housing stock should be a priority whether they are under or overheated. This would identify households in fuel poverty and over-consuming wealthier households.

4.3. Local Government Co-operation

Local Authorities have actively engaged with other Authorities; sharing knowledge and resources. Several councils spoke of regional collaboration groups, co-operative council meetings and joint service provisions. The justifications for these are highlighted with examples from accounts from interviews with Local Authority representatives. All of the Local Authorities interviewed saw the advantages of working with neighbouring councils, especially in terms of resource sharing and developing economies of scale. The Energy and Sustainability Manager expressed that working on a project together is 'better than by yourself, if you're doing a partnership you could just do half a day a week, saves on the workload'. This resource sharing aspect was also emphasised by the Home Energy Advice Manager, who outlined that the cross-country energy partnership their council was involved in 'works very closely with new schemes' with a bit of funding 'to develop a two-county wide climate change campaign'.

The rationale for collaboration is based on resource sharing and the belief that operating as 'larger units' gives Authorities the advantages of economies of scale. As discussed in later sections, there have been opportunities for smaller district councils to merge into large single tier units (such as at the county level). Potential administrative and political changes such as these and with a mix of councils acting individually and in collaboration require the model to be developed at an appropriate scale. Designing a model based on spatial units that may be abolished, or be inappropriate for policy would limit the applications of the benchmarks generated. Indeed, administrative boundary reform in 2009 saw the abolishment of lower tier Local Authorities, and the creation of 10 Unitary Authorities (ONS 2012b). For comparative purposes in this thesis, the statistical data used is based on the pre-2009 LA boundaries; however it is anticipated subsequent studies would incorporate the 2009 boundary changes. Lower layer super output areas are the preferred spatial unit used in this research because they are not subject to political or administrative boundaries, and have been constructed to remain constant over time. From consultation with Local Authority workers, spatial scales operated at for domestic energy policy were: Local Authority, Ward, Parish and Street Level. It appears each authority has their own idea of how best to report statistics and implement strategies. By using lower layer super output areas, these can be cross-references against wards, local authorities, county councils and the former government office regions, a point made explicit in interview by the Home Energy Team Leader. Designing the model at this scale does not require Local Authorities to work independently, or bind the model to particular political divisions of England.

4.4. Energy Policy Monitoring, Targeting and Resource Availability

The Local Area Agreements of 2008-2011 set out National Indicators, of which NI 186 focused on a reduction of per capita emissions within Local Authority boundaries (DCLG 2009). The NI 186 indicator has implications for domestic energy consumption given that the domestic sector accounts for 30% of the UK's CO2 emissions. This section discusses attitudes towards currently available domestic energy consumption data, and the methods of measuring progress of domestic sector energy demand reduction policies.

4.4.1 NI186 and DECC's Sub-National Energy Statistics

DECC has published domestic energy consumption data at sub-national level since 2005, and at LSOA since 2008. This data is published to aid in Local Authorities reporting of CO_2 emissions within their boundaries to encourage policy action. The advantages of using a nationally produced dataset is that it is calculated using a nationally consistent methodology, which is essential if Local Authorities are to be compared against each other, and if LSOAs within Local Authorities are to be examined. The Home Energy Advice Manager saw the DECC NI 186 data as being useful as 'a sort of benchmark against other councils'. The aim of this data is for a 'measuring reductions' approach to energy policy, whereby Local Authorities would measure the outcomes of their interventions, and this tied in with the Local Area Agreements, specifically NI 186 (reduction of per capita CO_2 emissions in Local Authority Area). All Local Authorities alluded to NI 186 in the interviews, and six actively followed NI 186. However the indicator and its associated dataset drew criticism.

The Home Energy Team Leader expressed the benefits of having consistent methodologies for datasets over time, having tried to keep the monitoring process 'consistent year on year since 1999' using the 'same guidelines, same parameters, contact the same groups' despite the changes to national policy over this period. Using consistent methodologies over time is vital for building familiarity for Local Authorities and enabling expertise to develop. By tying monitoring processes too tight to national policies, which are subject to change and revision, this adds to the resource demands on Local Authorities. The Affordable Warmth Officer stated in interview that despite NI 186 being scrapped, the framework from it is still 'really valid' and that the council is 'doing more from what springs out as NI 186'. These two council examples highlight the potential for a benchmarking tool that retains enough flexibility in its mechanism to be applied to a range of different government initiatives.

4.4.2 Reservation over Government Figures

From consultation with Local Authorities, over half expressed a preference for a 'measuring interventions approach'. This was justified on the basis that the national data published by DECC does not provide the right information for Local Authorities to measure their policies and there is considerable doubt regarding the accuracy of the DECC data expressed by six of the Local Authorities. A Borough Sustainability Officer explained in interview that having consulted the DECC methodology surrounding the construction of the figures was not very 'assured by the level of confidence in the information making up those figures'. The Climate Action Manager had further concerns about nationally collected data, stating:

> '[The NI 186 figures] seem wholly unbelievable to me, I haven't read the methodology but I suspect they're extraordinarily complicated...in the absence of

anything else we will use those figures but I will put a personal health warning on all of them'.

However several councils preferred to use the DECC data despite inaccuracies. The Borough Sustainability Officer acknowledged that 'no data is perfect' and instead looks at the 'best fit'. The Home Energy Advice Manager's views expressed in interviews agree with his viewpoint, stating that the NI186 figures:

> 'Served the purpose of giving an idea of our per capita CO_2 emissions...we don't want to be so tied up with the accuracy that we don't actually go and encourage people to improve the energy efficiency of their homes'

A way of overcoming data problems from national sources is to collect low-level statistics but this is seen as a time consuming exercise for Local Authorities who do not have the time or resources to do this. Some collaboration has been undertaken to produce local databases, allowing Local Authorities to pool resources and generate statistics which describe their local areas. The Affordable Warmth Officer cited in interview an example of a neighbouring council that has developed their own database, making it a subject of 'envy' for their council. The idea of local databases is seen as an 'aspiration' for the Home Energy Advice Manager, but looks towards 'other organisations to come up with that [data]'. The Private Sector Housing manager looks towards greater data availability, stating that it would allow the council to 'report things in more depth'. Measuring outputs to rank Local Authorities would be dependent on the availability and accuracy of national data sources constructed on a consistent methodology.

4.4.3 Measuring Interventions

Many Local Authorities questioned the relevance of attempting to measure the outcomes of their energy efficiency policies, instead preferring to measure the interventions that the council has made. This is best summed up in interview with the Environmental Policy Officer who states:

> ‘I think the Government has realised giving us figures like ‘8.8 tonnes CO_2 per capita is not telling anyone anything so why not look at what you’re doing on the ground, what you’ve got the capacity to do?’.

The Environmental Policy Officer continued to elaborate, giving an example of the council’s current policy to ‘fill 1000 lofts and cavities a year’. The Home Energy Advice Manager’s interview response supported this view, explaining how the Authority can ‘list the activities’ and estimate that it was ‘likely these would have a bearing on carbon emissions in the city’ but ultimately would simply ‘hope the figures would go down’, indicating that current targeting is not adequate. Other approaches to monitoring do not involve quantitative measures at all, instead relying on qualitative approaches and local knowledge. The Energy and Sustainability Manager emphasised in interview that local knowledge is ‘as good as anything’ in knowing which areas to target and how to intervene. The Affordable Warmth Officer stated that ‘sometimes there’s no substitute for having worked in this area for a long time’.

These responses give the impression that the idea of a benchmarking tool for Local Authorities targeting areas for efficiency improvements based on their own local knowledge, and the overriding aims of Central Government targets is more useful to Local Authorities than simply measuring the overall outcomes of their energy reduction policies. The form of the model will give Local Authorities indication of where energy efficiency improvements are required rather than attempting to calculate potential carbon savings. This approach is favoured by all of the councils interviewed, and ensures Local Authorities focus on improving domestic energy efficiency, rather than becoming concerned with factors outside their control, such as the uptake of micro-renewables and potential decarbonisation of the national electricity supply.

4.5. Financial Pressures

Perhaps the biggest pressure on Local Authorities is over the financing for their energy policies. All of the Authorities questioned expressed concerns over cuts to their budgets for pursuing energy reduction policies. However it is the smaller district councils that expressed greater concerns. There is a belief that it is political ideology that is influencing the decisions to cut allocations from Central Government, with an emphasis on collaboration with private industry rather than in-house work using state subsidies. This is strongly reinforced by the Climate Action Team Manager who believes that 'we try not to subsidise, everything is partnerships and private investment and private finance, that's a government culture'. The implications of this 'government culture' are best highlighted by the Private Sector Housing Manager who explains:

> '[The Government] are talking about this energy supplier's obligation, and they're talking about local authorities having a strategic enabling role to help reach hard to treat homes and low income households but it's not clear how they think that will work and it really depends how far the funding is going to be available for local authorities to deliver...or it's going to be the energy companies doing their own thing and we'll tell them where the properties are'.

The 'Warm Homes, Greener Homes' document explicitly states that energy companies will be obliged to work with Local Authorities for energy efficiency, and given the views expressed by Local Authorities in interview, it is clear that future energy efficiency policies in the domestic sector will not be undertaken by one organisation working in isolation. Therefore any models developed to aid Local Authorities in targeting areas will have to be relevant for public-private partnership. The results generated by the model must be applicable for Local Authorities to advise and direct private financers and private companies to which areas offer best value for money, and the best potential policy results.

The potential benefits of collaboration between a number of public and private organisations in energy efficiency was highlighted in an interview with an Energy and Carbon Manager at a City Council who recounted an existing scheme running in their area:

> ‘[We] are driving this low-carbon City initiative, there are a number of key stakeholders across the city so the big players like supermarkets, car companies, the universities, the city council, anyone that’s got some influence in the city. It’s about working on a city-wide scheme to reduce CO_2 emissions by 3% year on year’.

This was just one of eight accounts of the growing involvement of private companies, particularly supermarkets and energy companies offering their own schemes or offering Local Authorities financial backing for schemes. This was one of the directives from the previous Labour Government, building on from the Conservative Government of the early 1990s by reducing many of the regulations around Local Government and encouraging private companies to provide services for the public sector (Stoker 2004). Anecdotal evidence from Local Authorities and press-releases from Central Government strongly suggest this trend will continue. The growing involvement of private companies is likely to require quantitative indicators that can demonstrate performance of schemes to the shareholders of the private companies, ensuring these companies can demonstrate a return on their investment. This also fits into Local Authorities objectives of satisfying Central Government criteria. Three Local Authority representatives spoke of the financial restrictions preventing them from being able to employ statisticians or statistical workers. This requires the model and benchmarks generated to be easily interpreted and understood by Local Authorities and private companies, and not made excessively complicated.

4.6. Comparisons and Competition between Local Authorities

4.6.1 Ranking Authorities

Alongside the increasing role of private companies, another legacy of the previous Labour Government was the increasing prevalence of league tables for comparisons of Local Authorites (Stoker 2004). The issue of league tables, rankings, and comparison of Local Authorities divided opinions of the interviewees. Four council workers felt comparative analysis was a good idea and 'healthy competition' gave a good reflection of Local Authority performance, whilst three council workers felt the exercise was pointless due to the differences in housing stock, demographics, resources, and local factors that impacted on Local Authority domestic energy consumption. In the local governance literature this is addressed by Stoker (2004:220) who states:

> 'To be able to judge the performance of local institutions allowing fully for their circumstances and starting point is always going to be tough. Even then, it is based on the rather heroic assumption...that you can rely on what you are being told'

Development of a benchmark using appropriate, accurate and nationally consistent data is very important to ensure that Local Authorities (as well as private companies, national government and the general public) can trust that what they are being told is correct. As the Energy and Sustainability Manager suggested in interview, if 'someone created a set of data that all councils could use, to benchmark themselves to get some idea of where they stand in relation to other authorities, that would be useful'. These viewpoints give weight to the development of a model that utilises nationally produced data which would ensure local authorities to rate their own performance. Leach and Percy-Smith (2001) note the deficiency in Local Authorities conducting research into developing an evidence-base for policy monitoring, and question the reliability and quality of data collected by Local Authorities for the purposes of monitoring policy successes. Ensuring that Local Authorities use data collected by consistent methodologies is important for comparing results across councils and regions.

4.6.2 Difficulties with Comparisons

In contrast to the positive views on comparison expressed in the previous section, not all of the Local Authorities necessarily saw the positives of comparisons. The Sustainability and Planning Officer sees the benefit of comparison, but not with the raw data, explaining:

> 'With league tables we will be critically assessed by DECC and the Local Government Associations in the area... [but] it's very difficult, it's almost impossible. You've got different numbers of housing, different numbers of people in Local Authorities, different numbers of staff working in Local Authorities, resources are different, stock is different'.

Fitting with the quote from Stoker (2004) in Chapter 2, there is a need for data to be standardised in some way to account for the differences between Local Authorities. The Energy and Carbon Manager suggests comparison requires 'some context about it' and uses the example of the authority's calculation of NI 185 [CO_2 emission reduction from Local Authority estate] performance, which is 'normalised by revenue or employee'. The rationale for this is to account for potential estate expansion which may push overall CO_2 emissions up but hide energy efficiency improvements. The benefits of comparisons are not shared by all. The Climate Action Team Manager questions the value of making comparisons between authorities, asking:

> 'Do I want to compare our county with Northumberland? Or do I want to compare our county in 2015 with what it was like in 2008? [The latter] seems more realistic comparison to me'

The Environmental Policy Officer shares a similar view, saying that there is nothing better 'than to measure yourself against yourself, asking 'how can I improve that? Rather than 'look at what they're doing'. These viewpoints are interlinked with the earlier discussion about recording intervention measures rather than outputs (in the form of CO_2 reduction). The model used in this project does allow Local Authorities to compare their own progress over time, alongside giving an indication of their relative performance against other councils. The comparison aspect accounts for variations in factors that are beyond the council's control, which have been discussed extensively in the literature review.

4.6.3 Infrastructure Differences

Local Authorities face different standards of housing with different heating systems, and different standards of construction (e.g. wall type). These differences impact on the different schemes available for Local Authorities and the appropriate schemes for energy efficiency improvements, particularly for areas that are not connected to the gas grid. Off-gas houses are heated by alternative fuels and the full energy consumption of these houses will not appear in the DECC data unless they are heated electrically. The Affordable Warmth Officer highlights the difficulties of using the Green Deal to treat off-gas properties, stating:

> 'If I have a household who refuses warm front because they're scared of the gas bills if they do get a gas system put in, I have got a household who is not going to say yes to a 20 year loan putting £20 a month on their electricity bills...a long term loan, however favourable it may be, is not the answer for vulnerable households'.

From interview with an Environmental Policy Officer revealed that this particular council actively target off-gas regions, stating:

> 'We are targeting off-gas communities because that's where we find the most fuel poor and people paying over the odds bills. We've had householders paying £6000 a year in farm houses for things like LPG, sold fuel, and oil'.

Since off-gas properties do not show in the DECC gas consumption figures, and the difficulties in establishing the fuels used by these householders for heating, a decision has been made to exclude areas with no gas meters from the modelling phase. Bringing these houses onto the gas grid may have the effect of the data showing energy efficiency declining (since more gas consuming houses are now in the dataset) when in reality, the gas fuel used is more energy efficient than the alternative, non-recorded fuel.

The construction of the house plays an important role in determining which methods Local Authorities can use, and the financial costs of installing insulation. Solid wall properties are generally more expensive and difficult to renovate than cavity wall houses, and often the insulation process increases the 'hassle factor' for householders, and may alter the aesthetics of the house. This is summarised by a quote from an interview with a Home Energy Team Leader, who explains:

> 'One of the problems is...the housing stock, a lot of it is late 19th century Victorian terraced housing which has a lot of nice details on the front so if you render them you're going to lose a lot of the aesthetics.

This is an important point to consider, and due to personal attitudes and preferences simply identifying areas which may benefit from energy efficiency interventions does not necessarily mean there will be any action taken.

4.7. Behavioural Change

A recurring theme throughout the interviews is the role of behavioural change and attitudes of residents within Local Authority areas. Policies can have markedly different effects on householders depending on their attitudes towards energy efficiency, climate change and their views of the Local Council. Behavioural change is difficult to quantify, and councils themselves realise that people do not always react in ways that they expected. Attempting to develop models that can account for various household attitudes would lead to excessively complex modelling. Local Authorities can only encourage their residents to change their behaviours, as the District Sustainability Officer repeatedly stated:

'We can only influence, we can't force anyone to do anything'.

When attempting to encourage the uptake of energy efficiency schemes, many of the councils reported reactions of hostility, or apathy despite the personal and financial benefits being outlined and reinforced through promotions and canvassing. This is often where Local Authorities rely on interactions with community groups to encourage their residents to take-up energy efficiency installations in their properties and encourage behavioural change. However there are still very few methods that can accurately measure the impacts of intervention to induce behavioural change towards more energy efficient living.

4.7.1 Difficulties in Engaging the Local Community

Local Authorities did acknowledge the need to engage their communities to encourage uptake in their energy efficiency schemes. The Climate Action Manager made it clear that it's 'easy to identify the opportunity to [implement energy efficiency schemes], turning it into reality, into a project is really time-consuming and a bit of a problem really'. Where there is sufficient support for energy efficiency interventions, Local Authorities may be constrained by bureaucratic restrictions, and it was the Climate Action Manager who expressed doubts over the 'Golden Rule' of the Green Deal. Schemes do not always achieve popular support, and the attitudes of individuals towards energy efficiency schemes are shaped by a variety of social, political and cultural factors which Local Authorities must account for when designing and promoting their energy efficiency schemes (Owens and Driffill 2008). Apathy towards the energy efficiency and climate change agenda was implicit in the interviews conducted, and this was explicitly stated by the Energy and Sustainability Manager: 'people can't be bothered to do anything; they'll only do it if you do it for them'.

Overcoming apathy in the community towards schemes such as the Green Deal, and active behavioural change could be overcome by providing financial incentives to householders to encourage households to come forward and take up energy efficiency measures. The Sustainability Manager discussed this in interview, stating 'the only way they're going to do this and improve their homes is if we approach them proactively and give them free stuff and we haven't got the money to do that'. The Affordable Warmth Manager suggested even this action wouldn't be enough to entice residents to participate in energy efficiency schemes, saying 'people don't believe it's free...if they can get round that then people will take it up'. If Local Authorities are to identify areas within their boundaries that would benefit from energy efficiency interventions then there is a need for the Authority to develop appropriate policy responses using the knowledge of the residents in these particular areas and the best methods to encourage the householders to invest in energy efficiency schemes. This is a problem particularly for electricity use, as schemes such as the Green Deal are aimed at improving the technical efficiency of the housing stock. Reducing electricity consumption is seen to require behavioural change.

The policy response advocated will be influenced by the tenure of the housing stock. As stated in chapter 2, Local Authorities have a high degree of control over the social housing in their area but it is the owner-occupied sector that must be convinced to insulate their houses. Local Authorities must design clear strategies that clearly outline the benefits to owner-occupiers of taking up insulation measures as part of the Green Deal to see significant improvements in energy efficiency. The policies of energy efficiency are complicated even further by the private rented sector, as it is the obligation of the landlords to improve the energy efficiency of the housing by setting up the Green Deal options while the residents gain the benefits of improved living environments and lower fuel bills. The landlord and tenant would also have to organise a time for this process to take place that is mutually beneficial to both parties. The modelling process should incorporate tenure aspects to household energy efficiency schemes, especially concerning social and privately rented properties, as these areas will require different policy interventions to owner-occupied housing. This primarily concerns gas consumption which is the dominant fuel for space heating.

4.7.2 Alternative Methods of Engagement

To overcome this apparent apathy, the Environmental Policy Officer outlined how by rephrasing the ‘message’ about the benefits of energy efficiency interventions away from financial payback over relatively long time scales and meeting climate change targets, then there is some engagement with the community, stating:

> ‘The climate agenda doesn’t grab people in the community as much as it should do. It’s much more about ‘I’m cold, I’m poorly, I can’t afford it and my house is damp’. It’s those practical kind of things…well for most people...so I don’t run it along that basis, you just get doors closed’.

Two councils stated their beliefs that domestic energy efficiency could follow the example set by the air quality movement of the 1990s, where behavioural change has been achieved to some extent with regards to the phasing out of leaded petrol in favour of the cleaner unleaded variety. Incentivising energy efficiency practices could lead to permanent behavioural change. As the Home Energy Team Leader Explains:

> ‘I think at the beginning you have to incentivise these things to get the whole thing moving and then it develops a mind of its own and carries on’

This reinforces the need for consistent schemes that will allow residents and their communities to become familiar with new energy saving behaviours. Continual changing of policy can have the effect of disengaging individuals from making behavioural changes, or persevering with new behaviours. The model developed would not prescribe interventions for Local Authorities to use, but would advise local authorities which areas need intervention, and ultimately it would be the judgement of local councils to choose the schemes which best meet their community’s needs.

The use of a benchmarking tool to identify the least energy efficient regions within a Local Authority would give the council the ability to determine if an area is in need of large-scale retrofitting (because the housing stock is of a poor quality), some retrofitting and some behavioural change (moderately insulated with inefficient heating practices) or mostly behavioural change (well insulated but inefficient use of heating and appliances). Local Authorities can them focus on the most appropriate energy efficiency scheme to intervene in these areas, whether this be through encouraging householders to improve the thermal efficiency of their housing stock, or through pursuing educational schemes and other policies to influence behavioural change.

4.8. Political Issues

From the interviews with Local Authorities the political system is found to be an area of friction between Councils and the National Government. Nine of the Councils interviewed found the complete overhaul of many national policies and the changing of priorities of the new coalition Government has made it difficult for Local Authorities to adopt long-term strategies to increase the energy efficiency of the domestic sector. The Energy and Sustainability Manager took a negative view of Central Government involvement in domestic energy efficiency policy, suggesting that the Government 'don't want the responsibilities of the policies', adding 'they say it's up to you what you do and then if it goes wrong they come back and blame us for it'. This supports the views raised in the literature, where Local Authorities in the UK are seen as implementers of national policy, as opposed to federal or regional authorities in other countries which have a greater degree of flexibility for policy formulation and implementation. This is also highlighted by the literature in chapter 2 concerning 'centrally orchestrated localism' (Jones and Ward 2002), and 'centrally orchestrated regionalism' (Harrison 2008).

Some Local Authorities also see a desire to change the existing set-up of Local Government, citing the presence of two-tier authorities (i.e. a district council operating below the county council) as needless, believing a single-tier unitary authority set up. This is because the larger authorities are seen by [most] councils as the model for success. Unitary authorities are generally larger authorities and this gives them the advantages of economies of scale (as discussed in the collaboration section of this chapter). The Borough Sustainability Officer explained in interview that ‘the cities are better able [to implement schemes], they’ve got economies of scale and bigger teams and also unitary authorities get a bigger share of council tax’. These arguments in favour of unitary government were highlighted by the 2006 White Paper ‘Strong and Prosperous Communities’, outlining the support of the then Labour Government. However since the 2010 general election, the coalition government has indicated that it does not support further creation of unitary authorities (DCLG 2006b, Elcock et al 2011). These arguments in favour of larger single-tier units are similar to the arguments to in favour of increased collaboration between Local Authorities.

In the context of the belief that large councils benefit due to economies of scale, Elcock et al 2011 present the argument that smaller council units have the potential to engage closer with the local communities that they serve, as opposed to a larger, county based organisation. The reality is that in England there has been the creation of both county and district unitary authorities, and a pledge from the Central Government to maintain the status quo (Elcock et al 2011). This confusing and contradictory approach towards Local Government in England makes incorporating the size and type of authorities into the modelling equation difficult, and therefore the model will focus on factors that influence domestic energy consumption in lower layer super output areas. In interview with a representative from a county council, frustrations were cited of the current institutional framework, particularly regarding the differing attitudes to energy efficiency in the district councils below them, different political viewpoints, and the lack of power to hand down policy to be implemented by local districts. This viewpoint is highlighted when they state:

> ‘How do we provide the even service and support for all our residents in the county when you have [some districts] spending lots of money and doing things and [another district] not really believing it is an issue and not doing anything?’

For the Energy and Sustainability Manager, a reorganisation of council hierarchy is seen as the solution, highlighting the experience of a county council looking at becoming a unitary authority with the county council taking over all authorities, believing this ‘might be the right way to go’. The literature suggests that the prospect of abolishing two-tier authorities had been raised in the early 1990s with county council organisations being abolished. This was blocked by the County Councils. However given the potential economies of scale from re-organisation into larger authorities, it may be beneficial to re-organise Local Government by abolishing district councils. Trends since the proposed 1990s reforms have been inconclusive in this area, with some county councils becoming redundant (e.g. Bedfordshire, Berkshire) whilst other regions have undergone consolidation, with unitary counties (e.g. Wiltshire, County Durham) (DCLG 2006b, ONS 2012b). As a result Local Government in England remains incoherent (Elcock et al 2010). The Energy and Climate Manager questioned ‘will there even be a local authority?’, stating:

> ‘The way this Government are playing it, with the localism bill is likely to dissemble what is in place at the moment and placing more decision making onto local community groups. There may be more community driven social enterprise stuff driving this agenda’.

This was not a view expressed by any of the other respondents and perhaps is best considered a rather personal reflection on the growing frustration seen in the current political and economic climate. The consensus from councils themselves and from the literature produced by DECC and DCLG suggest that Local Areas will have a key role in both identifying and implementing energy efficiency policy. As discussed in the literature review, local and national desires to re-organise Local Government in England, and any successes in doing this, give further weight to the argument in favour of using LSOAs which are non-political boundaries.

4.9 Conclusion

In this chapter first-hand accounts from consultation with local authorities were presented, discussed, and evaluated to give a context to the practicalities of local energy policy. The results indicate that strategies and schemes and resources provided by Central Government are undergoing change, and have frequently been altered, modified and abolished by successive governments, benchmarks that are developed for targeting strategies should not be too attached to current government policy. The model designed should also not be tied down to political regions that are subject to future changes and boundary revisions, and therefore using census output areas which are designed to remain consistent is of benefit to the intended target audience. The advantages of using these census output areas are applicable to both lower-tier district councils and upper-tier county councils and are sheltered from re-organisation of Local Government in England and changes to Government policy. LSOAs benefit since they fit within the current local authority boundaries and are not subject to political re-organisation in the same way that political boundaries such as wards are.

One of the most Local Authorities are undergoing a transition phase, with the remaining remnants of the previous Government's schemes aimed at increasing household energy efficiency due to expire in 2012 and replaced with the Green Deal and the ECO. As well as this political change, Local Authorities are also undergoing change to their budgets, as well as dealing with increasing expectation that private companies will provide public services. With this in mind, there is a need for a benchmarking tool that can guide Local Authorities to where to commit resources to for reducing domestic energy consumption, to go alongside current Government monitoring requirements of CO_2 reduction. Due to the short-term nature of government policy, and potential for future political upheaval, and collaboration between councils beyond local authority boundaries, the model developed is not designed to fit any specific government scheme, but to develop benchmarks at lower layer super output area. These benchmarks can be aggregated up to the relevant policy level (e.g. ward, district council, county council). The benchmarks will guide local authorities to where energy efficiency policies are most needed given the social, technical, economic and geographical variations across the country and insulated from policy changes.

5. DOMESTIC ENERGY CONSUMPTION DATA

This chapter describes the gas and electricity consumption data used in this study. The DECC sub-national data for domestic gas and electricity consumption were the logical starting point for evaluating energy demand in the UK housing stock, these became the dependent variables in the modelling process described in chapter 7. The background to the data is described, and descriptive statistics are given for gas and electricity. Issues with disclosure and unallocated consumption are discussed. DECC (2010c:2) states that its aim in publishing these data is that it helps LAs (and other interested bodies) to target specific areas as part of the implementation and monitoring of local energy strategies. Beginning with the data for the year of 2005, DECC has been publishing domestic gas and electricity (standard and economy7) consumption statistics below Local Authority level measured in Kilowatt-hours (kW h), which were first published in 2007. These figures are published as a total for an area, and the average per meter (DECC 2010c). DECC has spent six years carrying out developmental work to produce sub-national statistical data for energy use in England and Wales for dissemination primarily within Government, Local Authorities and the energy industry (UK Statistics Authority 2009, DECC 2010d). In 2010 DECC released data at LSOA level for the year 2008, adding to the MSOA publications that have been published since 2005, improving the spatial resolution of the data and allowing Local Authorities to target increasingly smaller geographical areas. The UK Statistics Authority (2009), the independent monitoring and assessing authority for official statistics, expressed some criticisms over DECC's sub-national energy consumption data. It cites a lack of readily available and accessible information on methods and qualities, a lack of knowledge of data use by academia and other research, little disclosure on how data is collected (sampling methods) or who it is collected by. The recommendation is that DECC take steps to engage more effectively with users outside of Government and the Energy Industry (UK Statistics Authority 2009). The methodological process of producing this data is summarised and analysed in this section. Following this, descriptive statistics were calculated, and the distributions examined to establish if they were approximately normal and if transformations were required prior to multiple regression analysis. Outliers were also investigated in attempt to ensure that the models generated in subsequent chapters follow the assumptions of multiple regression (particularly that the residuals are normally distributed). Transformations where applied to the dependent variables where appropriate, since the non-normal distribution makes multiple regression analysis difficult to generate reliable results.

5.1 Gas Consumption Statistics

DECC publish gas consumption data obtained from sales figures made available by the National Grid (the company primarily responsible for the gas transmission network). This is allocated to the relevant super output area by their corresponding postcode sector (the postcode of the gas meter minus the last two characters, e.g. LE11 6). Restructuring of the UK's gas network in 2005 saw four local distribution zones (LDZs) being sold off by National Grid. The data from the gas transmission network is collected and maintained by Xoserve, a private company that is responsible for 22 million gas supply points (DECC 2010c, National Grid 2012, Xoserve 2006). There is a lack of reliable domestic-industrial split for classification of meter points, with the gas industry using an arbitrary level of 73,200kW h level as a cut off point for defining consumers as domestic or industrial. This is four times the national average for domestic annual gas consumption (18,000kW h). As a result of this cut-off figure, an estimated 2 million small and medium businesses are incorrectly allocated to the domestic sector (DECC 2010c). This potential misallocation is statistically analysed in chapter 8 as part of the data validation and how these errors in the energy consumption data recording may affect the form and results of the statistical models. A final note is (as introduced in section 3.3.2) that the gas consumption statistics are weather corrected, using a 'composite weather variable' (CWV) accounting for temperature and wind speed to a 'base year' of a 17-year average of 1988-2004 for each LDZ in the UK (National Grid 2012). This weather correction is to enable year-on-year comparisons of gas consumption independent of weather effects (DECC 2010c, National Grid 2012). Neither National Grid or DECC publish these variables used to correct the gas data.

Table 5.1 Descriptive Statistics for Per Meter Gas Consumption

	Mean	Median	St.Dev	Skew	Kurtosis	Inter-quartile Range (IQR)
2008	17072	16572	3842	1.025	2.545	4507
2009	15574	15080	3580	1.110	2.899	4116
2010	15732	14875	3581	1.168	3.196	4131

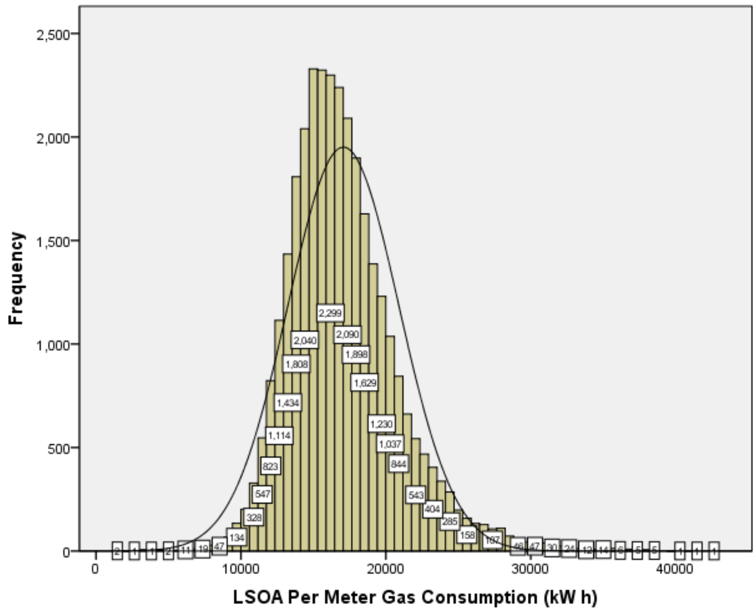


Figure 5.1 Distribution of Per Meter Gas Consumption (2008)

From Figure 5.1 and Table 5.1 it can be seen that there is a long, shallow tail above the mean. This skewed distribution was then transformed by taking the square root of the variable. Square root transformations are seen as the simplest to interpret and therefore if this is able to rectify the problem with skew, it is generally seen as the correct one to take. Taking the square root does bring the skew value below 1, to within the generally accepted level for an approximate normal distribution (Stevens 2009). The distributions of the square root gas consumption for 2009 and 2010 follow a similar pattern to 2008, suggesting the distribution holds true over these three years.

Table 5.2 Descriptive Statistics of Square Root Per Meter Gas Consumption (2008)

	Mean	**Median**	**St.Dev**	**Skew**	**Kurtosis**	**IQR**
2008	130	129	14.3	0.49	1.56	17.44
2009	124	123	13.9	0.56	1.70	16.84
2010	123	122	13.9	0.60	1.80	16.87

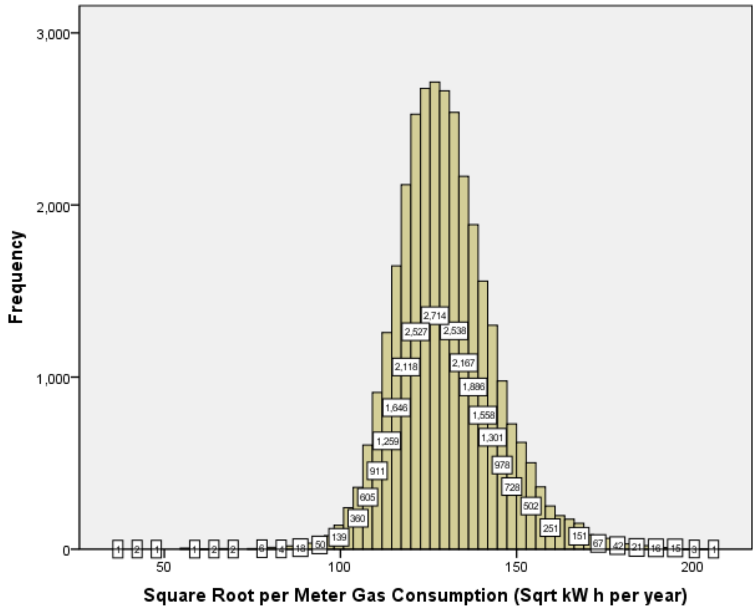


Figure 5.2 Distribution of Square Root Per Meter Gas Consumption (2008)

5.2 Electricity Consumption

Domestic electricity consumption in the UK is collected from Non Half-Hourly (NHH) meters, of which there are 29 million used by domestic and small/medium sized non-domestic consumers (DECC 2010c). NHH meters used by domestic consumers are profiles 1 and 2 which relate to standard and economy7 electricity use. DECC use an arbitrary cut-off point of 100,000kW h to discriminate between domestic and non-domestic users on these profiles (DECC 2010c). This cut-off point can reduce the accuracy of the precision of the data since DECC acknowledge that 'many high-energy users' (despite the cut off being 250 times the average annual domestic electricity consumption) may be incorrectly classified as industrial consumers, while small shops in residential areas using domestic profiles may be incorrectly classified as domestic properties. Where recorded meter readings are unavailable for a particular meter, electricity consumption is estimated using historical energy use data (DECC 2010c).

Prior to analysis, six LSOAs with implausible data were removed. These LSOAs were: Salford 004B (being recorded with negative electricity consumption), Huntingdon 002A, 002B, 002C, 002D (recorded as having 0 electricity consumption), and East Devon 007D (electricity consumption not recorded). This left 32476 LSOAs for analysis. From Figure 5.6, the distribution of per meter electricity consumption is skewed, with a very long tail above the mean. The skew (1.84) and kurtosis (9.60) are significantly non-normal and therefore there is a need for transformation of the dependent variable before proceeding with the regression modelling. Studies on both transformed and non-transformed variables were conducted since the non-transformed distribution produces results in the original units and do not require re-transformation after the regression analysis to generate benchmarks. The descriptive statistics and distribution of this transformed variable are shown in Figure 5.4 and Table 5.4.

Table 5.3 Descriptive Statistics for Per Meter Electricity Consumption

	Mean	**Median**	**St.Dev**	**Skew**	**Kurtosis**	**IQR**
2008	4226	4039	907	1.84	9.60	870
2009	4178	3993	899	2.02	14.05	862
2010	4140	3969	851	1.71	5.13	821

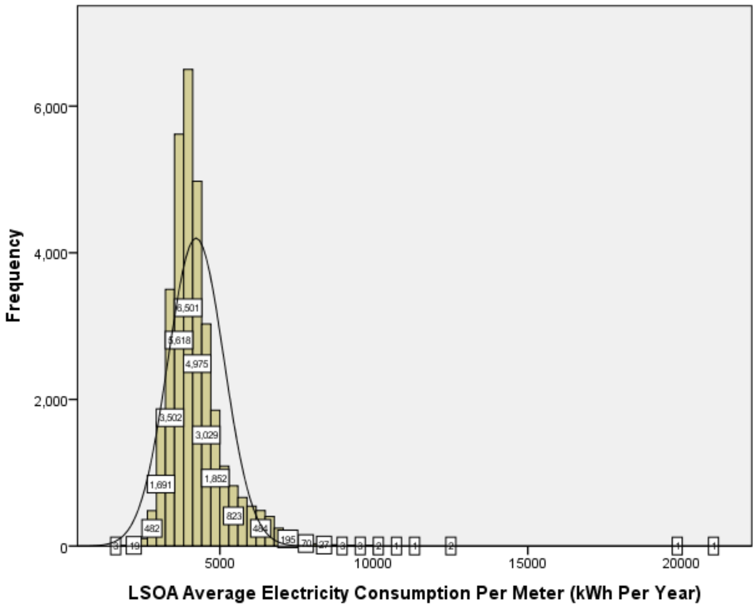


Figure 5.3 Distribution of Per Meter Electricity Consumption

Table 5.4 Descriptive Statistics for Square Root per Meter Electricity Consumption

	Mean	Median	St.Dev	Skew	Kurtosis	IQR
2008	65	64	6.5	1.13	2.02	6.8
2009	65	63	6.5	1.26	3.08	6.8
2010	64	63	6.2	1.23	2.77	6.5

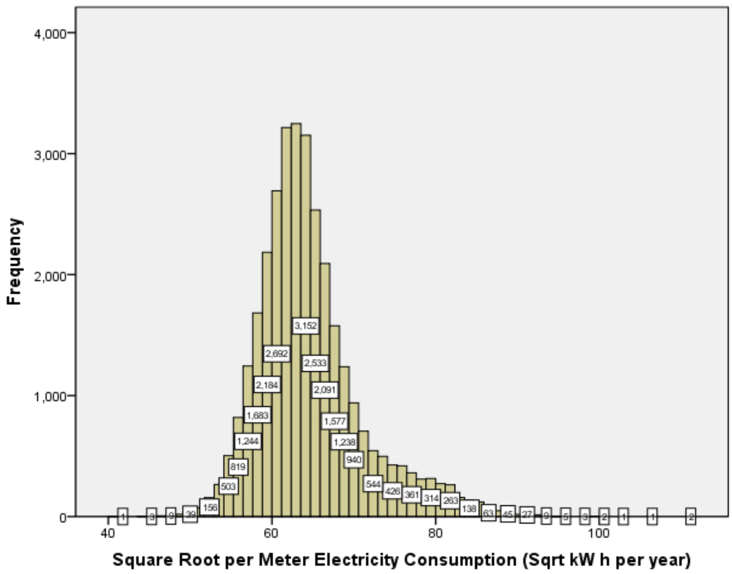


Figure 5.4 Distribution of Square Root per Meter Electricity Consumption (2008)

The square root transformation on per meter electricity consumption has given the dependent variable a distribution that is approximately normal, the skew and kurtosis are within the acceptable range for a normal approximation. As with the gas consumption figures, the distributions of the square root gas consumption for 2009 and 2010 follow a similar pattern to 2008, suggesting the distribution holds true over these three years.

5.3 Unallocated Data and Disclosure

Not all data at LSOA level can be published due to disclosure, where there must be at least six meters in a LSOA for the data on the fuel to be published to prevent potential identification of individuals (Rose 2011). For electricity consumption, this is split between economy7 and ordinary domestic, and all of the 'merged' consumption figures are as a result of areas having less than 6 economy7 meters. Where disclosure issues prevent DECC from allocating gas and electricity consumption to specific LSOAs, the consumption figures were merged with other LSOAs within the MSOA. Where the postcode of a property has not been assigned to a specific LSOA within a MSOA, this has been listed as being 'unallocated'. Statistics on this area listed in tables 5.5 and 5.6.

Table 5.5 Merged Consumption

Fuel Type	Number of Local Authorities	Number of LSOAs	Total Consumption (kW h)	% of Total England Consumption
Gas	117	548	993,265,154	0.30
Electricity	83	679	36,551,686	0.14

Table 5.6 Unallocated Consumption

Fuel Type	Number of Local Authorities	Number of LSOAs	Total Consumption (kW h)	% of Total England Consumption
Gas	353	6007	2,400,403,839	0.74
Electricity	353	355	308,405,061	0.32

For England as a whole, the proportion of ‘unaccounted’ consumption (i.e. the total of both unallocated and merged gas and electricity consumption) is less than 0.5% for electricity, and approximately 1% for gas consumption, a negligible proportion. However, these data were explored to ensure that the ‘errors’ in the data were not confined solely to specific geographical areas. From Figure 5.5, there appears to be a wide distribution of unallocated gas consumption across the country. Figure 5.6 shows how this distribution varies across LSOAs. The maximum figure for unaccounted gas consumption in any LSOA was 9.39%, although 90% of LSOAs have less than 5% unaccounted. Figure 5.7 shows unaccounted electricity consumption. The maximum was 2.32% of the total electricity consumption in a LSOA being unaccounted, with an average of 0.36%. From Figure 5.8 these appear to be concentrated in a belt across the Midlands and immediately west of London. From these findings it was assumed that the proportion of unaccounted consumption in individual LSOAs and the spread across the country of unaccounted consumption was not severe enough to distort analysis of the data.

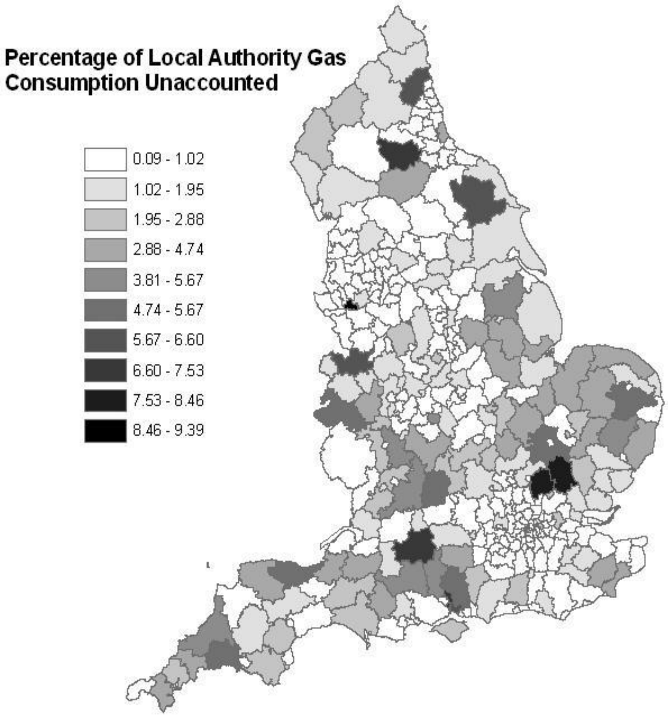
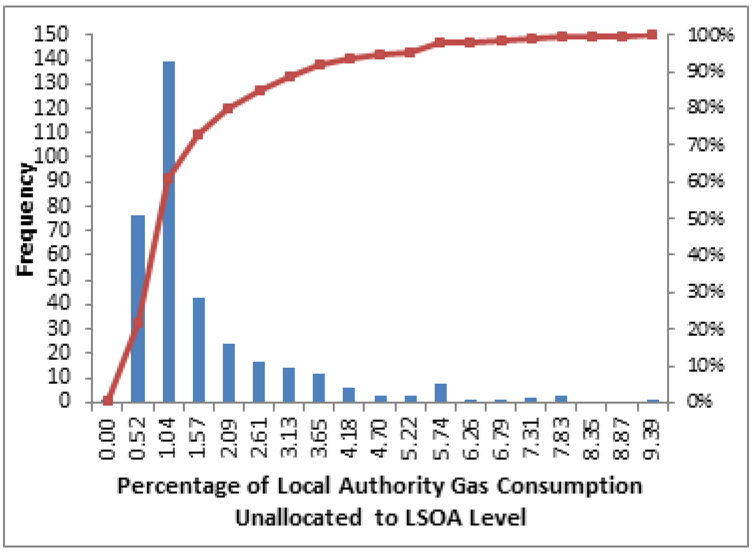


Figure 5.5 Geographical Distribution of 'Proportion of Unaccounted' Gas Consumption by Local Authority



Statistic	Value
Mean	1.41
Median	0.81
Standard Deviation	1.47
Range	9.39
Skew	5.94
Kurtosis	2.31
Minimum	0
Maximum	9.39

Figure 5.6 Histogram of 'Proportion of Unaccounted' Gas Consumption by Local Authority

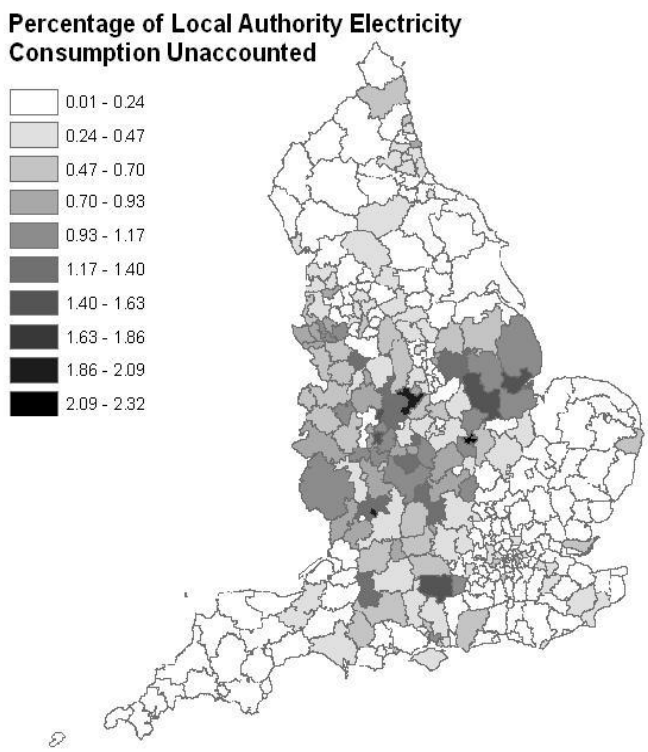
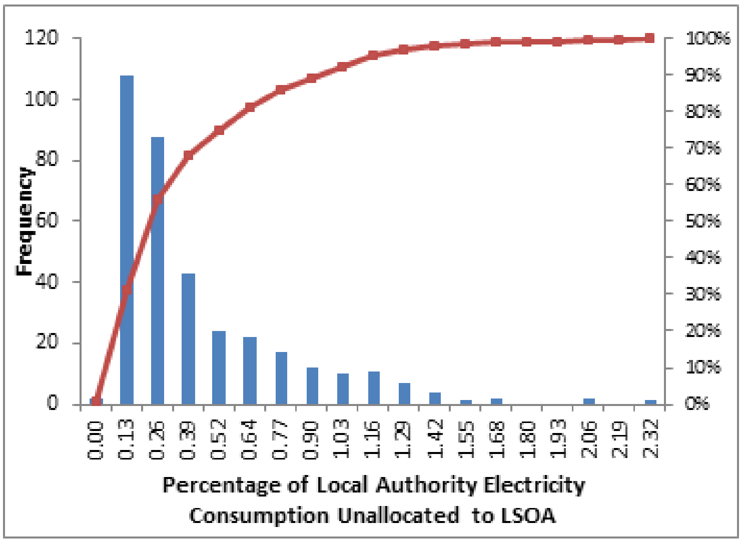


Figure 5.7 Geographical Distribution of ‘Proportion of Unaccounted’ Electricity Consumption by Local Authority



Statistic	Value
Mean	0.36
Median	0.22
Standard Deviation	0.38
Range	2.32
Skew	1.79
Kurtosis	3.74
Minimum	0

Figure 5.8 Histogram of ‘Proportion of Unaccounted’ Electricity Consumption by Local Authority

5.4 Conclusion

This study used the energy consumption statistics published by DECC that were published to aid Local Authorities in monitoring and measuring the successes in their energy reduction policies. The distribution of both gas and electricity data conforms to what is suggested from the literature. There is a slight positive skew in gas consumption and a greater skew in the electricity consumption figures. Examination of the descriptive statistics and distributions of the variables revealed that both the gas and electricity consumption figures deviated from a normal distribution but the skew and kurtosis were reduced by taking square root transformations of both variables. The clear benefits of using these data is that they are collected and published at LSOA level using a nationally consistent methodology, and are available for all 32482 LSOAs in England. Whilst the per meter figures for each LSOA are an average of approximately 700 houses which may hide extreme and unusual distributions of energy consumers within this LSOA, there is no other statistical source detailing energy consumption in the UK with such a comprehensive coverage of the UK.

6. DATA FOR UNDERSTANDING VARIATION IN DOMESTIC ENERGY CONSUMPTION

This chapter introduces the independent variables that represent the main predictors of domestic energy consumption as outlined by the literature review and from consultation with local authorities. The key variables were identified that may account for variations in domestic energy consumption. These cover demographic, social, economic, technical, and climatic factors. There are several datasets immediately available, published by the UK Government, with national datasets on domestic energy consumption published by DECC disaggregated as low as lower layer super output area (LSOA). These datasets are from Government, Commercial and Academic sources that have been used in previous Government statistical analysis, particularly with the NEED study. Data on demographic, technical, and climatic data are published by a variety of sources, including the ONS, 2001 Census, Experian, the MET Office, and academic institutions (including CSE, ICE and EDINA). These datasets and their sources were first introduced in chapter 3 and are analysed in more depth in this chapter. The 2001 Census has been used where more up-to-date variables that can be easily approximated to LSOA level do not exist. These cover variables specific to the housing stock, and tenure (average number of rooms, proportion of house types, proportion of tenure types, and proportion of houses without central heating). Despite being 10 years out of date, it is the most comprehensive and reliable data source for covering these topics, and is based on the relatively slow turnover of the UK housing stock, as identified in the literature review. With the 2011 census data due to be released from 2012, and detailed results released in 2014 (ONS 2011b) the methodology presented in the following chapters can be updated to incorporate this more up-to-date data sources and the results compared.

This chapter follows a similar structure to the previous chapter. The secondary data sources were identified and the underlying data collection methodologies were explored to understand the strengths and weaknesses of each data source and their appropriateness for this study) and the descriptive statistics were calculated and their distributions analysed. These data sources are used in the future correlation and regression analysis while the following sections of this chapter explore these data in more detail. Table 6.1 documents how the categories introduced from the literature review correspond to the data sources used to represent the independent variables that drive domestic energy consumption (for the sources of the original data see Table 3.3). The Table documents the year for which the data have been published for, and whether these data sources can be used straight from the publication, or if these have been derived by calculating new variables by combining two or more datasets. The descriptive statistics are displayed in Table 6.2 whilst distributions for each variable are displayed in the relevant sections.

Table 6.1 Categorising Independent Variable Data Sources

Variable Category	Variables Included	Years Available	Published/Derived
Demograpic	Population	2008-2010	Published
	People Per House	2008-2010	Derived
	Population Density	2008-2010	Derived
	Housing Density	2008-2010	Derived
Social	Tenure	2001	Published
	Fuel Poverty	2007	Published
Economic	Gas Prices	2008-2010	Published
	Electricity Prices	2008-2010	Published
	Median Household Income	2008-2010	Published
Technical	House Type	2001	Published
	Houses without Central Heating	2001	Published
	Average Number of Rooms	2001	Published
	Ratio of Gas to Electricity Meters	2008-2010	Derived
Climatic and Geographical	External Air Temperature	Average 1986-2004	Published
	Area of LSOA	Constant	Published
	Northing of LSOA Mid-Point	Constant	Published

Table 6.2 Descriptive Statistics of Independent Variables

Variable	Mean	St.Dev	Skew	Kurtosis	IQR
Population	1584	309	4.73	69.88	250
People Per House	2.34	0.57	28.57	1720.63	0
Population Density (People per km^2)	4057	4037	2.60	15.39	4382
Housing Density (People per km^2)	1775	1806	3.41	38.93	1901
Proportion of Owner-Occupied Households (%)	69.35	20.83	-0.74	-0.24	30.68
Proportion of Socially Renting Households (%)	18.93	18.93	1.22	0.70	24.88
Proportion of Privately Renting Households (%)	9.70	8.88	2.25	6.94	8.46
Proportion of Households in Fuel Poverty (%)	6.14	0.89	1.48	15.28	1
Median Household Income (£ per year)	28764	9717	0.93	1.13	12816
Proportion of Detached Houses (%)	23.05	22.58	0.99	-0.09	34.0
Proportion of Semi-Detached Houses (%)	32.37	20.13	0.61	-0.17	28.0
Proportion of Terraced Houses (%)	25.78	20.48	0.95	0.19	29.0
Proportion of Flats (%)	18.05	21.15	1.76	2.60	21.0
Proportion of Houses w/o Central Heating (%)	8.42	8.19	2.47	8.45	7.41
Average Number of Rooms	5.25	0.66	-0.04	0.03	0.86
Ratio of Gas to Electricity Meters	0.87	0.24	11.48	325.9	0.15
Heating Degree Days (1988-2004)	1871	195	0.39	1.16	237
Area of LSOA (km^2)	4.08	13.5	11.72	325.9	1.0
LSOA Northing	276846	14	0.42	-0.73	214391

6.1 Demographic Variables

The demographic variables deal with population and household counts, as well as the number of people per household, which is the derived variable, calculated by dividing the population of a LSOA by the number of electricity meters.

6.1.1 Population

Population mid-year estimates from the ONS are published annually. These are available at LSOA level and attempt to provide an 'accurate representation' of small area population between census years (ONS 2011a). The mid-year estimates take into account the registered births and deaths in an area, as well as attempting measure migration patterns through the patient register (when people register with a NHS doctor) and child benefit statistics (ONS 2011a). The ONS recognise that some elements of the population are more difficult to measure, such as migrants (both domestic and international) and students and that the errors in estimation vary geographically (ONS 2011a). Due to the lack of alternative data sources, the ONS claim that it is not possible to quantify the accuracy of the estimates (ONS 2011a). However the ONS population statistics do cover the whole of England, and use a consistent methodology, and is the best and easiest to use data source that is available for population statistics. The distribution of these statistics (Table 6.2 and Figure 6.1) shows a heavily skewed distribution above the mean, with LSOAs having population sizes up to 11000 people, which is nearly 10 times the size of the mean (1584). The inter-quartile range of 250 (1412-1662) is a fairer reflection of the distribution, as can be seen by the peak in the histogram around the mean and median.

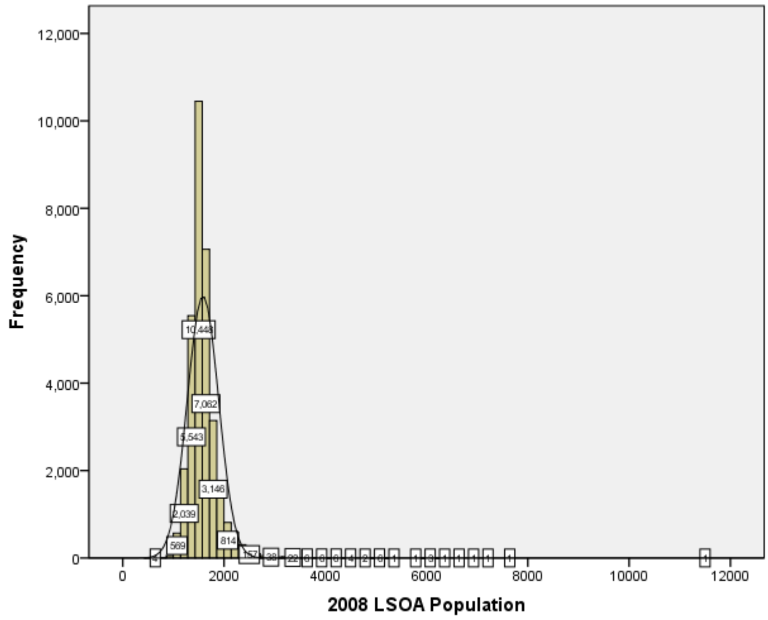


Figure 6.1 Histogram of LSOA Population

6.1.2 People per House

This variable was calculated by dividing the number of people in a LSOA (from the population mid-year estimates) by the number of electricity meters, giving a figure of average household occupancy size of a LSOA. The number of electricity meters recorded by DECC was chosen over using an alternative count of households because the thesis examines the number of energy consumers. The distribution (Table 6.2 and Figure 6.2) of this dataset shows a bell-shaped distribution but with a very long tail above the means and some extreme outliers, where four LSOAs reporting to have on average over 20 people per house, possibly a reflection in the inaccuracy of the DECC reporting of electricity meters for these areas. The mean of 2.34 people per house support the figures quoted in the literature review concerning household sizes and 99% of LSOAs have less than 5 people per house on average. The extreme LSOAs are examined in further detail in Chapter 8, comparing the number of electricity meters in an LSOA with the number of households indicated by council tax records.

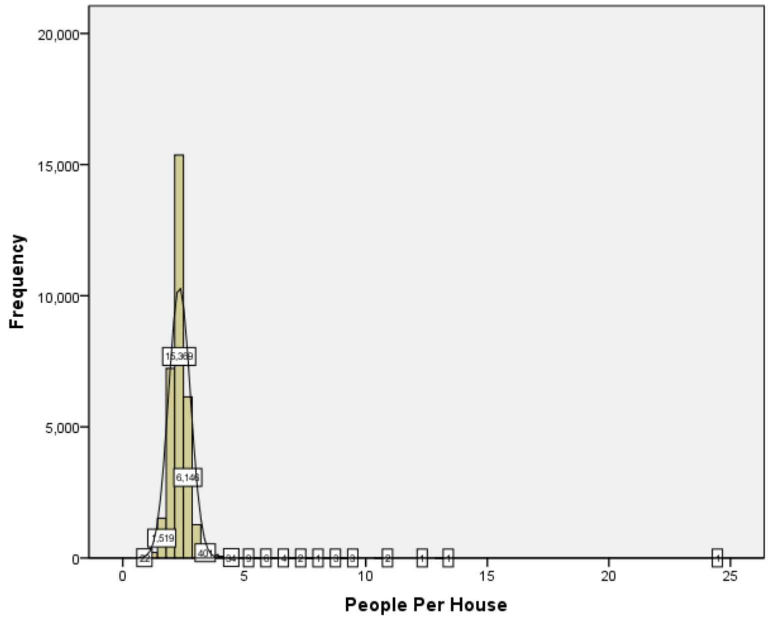


Figure 6.2 Histogram of People per House

6.1.3 Population and Housing Density

Whether an area is predominately urban or rural is indicated in the literature review to be an important factor in domestic energy consumption, and studies from the literature, including Weismann *et al* (2011) have used the population and housing densities as indicators of whether an area is rural or urban. Population density in each LSOA has been calculated by dividing the number of people from the 2008 population mid-year estimate by the area of the LSOA. Housing density has been calculated by dividing the number of electricity meters by the area of the LSOA. Both follow similar shaped distributions (see Table 6.2 and figures 6.3 and 6.4), with a large number of LSOAs being relatively sparsely populated, but with a tail of a small number of very densely populated LSOAs dominated by Central London Boroughs.

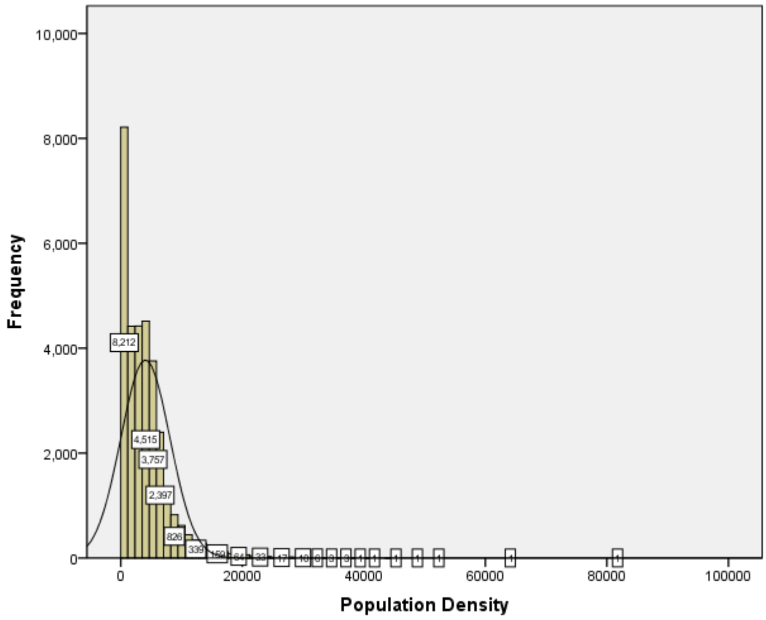


Figure 6.3 Histogram of Population Density

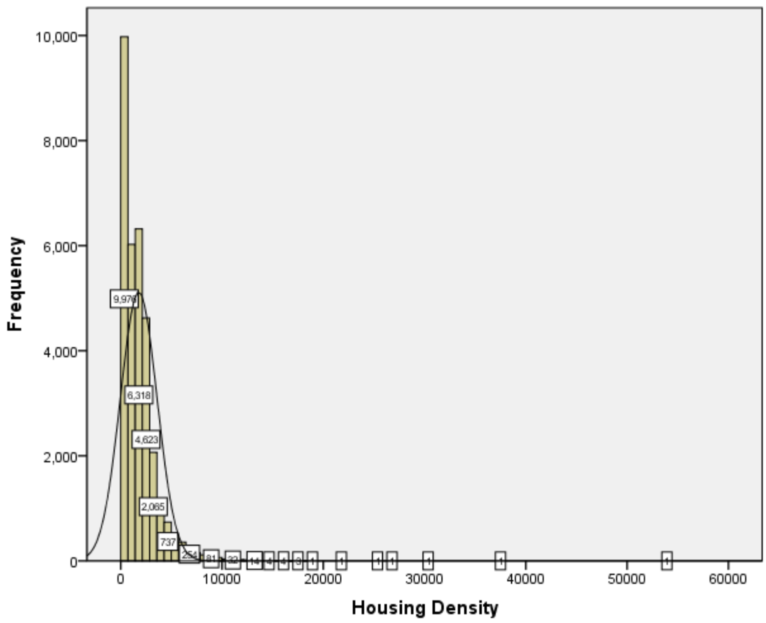


Figure 6.4 Histogram of Housing Density

6.2 Social Variables

The social variables in this study concern the tenure types for householders, and the proportion of fuel poverty in LSOAs.

6.2.1 Tenure

In the absence of more up-to-date tenure statistics which provide a comprehensive coverage of LSOAs in England, the 2001 Census was used as an approximation of current trends in LSOA tenure proportions. Tenure in the 2001 Census is split into the categories of: owned-outright, owned with a mortgage, shared ownership, council rented, rented from a housing association or registered social landlord, and private rented. For this study these were re-classified into three main categories: owner-occupier (owned outright and owned with a mortgage), socially renting households (council rented and housing association/registered social rented) and privately rented. These categories reflect the tenure composition of the UK without the added complexity of subsections and are frequently referred to in the literature and by the DCLG in their breakdowns of households by tenure type (DCLG 2010b). As shown in the distributions (see Table 6.2 and Figures 6.5, 6.6 and 6.7), there is an increase in the number of LSOAs as the proportion of owner-occupier households increases, whilst the mirror image occurs with social and private rented housing, with a steep decline in the numbers of LSOAs as the proportions increase. This reflects the dominance of owner-occupier households in the UK. This is supported by the DCLG's (2010b) England statistics of 68% owner-occupier, 18% socially renting and 14% privately renting (in comparison with the 2001 Census figures in Table 6.2).

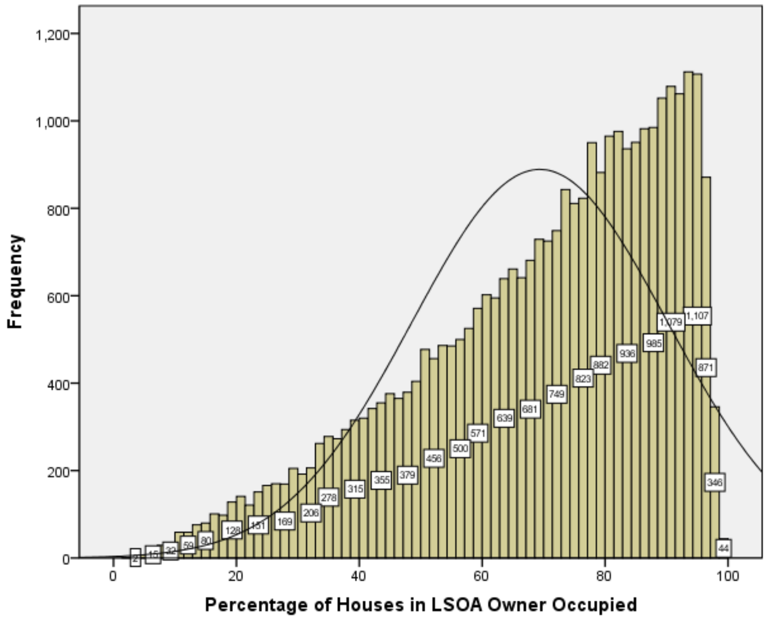


Figure 6.5 Percentage of Owner Occupier Houses

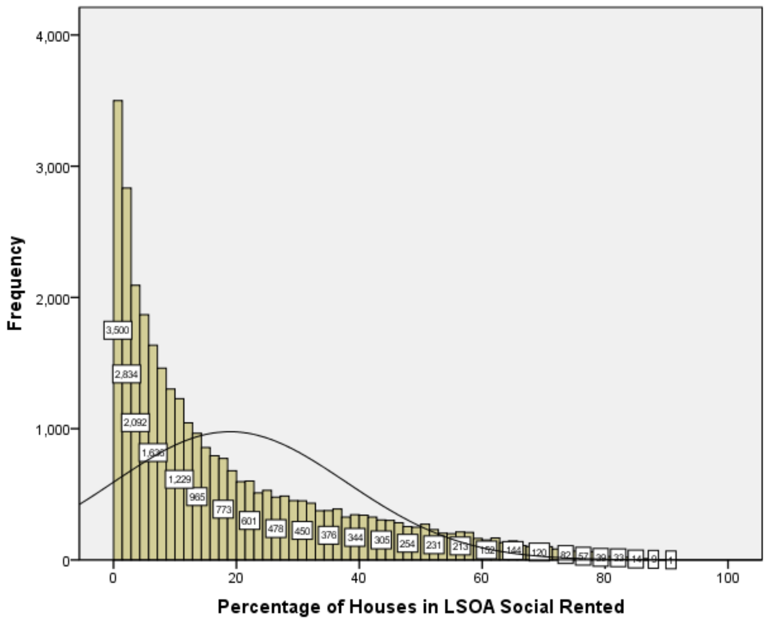


Figure 6.6 Percentage of Social Rented Houses

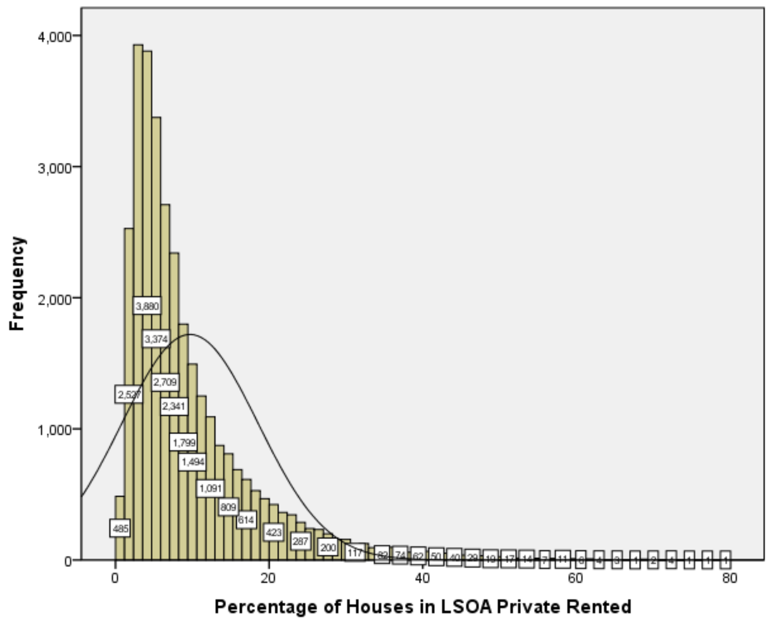


Figure 6.7 Percentage of Private Rented Houses

6.2.2 Fuel Poverty

As discussed in the literature review and from consultation with Local Authorities, fuel poverty is an important variable to consider for Local Authorities when targeting areas for domestic energy efficiency since policies to tackle fuel poverty and domestic carbon emission reduction programmes often have similar strategies through insulation to improve energy efficiency of the housing stock. The fuel poverty indicator developed by the Centre for Sustainable Energy (CSE) at Bristol University has been used in this study because it is disaggregated to LSOA level, and is promoted by the Energy Savings Trust (2011) as a useful resource to help design area-based programmes to monitor and evaluate schemes aimed at reducing fuel poverty. Morrison and Shortt (2008) use the CSE's fuel poverty indicator as the basis for their development of a 'Scottish specific' fuel poverty indicator for Stirling City Council, having evaluated other data sources and concluding CSE's advantages are based on being built on output areas which can be summed up to Local Authority level. CSE fuel poverty indicator is derives from predictions of fuel poverty incidence, based on variables from the census and English House Condition Survey. Morrison and Shortt (2008) do express some reservations about the CSE fuel poverty indicator for identifying small pockets of fuel poverty within a larger, more affluent area, and the use of aggregated, top-down methodologies causes problems when making inferences about individuals. The CSE indicator is also seen to be limited at predicting fuel poverty in rural areas, hence the need for the development of a separate Scottish indicator. However as this study is only examining England, the CSE indicator is deemed to be the best option available. The Fuel Poverty Indicator has multiple definitions of fuel poverty; however the ‘full income’ measure has been used, which is the UK Government’s current definition of fuel poverty. Full Income' includes Housing Benefit, Income Support for Mortgage Interest Relief (ISMIR) and Council Tax Benefit. Council Tax payments are deducted from 'income' (Fahmy and Gordon 2007).

The distribution of fuel poverty across LSOAs is positively skewed, with a mean of 6% in fuel poverty per LSOA (see Table 6.2 and Figure 6.8). However there are LSOAs with much higher levels of predicted fuel poverty, with a maximum value of 25%. These results suggest even in the areas with the highest levels of fuel poverty, it is still a minority of households in the LSOA.

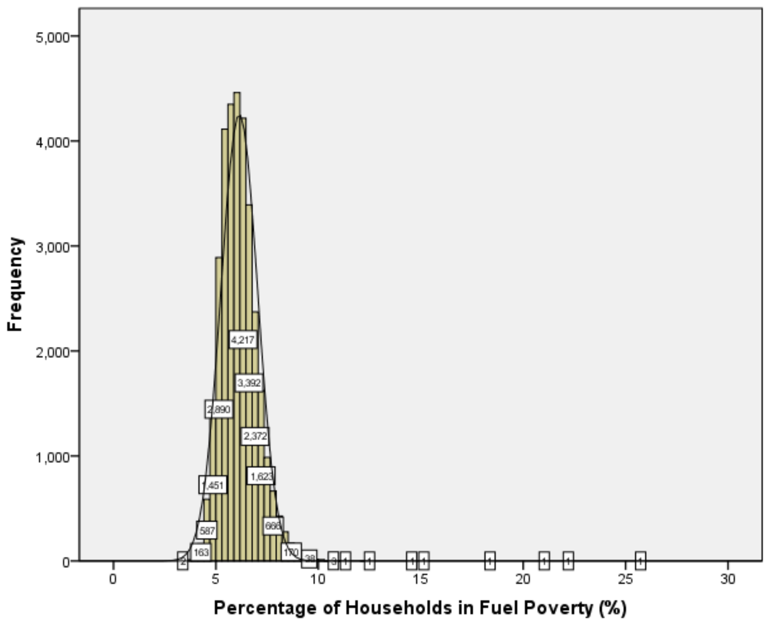


Figure 6.8 Histogram of Percentage of Households in Fuel Poverty

6.3 Economic Variables

Economic variables relate to the affordability of energy by examining the relative unit costs of gas and electricity for domestic consumers, and the median average household incomes in LSOAs.

6.3.1 Energy Prices

As stated in chapter 2, energy prices directly impact the affordability of energy and therefore levels of consumption. In view of this, DECC has published energy cost data for 11 different regions in England, based on gas distribution zones and the public electricity suppliers (PES) these are shown in Table 6.3 with the relevant DECC named city (DECC 2010d). The regions are mapped in Figure 6.9.

Table 6.3 Regions of DECC Energy Prices

Region	DECC Named City
North West	Manchester
North East	Newcastle
Merseyside	Liverpool
Yorkshire and the Humber	Leeds
West Midlands	Birmingham
East Midlands	Nottingham
South West	Plymouth
Southern	Southampton
London	London
South East	Canterbury
Anglia	Ipswich

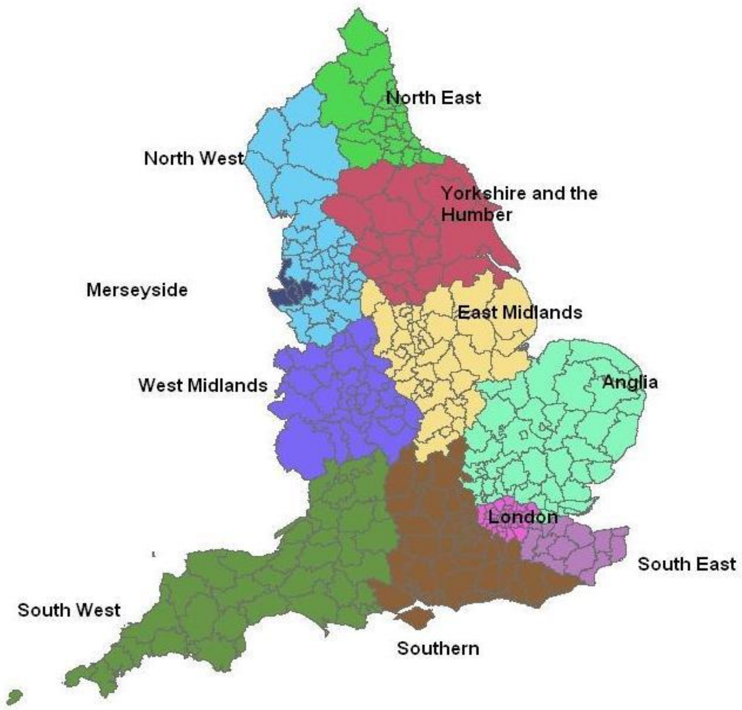


Figure 6.9 DECC Energy Price Regions

Energy price data is described by minimum, maximum and average cost per unit (pence per kW h) for both electricity and gas by the three payment methods (Pre-Payment, Credit and Direct Debit). The national proportion for customers on each tariff is shown in Table 6.4:

Table 6.4 National Proportion of Customers on Energy Payment Tariffs

	Standard Credit	Direct Debit	Pre-Payment
Gas	36%	52%	12%
Electricity	35%	50%	15%

In the absence of data on the regional variation of the proportions of customers on payment tariffs, the national figures have been used. Using these proportions allows for the calculation of an 'average' unit cost of energy for all regions in England. However this does not allow for intra-regional variation in both unit costs of energy and proportions of residents on each payment tariff. DECC's figures will be used despite of the limitations because there is no alternative source and the DECC figures form part of the UK Government's household expenditure survey and inflation calculations.

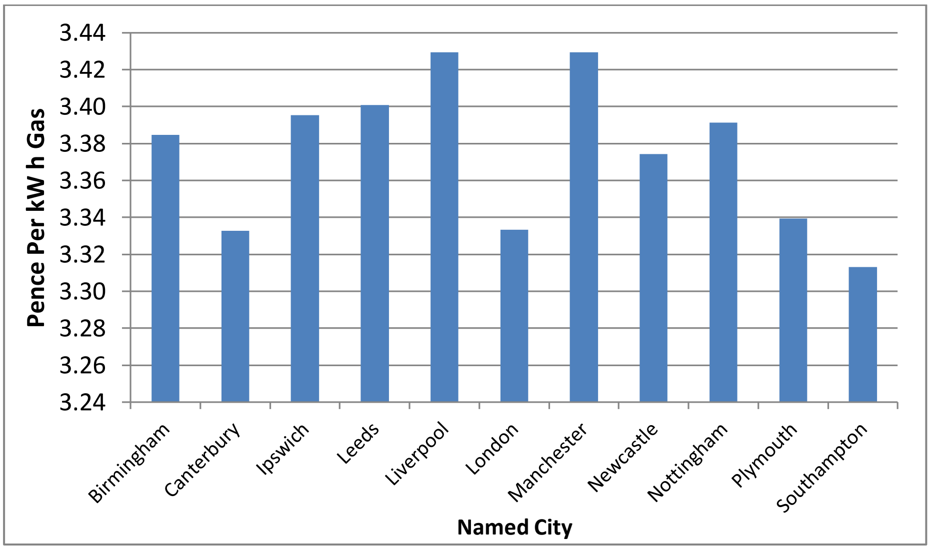


Figure 6.10 Pence per kW h Gas for DECC Energy Regions

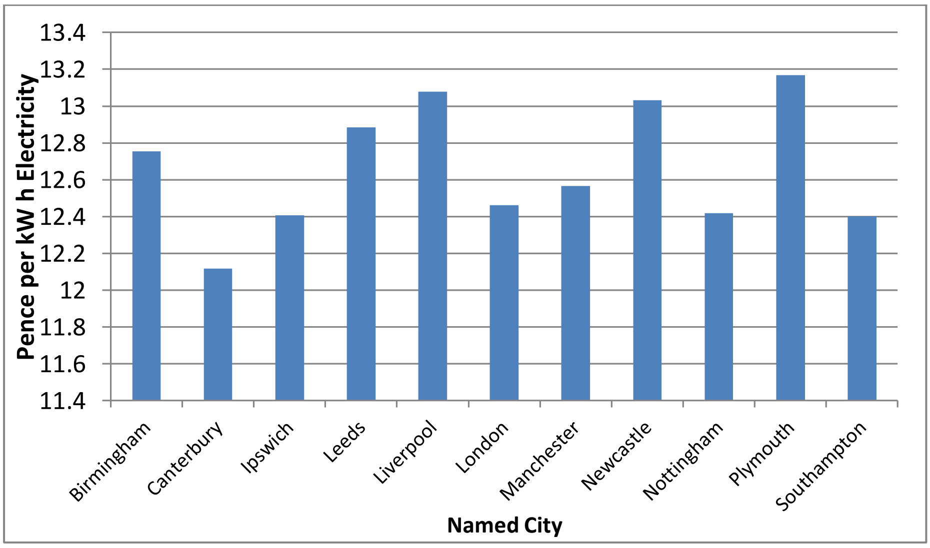


Figure 6.11 Pence per kW h Electricity for DECC Energy Regions

The figures 6.10 and 6.11 show that the unit cost of electricity and gas is cheapest in London and is most expensive in the Liverpool/Merseyside Area. Other patterns emerge from analysis of the 'average' prices of these fuels, where both the Anglia and East Midlands regions having relatively low electricity prices and but relatively high gas prices. In contrast the South West region has relatively low gas prices but relatively high electricity prices.

6.3.2 Median Household Income

Accurate information on household income is difficult to obtain. The Census does not ask householders to disclose their income as it is seen as 'too sensitive' (White 2010). In the absence of official sources, alternatives were sought that would cover the entire country. Experian, a commercial credit rating agency publish median household income estimates at LSOA level for England. This income data is also used by DECC in its NEED analysis, acknowledged as 'a best guess' of household income. The data is calculated based on credit application surveys and modelled using logistic regression (a statistical method to estimate the probability of occurrence) to estimate individual incomes from employment types and this is aggregated to LSOA level using linear regression based on census variables (Experian 2008). The distribution of median household income is positively skewed, with a relatively low number of very high earning areas (which are four times the size of the mean) (see Table 6.2 and Figure 6.12). Median Income was expressed in terms of £1000s rather than in Experian's published £s. This was so that it would reduce the number of decimal places for its co-efficient size in the model.

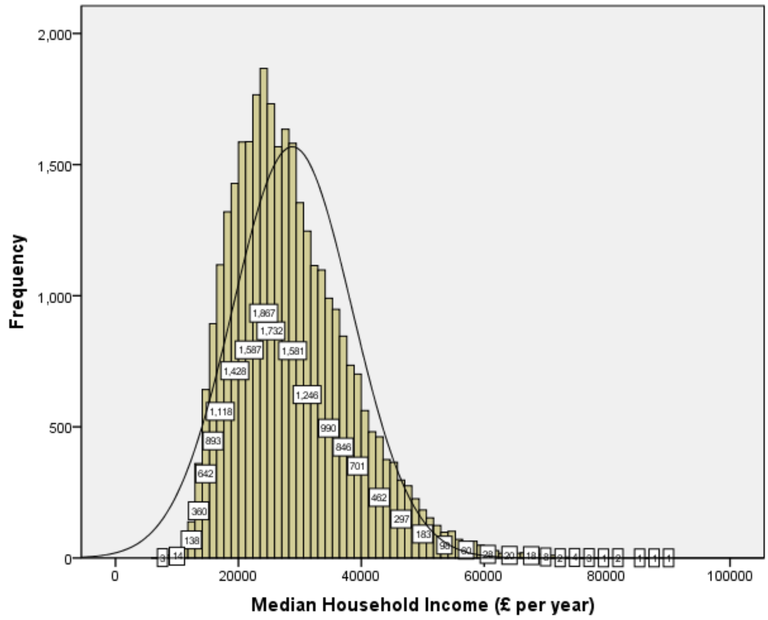


Figure 6.12 Histogram of Median Household Income

6.4 Technical Variables

Technical variables are concerned with the physical characteristics of the housing stock and amenities.

6.4.1 House Type

Similar to the tenure statistics described in 5.4, the 2001 census has been used to identify the proportion of houses, classified into four major house types In each LSOA: detached, semi-detached, terraced, and flat. There are also a small percentage of house types listed as ‘temporary accommodation’ which have also been included. The 2001 Census has been used in the absence of up-to-date data that covers the whole of England. The pattern for house type distributions show a declining frequency of LSOAs as the proportion of each house type increases, which is more pronounced for flats and detached housing (see Table 6.2 and Figures 6.13, 6.14, 6.15 and 6.16). An exception to this pattern is semi-detached housing, which climbs to a peak of 35% before declining at a much slower rate than for the other house types, reflecting that semi-detached houses are the most common house type in England. These figures suggest that LSOAs are not particularly homogenous by house type, which was the criterion that ONS use when constructing LSOAs.

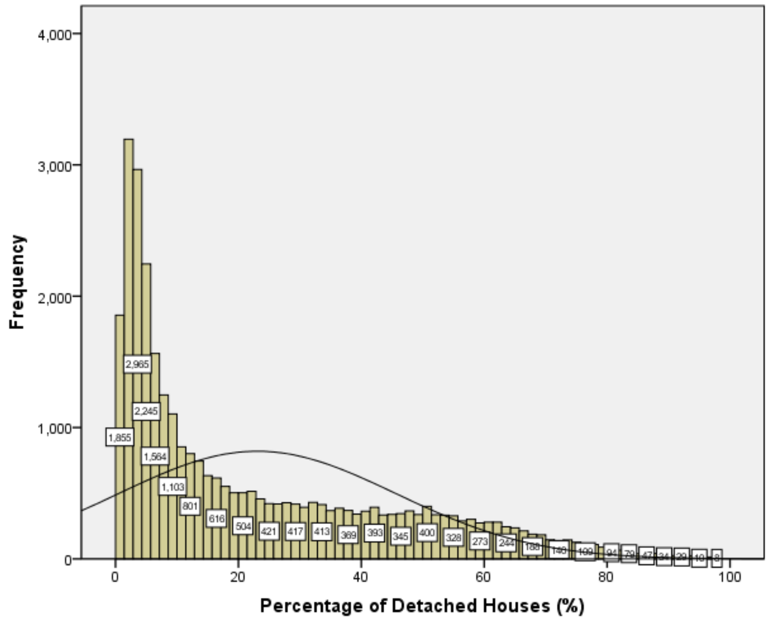


Figure 6.13 Histogram of Percentage of Detached Houses

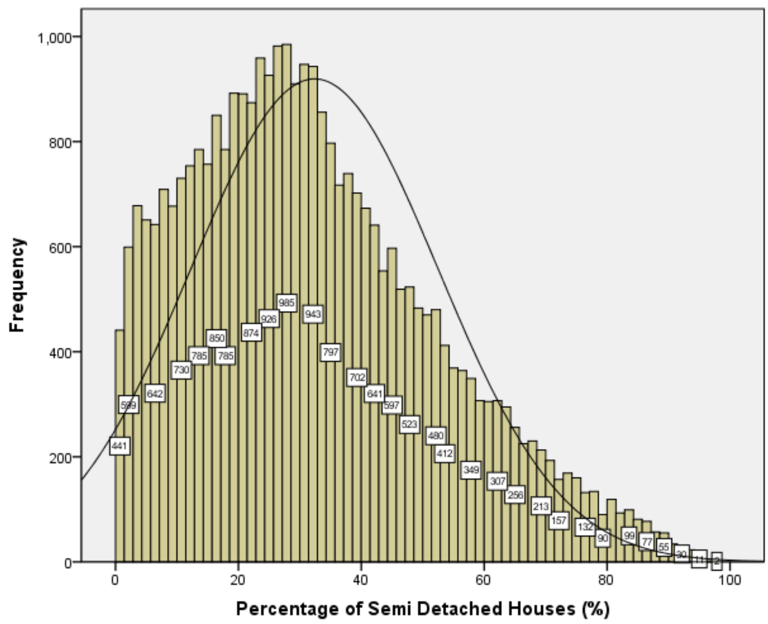


Figure 6.14 Histogram of Percentage of Semi Detached Houses

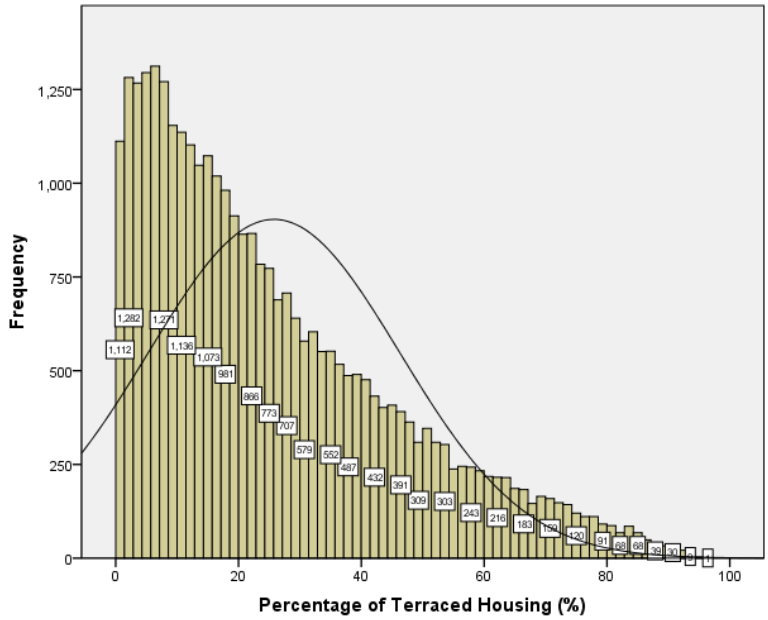


Figure 6.15 Histogram of Percentage of Terraced Housing

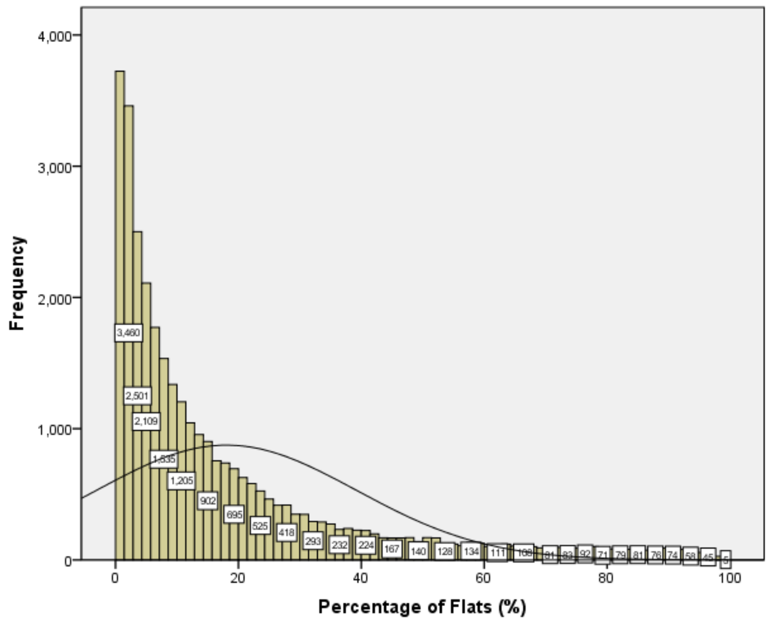


Figure 6.16 Histogram of Percentage of Flats

6.4.2 Houses without Central Heating

The 2001 Census collects information on households who lack central heating. However because this data is from 2001, households listed as lacking central heating in 2001 may have had upgrades over the past 10 years and are now no longer lacking fully functioning heating systems. The distribution of houses without central heating shows that the frequency of LSOAs declines rapidly from a peak of 8% but there is a long tail, with the highest percentage of an LSOA housing stock lacking central heating comprising 82% of the housing stock (see Table 6.2 and 6.17). These high non-centrally heated areas are generally characterised by being inner-city areas of predominately socially renting tenures and terraced houses.

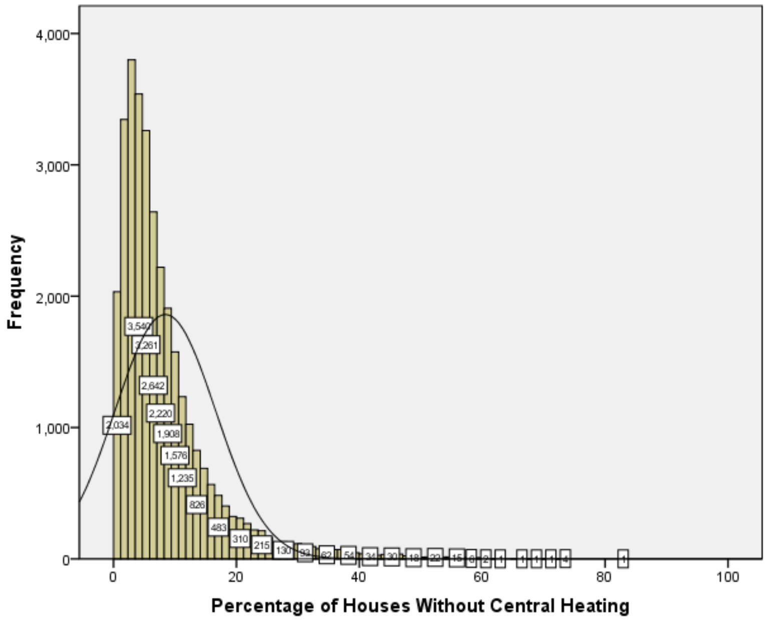


Figure 6.17 Histogram of Percentage of Houses without Central Heating

6.4.3 Average Number of Rooms

The literature review indicates that the physical size of the house is likely to impact the energy demands of its residents. Data at LSOA level on the physical household size is difficult to obtain so alternative measures have been sought. The study by Weismann *et al* (2011) uses the average number of rooms to model domestic electricity consumption in Portugal, and this is the approach DECC (2011c) have taken in their NEED analysis. The 2001 Census collected data on the number of rooms per house. A room is defined as being: kitchen, living rooms, bedrooms, utility rooms, and studies. The household spaces excluded from being classed as rooms are: bathrooms, toilets, halls, landings, and rooms that can only be used for storage. Rooms that are communal between multiple households are excluded, e.g. communal kitchens in apartment blocks (ONS 2012c). The data is published as number of properties in an LSOA with each number of rooms up to 8, which is recorded as '8 and above'. The average is then calculated by multiplying the number of rooms by the number of properties and dividing by the total number of households in a LSOA (from the sum of houses from this data). In this instance, '8 and above' is recorded as '8'. This does under-report the number of very large houses in LSOAs which have 9 rooms or more. Houses with 8 or more rooms account for 10.6% of the total housing stock in England. The distribution (see Table 6.2 and Figure 6.18) is approximately normal, with a very slight negative skew. The mean is 5.25 rooms per house (e.g. 3 bedrooms, a lounge, and a dining room).

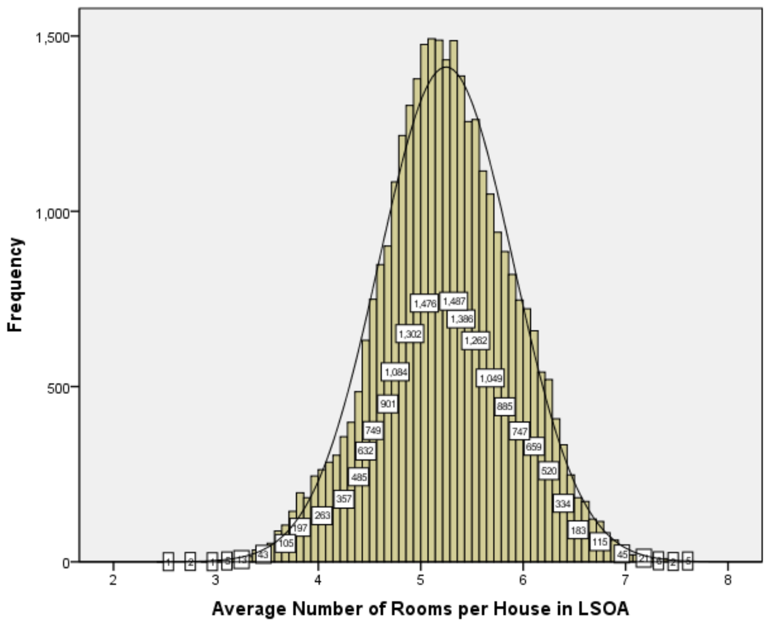


Figure 6.18 Histogram of Average Number of Rooms per House

6.4.4 Ratio of Gas Meters to Electricity Meters

A final technical factor to consider is the primary heating fuel. As already affirmed in previous chapters, those LSOAs with no connection to the national gas grid have been intentionally excluded. However this still leaves LSOAs with discrepancies between electricity and gas meters. By calculating the ratio of gas meters to electricity meters in each LSOA from the DECC energy consumption data, the number of houses heated by electric heating and alternative fuels can be approximated. The distribution (see Table 6.2 and Figure 6.18) of this ratio has a mean of 0.87 (87% of houses have a connection to the gas grid, assuming every electricity meter represents one house). This has a fairly narrow interquartile range, with 75% of LSOAs having between 80% and 110% of gas meters compared to electricity meters. There are some LSOAs with more gas meters than electricity meters and the implications for this are evaluated in chapter 8.

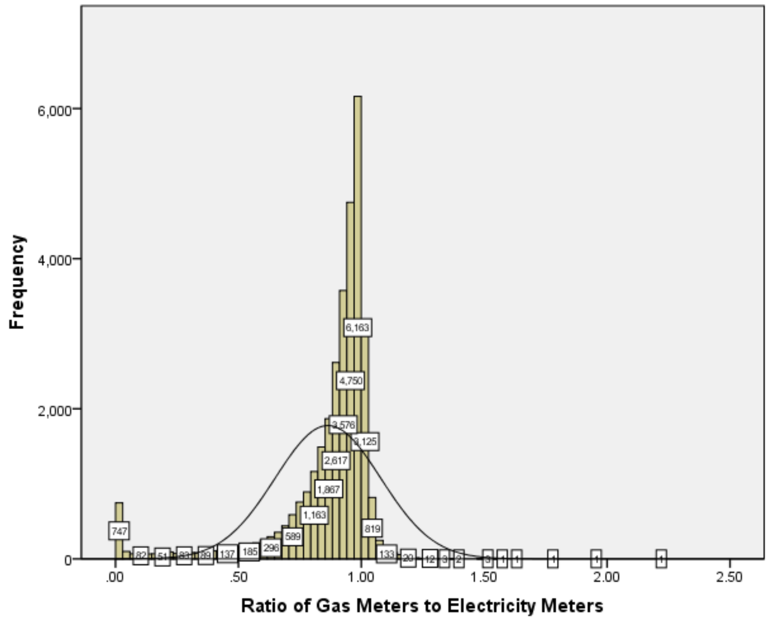


Figure 6.18 Histogram of Ratio of Gas Meters to Electricity Meters

6.5 Climatic Variables

The climatic variables give an indication of external air temperatures through heating degree days.

6.5.1 External Air Temperature

To match the 'base year' of gas consumption data weather correction with variations in external air temperature across England, Heating Degree data was obtained from the

MET Office with a base temperature of 15.5°C. After creating the 17-year average for 1987-2004 and assigning these values to LSOAs by ArcGIS spatial tools (see section 3.3.2), each LSOA was assigned a heating degree day figure. The heating degree day grids were derived using air temperature data (Perry and Hollis 2006). Temperature data were recorded at temperature stations covering an average of 21x21km^2 across the UK between 1961 and 2006, although the exact number of temperature stations varies over this 45 year period. After converting to heating degree days (see section 2.1.5), these values were then extracted to cover 5x5km^2 gridded areas by applying a regression model using the inputs of: altitude, terrain elevation, percentage of urban land use, and percentage of open water, within a 5km radius of the temperature station (Perry and Hollis 2006). From a regression analysis, these four variables account for 92% of the variation in heating degree day values across the UK (Perry and Hollis 2006). Perry and Hollis (2006:18), in their report in the derivation of gridded datasets for the MET Office state: 'The values of climate variables at locations between observing stations have been estimated to a good degree of accuracy, producing detailed and representative maps of the UK climate' but go on to add: 'Errors will be highest in areas of sparse station coverage, particularly the Scottish Highlands which are also areas of complex mountainous terrain'. Specific to England, sparse station coverage is found in the Peak District and Lake District National Parks. Despite some geographical weakness in the dataset, the MET Office UKCP09 Heating Degree Day data source provides a comprehensive coverage of spatial heating degree day variation across England, and can be matched to the base year to which DECC gas consumption weather correction is applied.

The study from Meier and Redhanz (2010) suggests that there is a clear north to south decline in heating degree days consistent between 1991 and 2005, with London consistently having the fewest heating degree days over this 14 year period. The 17-year average was seen as a fair reflection of the climatic differences, and since this is used as the basis by the gas distribution network for weather correction was seen as sufficient evidence this was the correct approach for accounting for temperature variations in

England. The distribution of heating degree days across England shows two peaks in the data, with the major peak at around 1900 heating degree days per year (above the mean of 1871) (see Table 6.2 and Figure 6.19). There is a minor peak at around 1600 heating degree days per year. Without this minor peak, the histogram distribution would approximately follow a normal distribution.

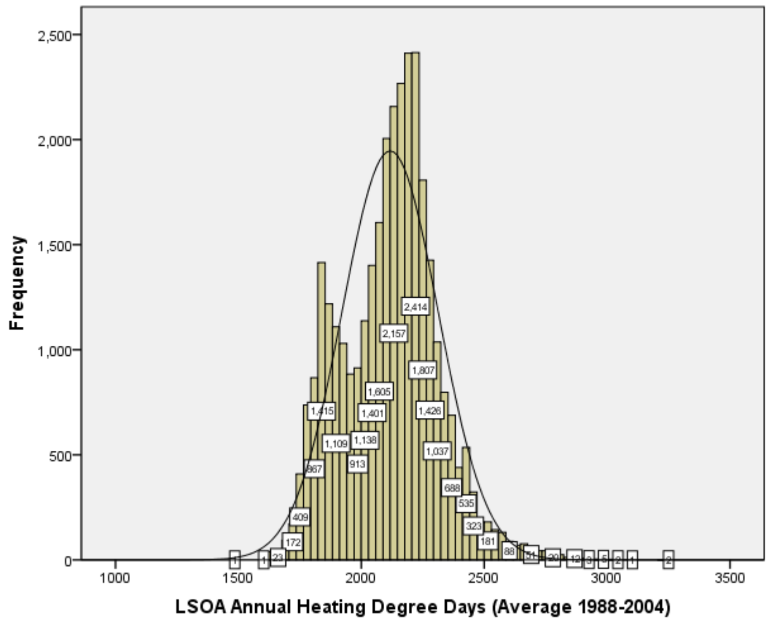


Figure 6.19 Histogram of 17-Year Average Annual Heating Degree Days

6.6 Spatial

The spatial variables describe the physical size of LSOAs and the relative position (in terms of north/south) of the LSOA in England.

6.6.1 Area of Lower Super Output Area

The physical area of LSOAs in England were obtained using ArcGIS spatial tools extracting data from maps published by the UKBORDERS facility based at Edinburgh University (Edina 2011). The distribution (see Table 6.2 and Figure 6.20) of LSOA Area is very heavily skewed, with a very long tail above the mean of 4.09km^2. The largest LSOA has an area 167 times greater than the mean, which in turn is 28 times the median. This distribution reflects the divide between City Authorities (which contain a large number of very small LSOAs) and Rural Authorities (which contain a small number of very large LSOAs). These patterns exist because LSOAs are constructed based on averages of 1500 people per LSOA.

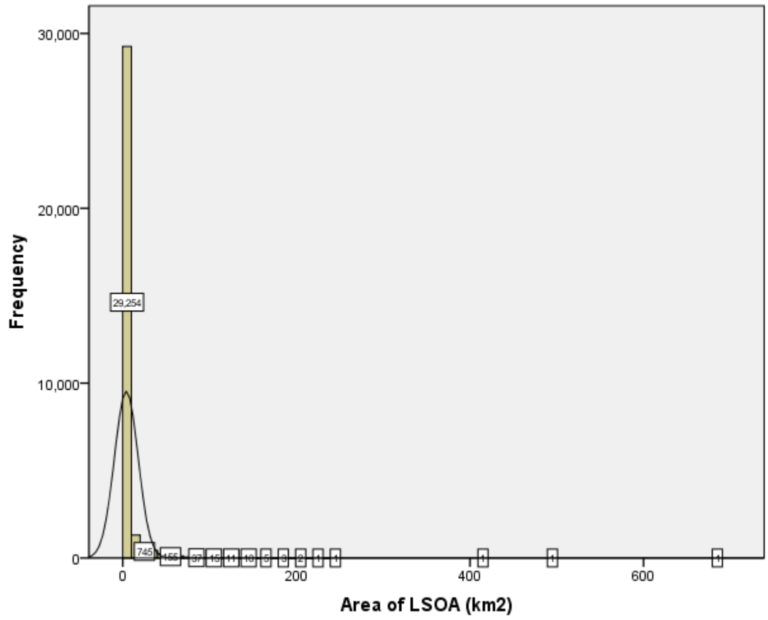


Figure 6.20 Histogram of LSOA Area

6.6.2 Northing of Lower Super Output Area

The northing figure was calculated in a similar way to the area of the LSOA, by extracting the LSOA centre-point from the Edina maps using ArcGIS spatial tools. Meier and Reidhanz (2010) suggest areas further north in the country are likely to have lower external air temperatures, and so northing would indicate whether the LSOA is general warmer or cooler. The Northing distribution (see Table 6.2 and Figure 6.21) is multi-modal, with many peaks indicating the northings of the major cities in England (which have multiple LSOAs with the same northing).

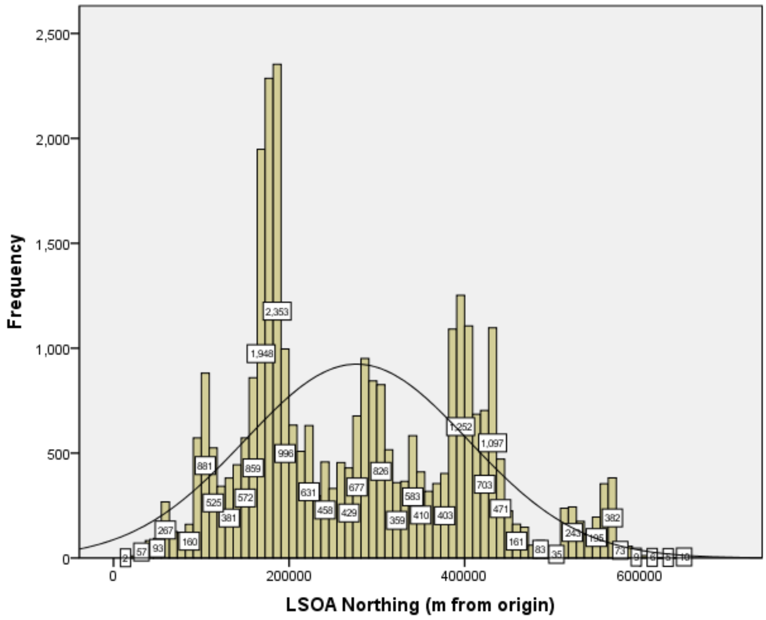


Figure 6.21 Histogram of LSOA Northing

6.7 Conclusion

This chapter has presented the independent variables that are appropriate for modelling the per meter consumption of domestic gas and electricity in English LSOAs. These datasets are obtained from sources published, or utilised by the UK Government. These datasets are the best available for representing the key drivers of household energy consumption as described in the literature review, and are widely available and meet main criteria for inclusion. These criteria were: a consistent methodology for the whole of England, published at LSOA level (or easily converted to LSOA level), and available for the year 2008. All the data sources described in this chapter met the first criteria. The second criteria was met by all the data sources with the exception of the energy price statistics, whilst the third criteria was not met for tenure statistics, technical variables or for heating degree days. The assumption for these data sources is that data from previous years serve as approximations for 2008 and in the case of heating degree days are an approximate of the base year (17 year average of 1988-2004) that the weather correction to the gas consumption data is applied to. Crucially, all of these data sources require little manipulation to be used for analysis. This meets the requirements from Local Authorities, where the consensus from the interview study was that data sources should be widely available and require no added data collection, and very little manipulation prior to being used for analytical purposes.

7. MODELLING DOMESTIC ENERGY CONSUMPTION

This chapter describes how statistical models were constructed to develop benchmark levels of gas and electricity consumption at LSOA level for the year 2008 having accounted for demographic, social, economic, technical and climatic variations. The models for LSOA per meter gas and electricity consumption were constructed by first identifying predictor (independent) variables using correlation analysis. Secondly, correlation analysis identified pairs of independent variables strongly related to each other. Following the correlation analysis, multiple regression models for gas and electricity were constructed using step-wise hierarchical methods (see section 3.4.2 for a description). Finally, the models were tested using data from 2009 and 2010 to explore if relationships hold true over time and therefore are not spurious.

7.1 Building the Model

Building the models was achieved using specified criteria, detailing the selection of variables for entry in to the regression models as follows:

- The correlation between dependent and independent variables was reasonably strong ($|r|>0.2$). This reduced the number of variables included in the modelling process by removing the independent variables with weak associations with the dependent variable
- Where the correlation between pairs of independent variables was very strong ($|r|>0.7$) had only one variable of the pair was included in the model. The variable selected was the one which adds the most to the overall fit of the model (given by the greatest increase in r^2). This reduced the possibility of violating the independence assumption of multiple regression (where two independent variables in the model are strongly correlated with each other).
- Finally, entry of qualifying variables into the regression model used a stepwise entry method, excluding those variables that failed to increase the r^2 value by more than 0.01.

Details of this process are shown in section 7.2. After determining the inputs for entry into the model, the residuals were then assessed to ensure that these met the assumptions of multiple regression: they followed a normal distribution, and that the residuals were not correlated with the predicted values of the regression models. Violations of the regression assumptions were dealt with by modelling the square root of the dependent variable. The model where the residuals most closely followed a normal distribution was chosen. The details of the transformations are dealt with in 7.2 and 7.3 for the gas and electricity models respectively.

7.1.1 Correlation against Dependent Variables

Table 7.1 displays the correlation co-efficients between independent variables and the two dependent variables that meet the criteria of having $|r|>0.2$. The square root transformed dependent variables were also included to show that the transformations do not significantly change the associations with the independent variables. The figures from Table 7.1 indicate that the average number of rooms (r=0.724) and median household income (r=0.637) have the strongest associations with per meter gas consumption. This confirms that larger houses are expected to have higher demands for gas consumption for heating energy and those households with higher incomes are expected to be better able to afford larger levels of gas consumption. The result is similar for electricity consumption with average number of rooms (r=0.605) and median household income (r=0.593) also having a strong association with the dependent variable. However the independent variable with the strongest association with per meter electricity consumption is the proportion of gas to electricity meters (r=-0.617), identifying that those LSOAs with a lower proportion of housing connected to the gas grid have greater demands for electricity (due to potentially higher rates of electrical heating).

The proportion of house types in a LSOA also has strong correlation co-efficients with per meter gas consumption. The proportion of detached houses has a strong positive correlation with per meter gas consumption (r=0.546) and this is the second strongest association with per meter electricity consumption (r=0.598). As highlighted in section 7.1.2, detached houses are likely to be larger properties, therefore have greater heating demands and potentially contain a greater number of electrical gadgets. The proportion of tenure types has high correlation co-efficients with per meter gas consumption. The proportion of owner occupier households is positively correlated with per meter gas consumption (r=0.555), but this relationship is weaker with per meter electricity consumption (r=0.369). The proportion of socially renting households is negatively correlated with both per meter gas consumption and electricity consumption (r=-0.547 and r=-0.406) which likely reflects the differences in income and wealth between these two tenure types. These results also indicate that per meter gas consumption in a LSOA has a stronger relationship with tenure types than for electricity consumption.

Table 7.1 Correlation between Dependent and Independent Variables (2008)

Variable	Untransformed Per Meter Gas Consumption	Square Root Per Meter Gas Consumption	Untransformed Per Meter Electricity Consumption	Square Root Per Meter Electricity Consumption
Area of LSOA	0.207	0.206	0.470	0.458
Average Number of Rooms	0.724	0.731	0.605	0.618
Housing Density	-0.380	-0.400	-0.408	-0.422
Median Household Income	0.637	0.624	0.593	0.599
Number of Heating Degree Days	0.241	0.258	-	-
Population Density	-0.344	-0.362	-0.401	-0.413
Proportion of Detached Houses	0.546	0.543	0.598	0.604
Proportion of Flats	-0.364	-0.390	-0.260	-0.274
Proportion of Owner Occupied Houses	0.555	0.577	0.369	0.394
Proportion of Socially Rented Houses	-0.547	-0.571	-0.406	-0.430
Proportion of Terraced Houses	-0.349	-0.342	-0.362	-0.368
Without Central Heating	-0.274	-0.274	-	-
Proportion of Gas to Electricity Meters	-	-	-0.617	-.0597

7.1.2 Correlation between Independent Variables

Correlation analysis between the independent variables was carried out to ensure that there were not strong correlations between pairs of independent variables as this would violate the independence assumption of multiple linear regression. The pairs of independent variables with correlation co-efficients of $|r|>0.7$ are listed in Table 7.2. The r values for the datasets used in the gas and electricity samples are shown due to the different numbers of LSOAs (as a result of excluding off-gas LSOAs), though this does not significantly alter the results.

Table 7.2 Correlation Co-Efficients for Pairs of Independent Variables (|r|>0.7)

Variable 1	Variable 2	r (gas sample)	r (electricity sample)
Population Density	Housing Density	0.961	0.962
Proportion of Owner Occupied	Proportion of Socially Rented	-0.899	-0.899
Average Number of Rooms	Proportion of Detached Houses	0.751	0.755
Average Number of Rooms	Proportion of Owner Occupied	0.744	0.740
Average Number of Rooms	Proportion of Flats	-0.715	-0.716

There are strong associations between the average number of rooms in houses in a LSOA, the proportion of owner-occupier households and the proportion of detached houses (the r values between these variables are between 0.7 and 0.8). This is an expected finding as detached houses are expected to be larger properties, and to be owner-occupied. The implication of this is that only one of these three independent variables is needed for inclusion in the model. The proportion of owner occupied housing and socially renting houses in LSOAs are strongly negatively correlated (r=-0.899), indicating that LSOAs are unlikely to contain a mix of social renting and owner occupiers. The implication of this finding is that only one of these tenure variables is required for the modelling process. The average number of rooms is inversely related to the proportion of flats in a LSOA (r=-0.715), which is an expected finding as flats are expected to have a relatively low average number of rooms. The implication of this finding is to include just one of these variables. Finally, the housing density and population density variables are very strongly related (r=0.962) and only one of these variables should be included in the model.

7.2 Constructing the Gas Consumption Model

Following the correlation analysis against the dependent variable which reduced the number of independent variables for entry into the gas consumption model to 12, these 12 variables were then ranked in order of the impact they had on the fit of the model using the stepwise entry method (see Table 7.3). This ranking enabled the removal of independent variables with strong associations with other variables included in the model. Alongside the R^2 and adjusted R square values, Table 7.3 also lists the p-value of the variables in the model to assess the statistical significance of the change in R^2. All of the variables entered into the model are statistically significant at the 0.05 level (all the p values are less than 0.01).

Table 7.3 Stepwise Entry Method for Per Meter Gas Consumption

Independent Variable	**Change in R^2**	**Adjusted R Square**	**p**
Average Number of Rooms	0.524	0.524	<0.000
Median Household Income	0.090	0.614	<0.000
Heating Degree Day	0.036	0.651	<0.000
Percentage of Flats	0.011	0.661	<0.000
Percentage of Detached Houses	0.006	0.667	<0.000
Percentage of Terraced Houses	0.004	0.670	<0.000
Housing Density	0.003	0.672	<0.000
Population Density	0.002	0.677	<0.000
Percentage of Socially Renting	0.002	0.679	<0.000
Percentage of Owner Occupied	0.002	0.681	<0.000
Area of LSOA	0.003	0.684	<0.000
Percentage Without Central Heating	0.000	0.684	<0.000

Average number of rooms had the strongest impact on the per meter electricity consumption model, adding 0.524 to the R^2 value. Median household income added a further 0.09 to the fit of the model. Heating Degree Days had the third highest impact on the R^2 (0.036), followed by the percentage of flats (0.011). These four variables accounted for 66.1% of the variation in LSOA per meter gas consumption. The next nine variables added just 0.023 to the model R^2 value. These were the only four variables to meet the change in R^2 criteria (0.05).

7.2.1 Untransformed Model

To deal with the violation of the independence assumption, variables were removed from the entry method. As Average Number of Rooms was the strongest predictor of per meter gas consumption, the independent variables that it had strong correlations with were removed. These variables were: the proportion of flats, proportion of owner-occupier households, and proportion of detached houses. Housing density appeared higher up the list of variables from the stepwise entry and was included at the expense of population density. Re-running the stepwise entry method and removing those variables that did not add at least 0.01 to the model left three variables in the model as shown in Table 7.4. The model satisfies the independence assumption, and has an overall R^2 value of 0.651 which is statistically significant at the 0.05 level ($F_{3,31956}$=19844, p<0.01). This R^2 value is of practical significance, since the model can explain 65.1% of the geographical variation in gas consumption in English LSOAs, a high proportion given that the model does not take into account energy efficiency interventions, community attitudes, or the overall quality of the housing stock.

Table 7.4 Stepwise Entry Method for Per Meter Gas Consumption

	Model Statistics			Co-Efficients			Variable Significance Test	
Independent Variable	**Change in R^2**	**Adjusted R^2**	**p**	**Unstandardised**	**Standard Error**	**Standardised**	**t-value**	**P**
Constant	-	-	-	-10273	0.59	-	-65	<0.000
Average Number of Rooms	0.524	0.524	<0.000	2565	0.09	0.44	102	<0.000
Median Household Income (£ 000)	0.090	0.614	<0.000	175	1.66	0.45	106	<0.000
Heating Degree Days (1000 K-days)	0.036	0.651	<0.000	4192	72.75	0.21	58	<0.000

7.2.2 Assumption Checking

From the histogram of Figure 7.1 it can be seen that there is a slight deviation from the normal distribution with a longer tail above the mean. The normal probability plot in Figure 7.2 confirms this, with deviations from the 45° either side of the mean.

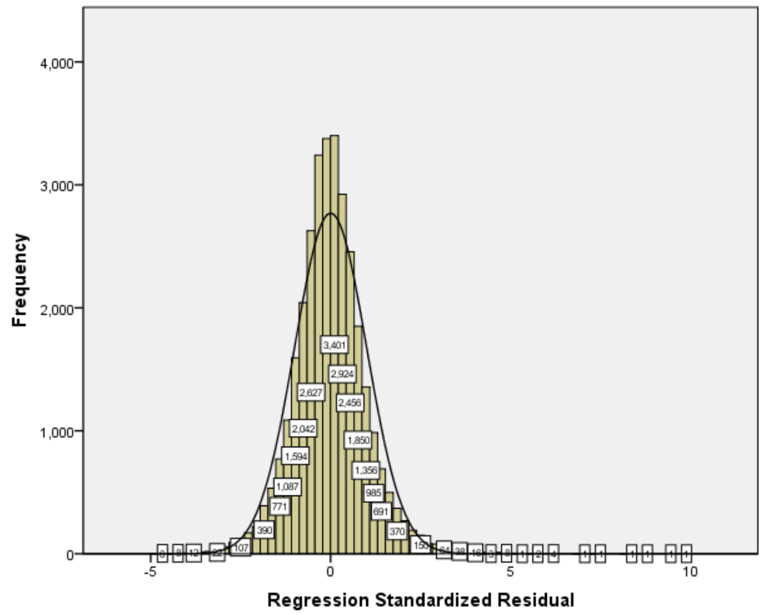


Figure 7.1 Standardised Residuals for Gas Consumption Model

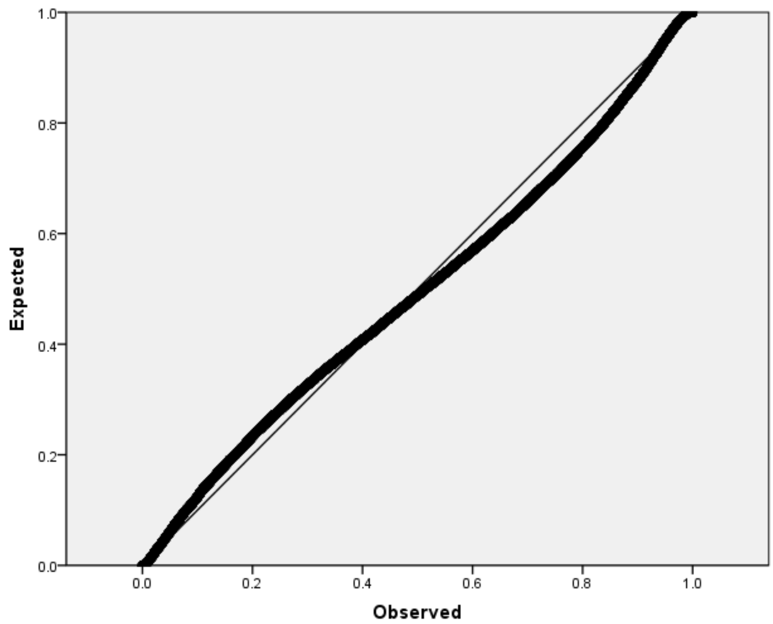


Figure 7.2 Normal Probability Plot of Regression Residuals

In Figure 7.3, plotting the residuals against the predicted values shows scatter around the y=0 line, with a correlation co-efficient of approximately zero. This satisfies the heteroskedasticity criteria as the residuals are not correlated with the predicted variables. From Figure 7.4, the predicted against observed values have the line of best fit of y=x however the model over predicts values at the upper end of the distribution.

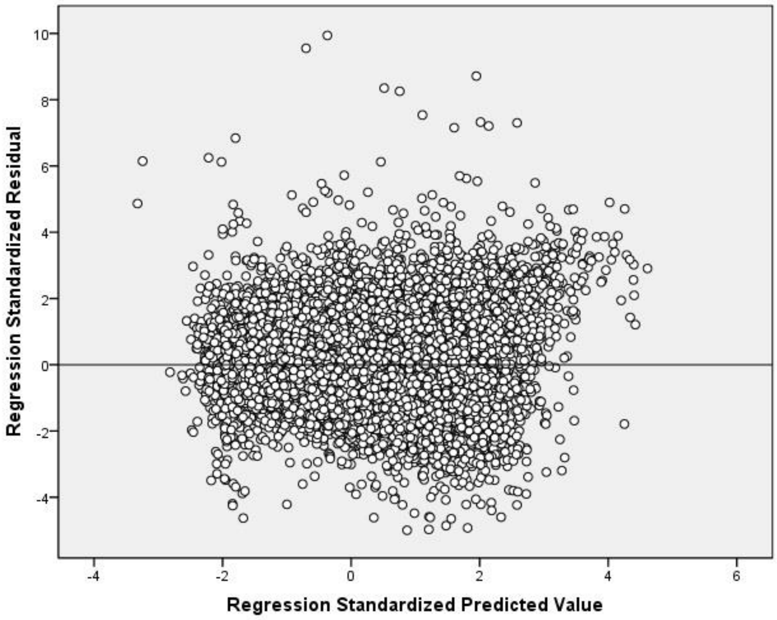


Figure 7.3 Plot of Standardised Predicted Values against Standardised Residuals

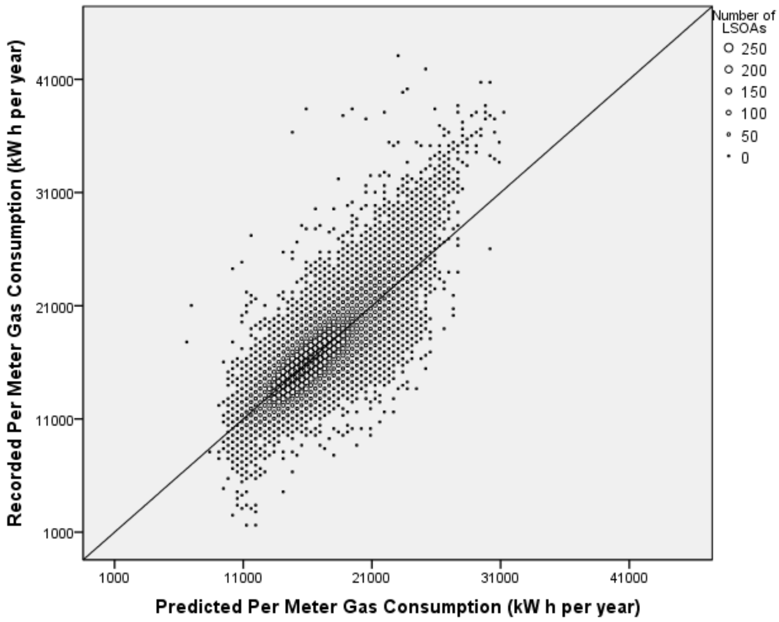


Figure 7.4 Plot of Predicted Values against Recorded Per Meter Gas Consumption Figures

The modelling process was re-run using a square root transformation to correct the slight violation of the normality assumption.

7.2.3 Transformed Model

By following the same procedure as in section 7.2.1 but modelling square root per meter gas consumption, the same three variables were included in the regression model. The R^2 value shows a slight increase to 0.653 as shown in Table 7.5. From figures 7.5 and 7.6 the distribution of residuals of the transformed dependent variable has less skew than using the untransformed variable. Figure 7.7 confirms that the model continues to meet the heteroskedasticity assumption. Figure 7.8 also highlights that the over prediction of the higher values is less pronounced.

Table 7.5 Multiple Regreession Model for Square Root per Meter Gas Consumption

	Model Statistics			Co-Efficients			Variable Significance Test	
Independent Variable	**Change in R^2**	**Adjusted R^2**	**p**	**Unstandardised**	**Standard Error**	**Standardised**	**t-value**	**P**
Constant	-	-	-	-25.53	0.59	-	44	<0.000
Average Number of Rooms	0.534	0.534	<0.000	9.88	0.09	0.45	106	<0.000
Median Household Income (£ 000)	0.079	0.613	<0.000	0.63	0.01	0.43	102	<0.000
Heating Degree Day (1000 K-days)	0.040	0.653	<0.000	16.36	0.27	0.22	60	<0.000

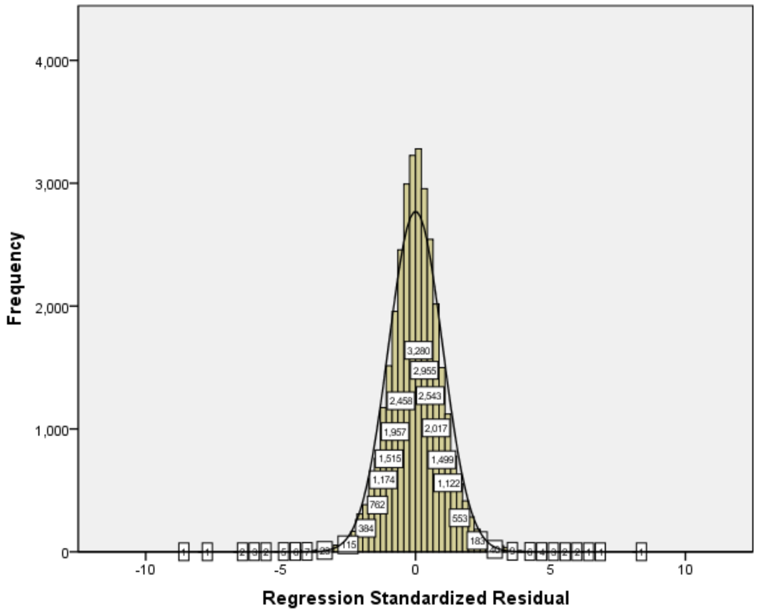


Figure 7.5 Distribution of Square Root Gas Consumption Regression Model Standardised Residuals

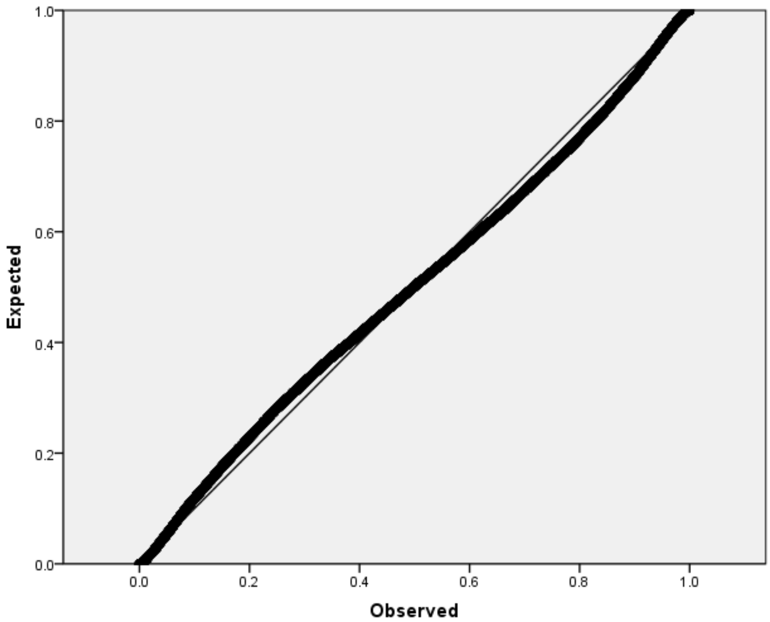


Figure 7.6 Normal Probability plot of Square Root Gas Consumption Regression Residuals

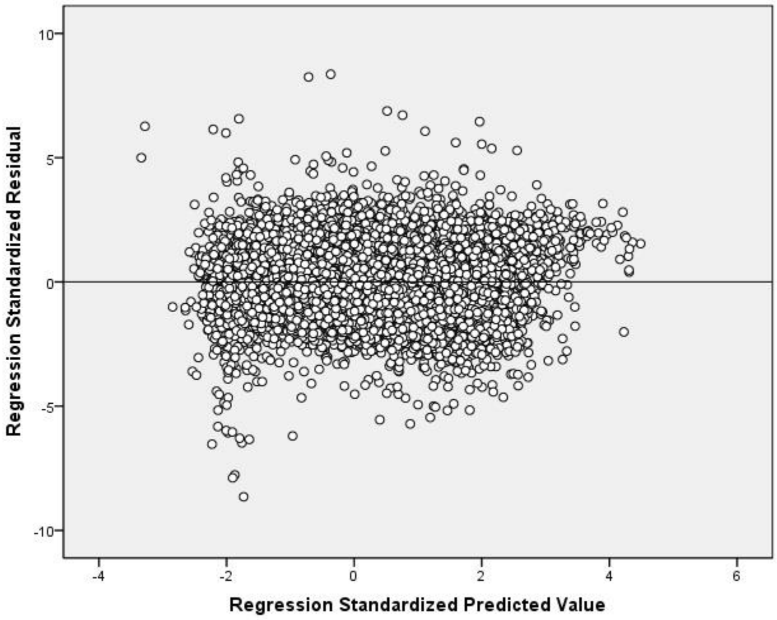


Figure 7.7 Plot of Standardised Predicted Value against Standardised Residuals

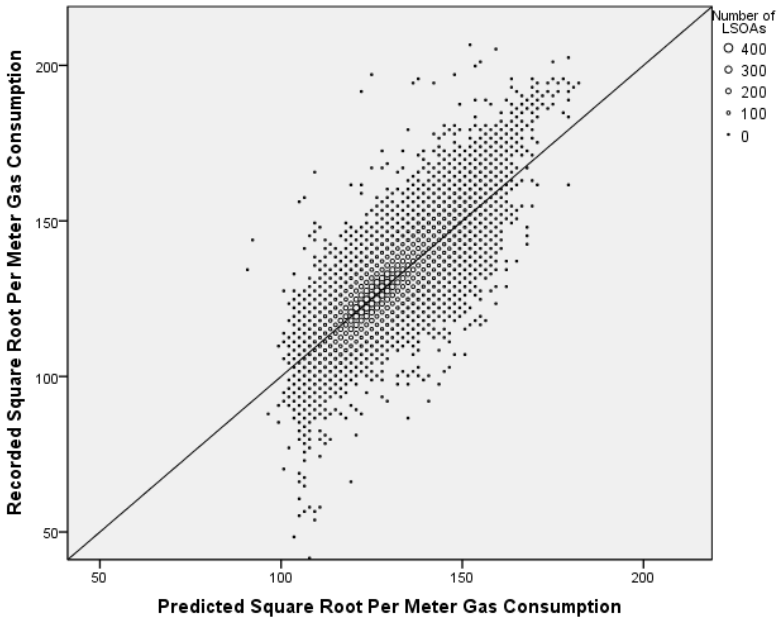


Figure 7.8 Plot of Predicted Values against Recorded Square Root Per Meter Gas Consumption

The final model has the equation:

(Equation 1. Per Meter Gas Consumption Model)

$$\mathbf{BMG = (-25.53 + 9.88\mathit{ANR} + 0.63\mathit{MHI} + 16.36\mathit{HDD})^2}$$

Where *BMG=Benchmark Gas Consumption*, A*NR=average number of rooms, MHI=median household income (£ 000), HDD=Heating Degree Days (1000 K-days)*

As well as greater symmetry in the residuals, the r^2 value of the transformed variable model was also higher and therefore it was decided to proceed using the transformed variable.

The variables included in the model are consistent with the theoretical suggestions in the literature (see section 2.1). It would be expected that higher income households living in larger houses (with a higher average number of rooms) would have higher levels of gas consumption. Heating degree days were expected to be included in the model since houses located in colder areas were expected to have higher heating demands, but this analysis suggests that heating demands in English homes are more dependent on household income and the size of the house, which with just these two variables accounting for over 60% of the variation in per meter gas consumption. Whilst the heating degree day variable has a relatively low correlation co-efficient with per meter gas consumption, it becomes the third strongest predictor in the final regression model.

7.3 Constructing the Electricity Consumption Regression Model

Following the same procedure as used for the gas consumption model, correlation analysis against per meter electricity consumption reduced the number of independent variables for entry into the electricity consumption model to 11. These 11 variables are ranked in order of the impact they have on the fit of the model using the stepwise entry method. The entry list is shown in Table 7.6.

Table 7.6 Stepwise Entry for per Meter Electricity Consumption

Independent Variable	**Change in R^2**	**Adjusted R Square**	**P**
Percentage of Gas to Electricity Meters	0.381	0.381	<0.000
Average Number of Rooms	0.284	0.665	<0.000
Median Household Income	0.072	0.737	<0.000
Housing Density	0.009	0.747	<0.000
Northing	0.008	0.754	<0.000
Percentage of Owner Occupiers	0.005	0.760	<0.000
Population Density	0.002	0.762	<0.000
Percentage of Flats	0.000	0.762	<0.000
Percentage of Socially Renting	0.000	0.762	<0.000
Percentage of Terraced Houses	0.000	0.762	<0.000
Percentage of Detached	0.000	0.762	<0.000

The ratio of gas to electricity meters had the strongest impact on the per meter electricity consumption, adding 0.381 to the R^2 of the model. The average number of rooms added a further 0.248 to the fit of the model and median household income added 0.072 to the model. No other independent variable met the 0.01 change in R^2 criteria and the remaining 8 variables added just 0.025 to the overall fit of the model. Of these three variables that met the criteria, none of them violated the $|r|>0.7$ correlation between pairs of independent variables rule.

7.3.1 Untransformed Model

Re-running the entry method using just the three variables stated above gave the model shown in Table 7.7.

Table 7.7 Stepwise Entry Model for Per Meter Electricity Consumption

	Model Statistics			Co-Efficients			Variable Significance Test	
Independent Variable	**Change in R^2**	**Adjusted R^2**	**p**	**Unstandardised**	**Standard Error**	**Standardised**	**t-value**	**P**
Constant	-	-	-	2604	25.5	-	106	<0.000
Ratio of Gas to Electricity Meters	0.381	0.381	<0.000	-2196	12.1	-5.23	-181	<0.000
Average Number of Rooms	0.284	0.665	<0.000	508	4.6	0.37	110	<0.000
Median Household Income (£ 000)	0.072	0.737	<0.000	29	0.3	0.32	94	<0.000

7.3.2 Assumption Checking

From the histogram of Figure 7.9 it can be seen that there is a deviation from the normal distribution with a longer tail above the mean. The normal probability plot in Figure 7.10 confirms this, with deviations from the 45° either side of the mean and these deviations are greater than those present in the gas consumption model. This was to be expected given the skew and kurtosis values present in the distribution of the dependent variable.

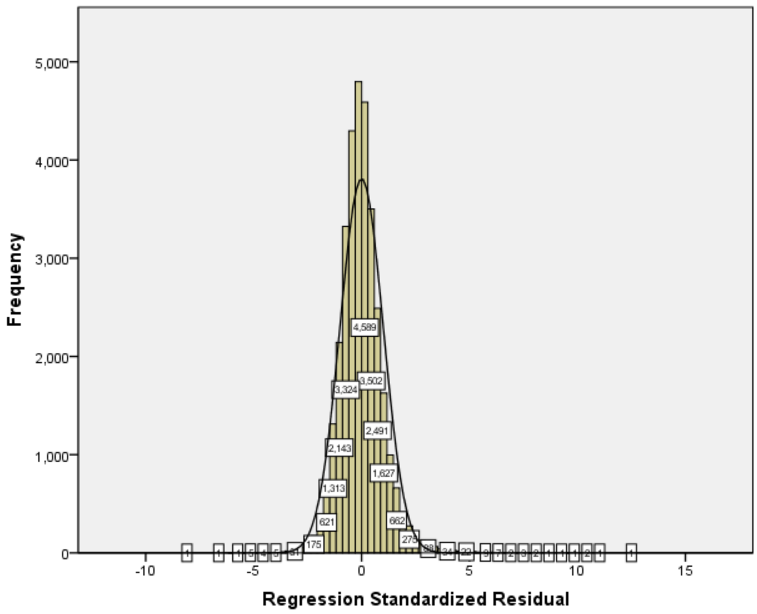


Figure 7.9 Distribution of Electricity Consumption Regression Model Standardised Residuals

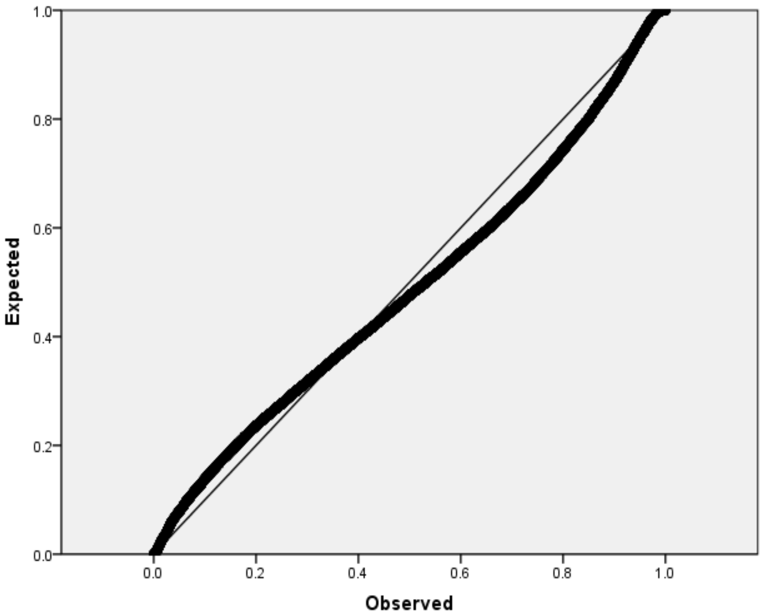


Figure 7.10 Normal Probability Plot of Regression Residuals

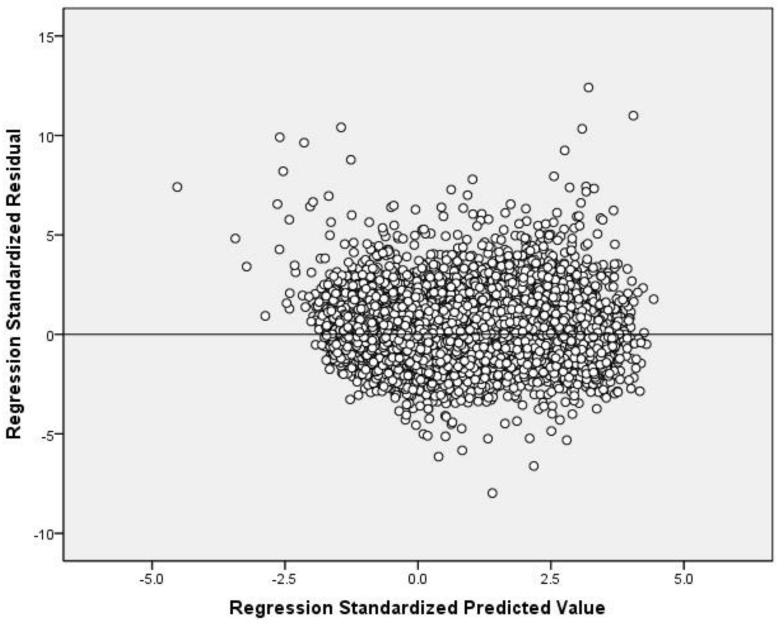


Figure 7.11 Plot of Standardised Residuals against Standardised Predicted Values

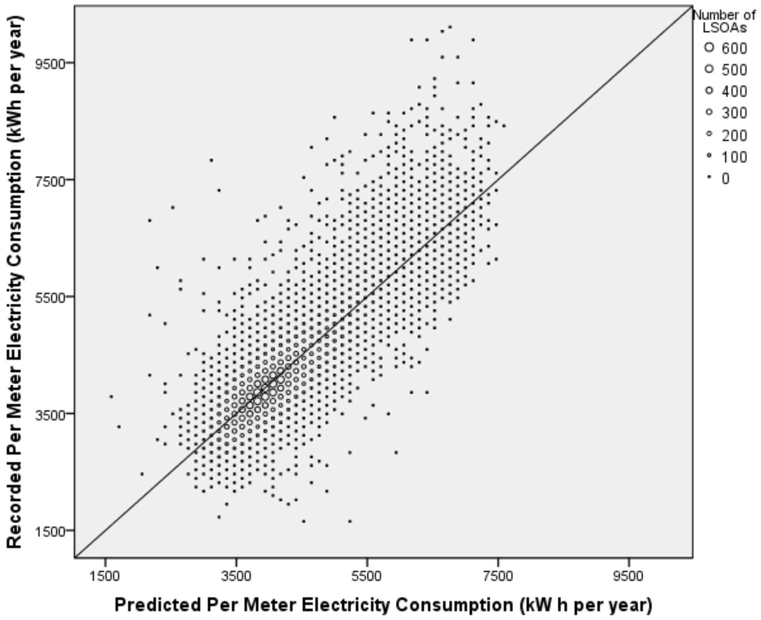


Figure 7.12 Plot of Predicted Values against Per Meter Electricity Consumption

Despite the skew in the residuals, the model still meets the heteroskedasticity criteria as seen in figures 7.11 and 7.12. The residuals are not correlated with the predicted values and the line of best fit between the recorded and predicted values follows the y=x line. However to correct the skew in the residuals, the regression analysis was re-run using the square-root transformation.

7.3.3 Transformed Model

As with the gas consumption model, to correct the violation of the normally distributed residual assumption a square root transformation. By following the same procedure, the same three variables were included in the regression model. The R^2 value shows a slight decrease to 0.731 as detailed in Table 7.8.

Table 7.8 Multiple Regression Model for Square Root per Meter Electricity Consumption

	Model Statistics			Co-Efficients			Variable Significance Test	
Independent Variable	**Change in R^2**	**Adjusted R^2**	**p**	**Unstandardised**	**Standard Error**	**Standardised**	**t-value**	**P**
Constant	-	-	-	51.47	0.18	-	285	<0.000
Average Number of Rooms	0.382	0.382	<0.000	3.86	0.03	0.39	113	<0.000
Ratio of Gas to Electricity Meters	0.276	0.658	<0.000	-15.34	0.09	-0.50	-172	<0.000
Median Household Income (£ 000)	0.073	0.731	<0.000	0.22	0.00	0.32	94	<0.000

Examining the residuals of the square root transformed per meter electricity consumption shows that the skew has been reduced, and the distribution of residuals to have greater symmetry. Therefore the analysis proceeds with the square root transformed model for both variables. Modelling the square root per meter electricity consumption gives a slightly reduced R^2 value of 0.731 but crucially as seen in the residual plots of Figure 7.13 and 7.14 the residuals are closer to a normal distribution and this was considered to be of greater importance than a negligibly stronger R^2 value. The plots of 7.15 and 7.16 show that the residuals satisfy the heteroskedasticity criteria and the square root transformed model is closer to satisfying the assumptions of multiple linear regression than using the untransformed dependent variable. The final model has the equation:

(Equation 2. Per Meter Electricity Consumption Model)

BME = (51.47 + 3.*86ANR* -15.*34RGE* +0.*22MHI*)^2

Where *BME=Benchmark Electricity Consumption*, *ANR=average number of rooms, RGE = Ratio of Gas to Electricity Meters, MHI=median household income (£ 000)*

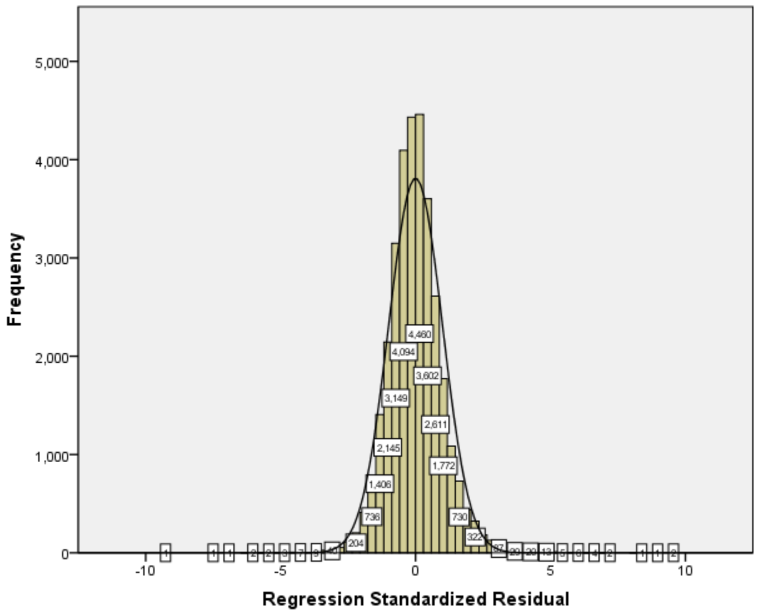


Figure 7.13 Distribution of Standardised Residuals (Square Root Transformation)

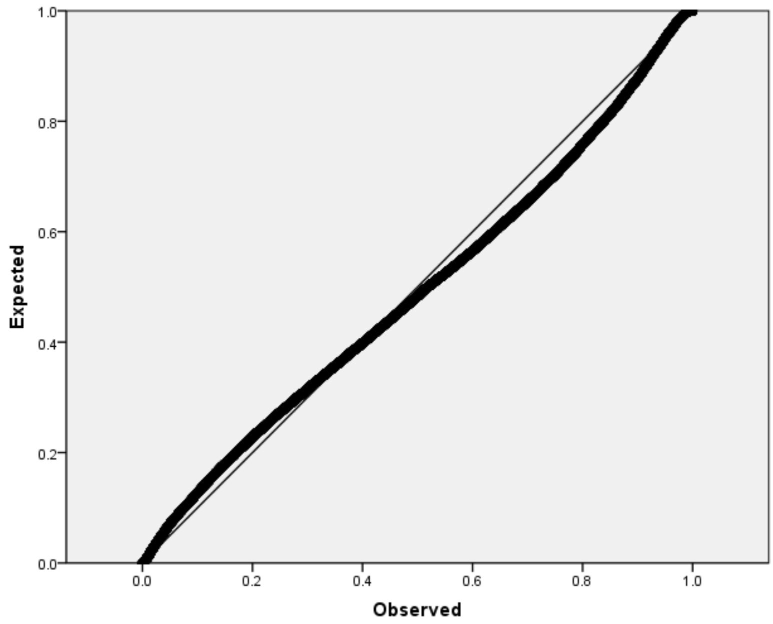


Figure 7.14 Normal Probability Plot of Regression Residuals

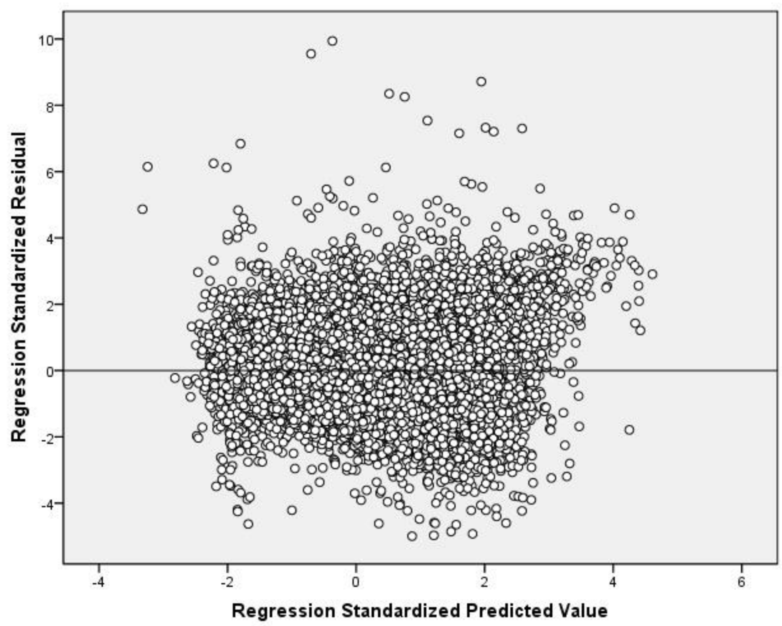


Figure 7.15 Plot of Standardised Residuals against Standardised Predicted Values (Square Root Transformation)

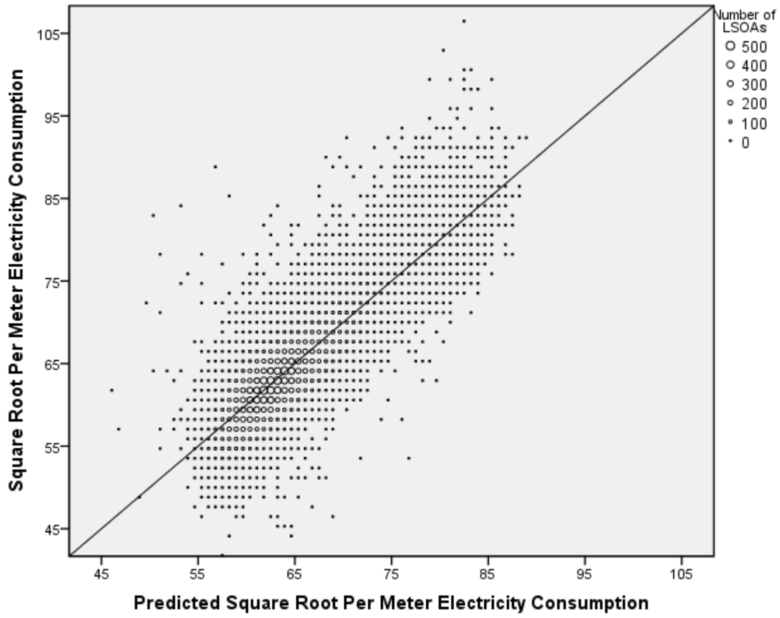


Figure 7.16 Plot of Predicted Values against Square Root Per Meter Electricity Consumption

7.4 Testing the Model Using Data from Other Years

Predicted values for per meter gas and electricity consumption were produced using equations 1 and 2, using the 2009 and 2010 Experian Income data, and the ratio of gas to electricity meters from the 2009 and 2010 DECC data. These predicted values were compared to the recorded figures for 2009 and 2010 data published by DECC. This was done to ensure that the variables included were strong predictors of LSOA per meter gas and electricity consumption across a range of years (i.e. not specific to 2008). Secondly, the modelling process in section 7.2 and 7.3 were repeated to generate models for 2009 and 2010. These models also tested that the relationships between dependent and independent variables were consistent for 2009 and 2010. These 'new' equations were subsequently used in Chapter 8 to test the how the outputs from the models varied over time.

7.4.1 Predicting 2009 and 2010 Consumption using the 2008 Equation

The validation of the regression model and its benchmarking capacities firstly used the 2008 regression equations for the gas and electricity consumption for 2009 and 2010. These predicted variables were then compared with the recorded figures for these years to ensure that the relationships between independent and dependent variables for 2008 hold true in 2009 and 2010. Testing the 2008 gas consumption model from using the measured 2009 and 2010 per meter gas consumption shows that the correlation co-efficient between measured values and 2008 model predicted values are strong (r>0.75) and that the R^2 values are close to the R^2 value for the 2008 model (0.65 – see Table 7.9).

Table 7.9 Relationship between 2008 Model Predicted and Recorded Per Meter Gas Consumption for 2009 and 2010

	2008 Model Predicted Values	
	Correlation Co-Efficient	R^2
Recorded Values 2009	0.78	0.61
Recorded Values 2010	0.81	0.65

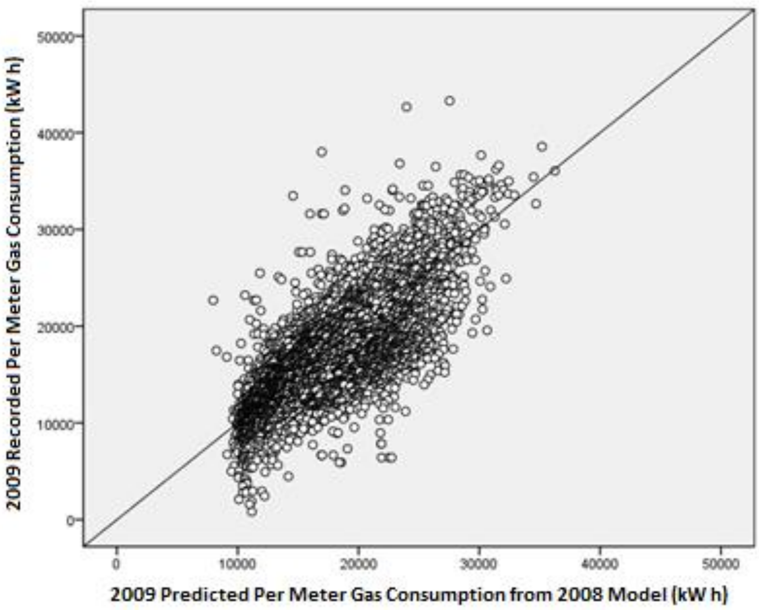


Figure 7.17 Plot of Predicted Values from 2008 Model against 2009 Recorded Per Meter Gas Consumption

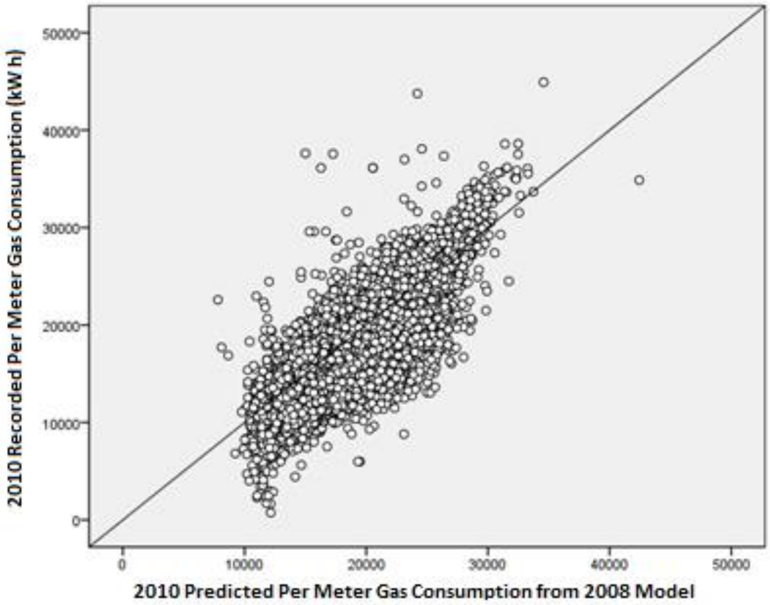


Figure 7.18 Plot of Predicted Values from 2008 Model against 2010 Recorded Per Meter Gas Consumption

Testing the 2008 electricity model from using the measured 2009 and 2010 per meter electricity consumption shows that the correlation co-efficient between measured values and 2008 model predicted values are strong (r>0.8) and that the R^2 values are close to the R^2 value for the 2008 model (0.73 – see Table 7.10). These relationships are graphically displayed in figures 7.19 and 7.20. It can therefore be concluded from this analysis that the 2008 model does provide reasonable predictions for 2009 and 2010 per meter gas consumption data, and that the independent variables included in the model are not specific to one year, and this is true for both gas and electricity consumption.

Table 7.10 Relationship between 2008 Model Predicted and Recorded Per Meter Electricity Consumption for 2009 and 2010

	2008 Model Predicted Values	
	Correlation Co-Efficient	R^2 Value
Recorded Values 2009	0.85	0.72
Recorded Values 2010	0.86	0.74

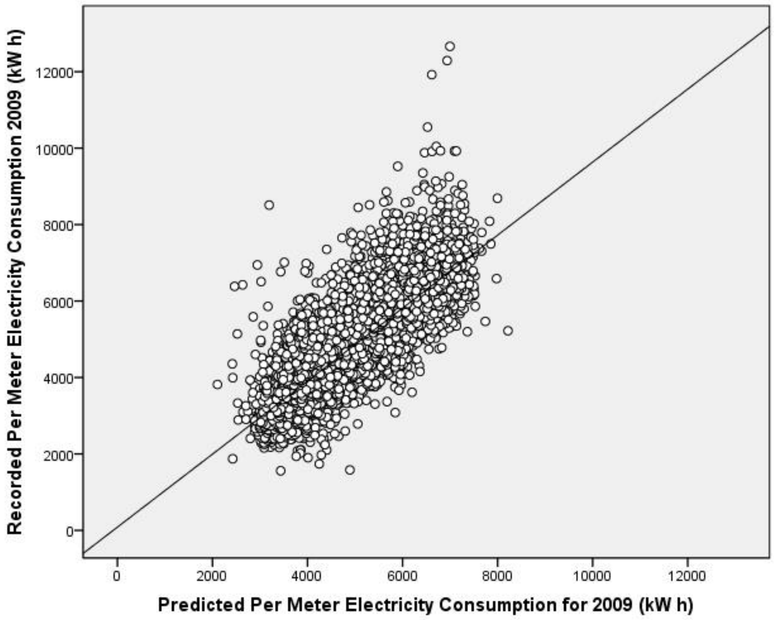


Figure 7.19 Plot of Predicted Values from 2008 Model against 2009 Recorded Per Meter Electricity Consumption

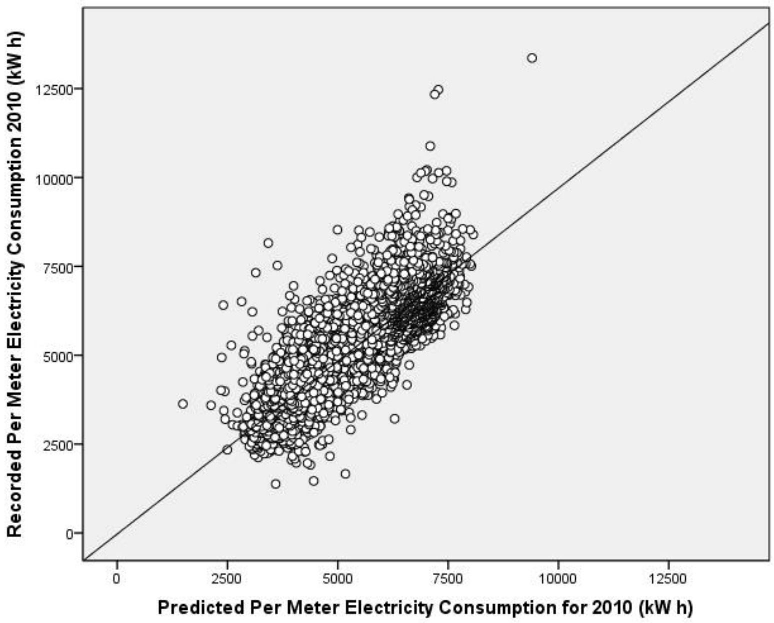


Figure 7.20 Plot of Predicted Values from 2008 Model against 2010 Recorded Per Meter Electricity Consumption

From these tests it can be concluded that the regression model constructed on the 2008 data is reliable for predicting the consumption levels of both domestic gas and electricity for 2009 and 2010. The overall relationship that was prevalent in 2008 hold true for 2009 and 2010. Predicting gas and electricity consumption using the 2008 model for 2009 and 2010 produced R^2 values against the recorded values for these years within 5% of the R^2 values of the original models. It is therefore highly likely that these relationships are genuine and are not specific to the circumstances that existed in 2008. Local Authorities could also use this model in practical applications by creating benchmarks over time by using the equations in these two models using the updated datasets for each specific year.

7.4.2 Multiple Regression Models Using New Data

A second statistical test is to assess how the form of the regression models change each year and what variables were included. Four further multiple regression models were calculated, two each for gas and electricity based on the 2009 and 2010 data. This was to ensure the independent variables were not spuriously important for one particular year if regression analysis was re-run using an alternative data source. This is important if ratings were to be 'recalibrated' year on year. Running the regression analysis for square root per meter gas and square root per meter electricity consumption for 2009 and 2010 (see Tables 7.11) gives the same independent variables that were included for modelling the 2008 consumption (Table 7.5 and 7.8). The 2010 model's co-efficient values are much similar to the 2008 model than the 2009 model for both fuels, and the R^2 values reflect this similarity. The R^2 value for the 2009 model is still within 5% of the 2008 R^2 value. This highlights the similar fit of the regression models for the three years. Given the inclusion of the same variables into the models over all three years for which data is available, and that the R^2 values of these models are within 5% of each other gives confidence that these relationships are not specific to 2008.

Table 7.11 Comparisons of Regression Models for Square Root per Meter Gas and Electricity Consumption (2008-2010)

	Gas Consumption Model Co-Efficients					**Electricity Consumption Model Co-Efficients**				
	Constant	**ANR**	**MHI**	**HDD**	R^2	**Constant**	**ANR**	**RGE**	**MHI**	R^2
2008	-25.53	9.88	0.63	16.36	0.653	51.47	3.86	-15.34	0.22	0.731
2009	41.88	8.46	0.63	9.09	0.621	52.31	3.45	-14.82	0.22	0.712
2010	26.83	9.01	0.61	9.14	0.658	50.83	3.89	-15.40	0.20	0.736

Key:

ANR = Average Number of Rooms

MHI = Median Household Income (£000)

HDD = Heating Degree Days (1000K-days)

RGE = Ratio of Gas to Electricity Meters

7.5 Conclusions

This chapter described the construction of the multiple regression models that underpin the benchmarking tool for Local Authority domestic energy reduction policy targeting. There was one model for gas consumption and one for electricity consumption. After applying a square root transformation to both dependent variables to ensure the models met the assumptions of multiple regression, and accounting for demographic, economic, climatic, social, and technical factors to explain 65.3% of the variation in LSOA per meter gas consumption, and 73% of the variation in LSOA per meter electricity consumption. The size of the house and median income are important factors in explaining the geographical variation in both fuels at LSOA level with heating degree days being the third most important variable for per meter gas consumption, and the ratio of gas to electricity meters being the most important variable for the per meter electricity consumption. The models and their coefficients are statistically significant at the 0.01 level and have practical impacts on the fit of the model by increasing the R^2 value by at least 0.01.

Testing the models using the 2008 model and energy consumption data for 2009 and 2010 indicated that the 2008 models for both gas and electricity were able to forecast gas and electricity consumption levels in LSOAs for 2009 and 2010 to within 5% of the R^2 value of the 2008 model's initial prediction. Repeating the regression analysis for 2009 and 2010 to create separate models for these years highlighted that the form of the models remains constant over the observed years. This determined that the independent variables included in the model are not specific to 2008 and are valid for 2009 and 2010. These updated benchmarks would be used as part of the over-time monitoring strategy, updating the input of the independent variables each year (as shown in Chapter 8). It is anticipated these independent variables would continue to be the inputs in the models. The predicted values from the models generated for 2008, 2009 and 2010 would be used as benchmarks for energy consumption in these years. This is expanded in the next chapter, which demonstrates how these benchmarks can be applied to Local Authority energy policy.

8. OUTPUTS AND VALIDATIONS

This chapter demonstrates the practical applications of the results from the final models described in chapter 7. Firstly consumption indices were calculated for gas and electricity consumption at LSOA level that identifies areas of potential energy efficiency and inefficiency in England. Secondly, the way these consumption indices changed over time was explored for all of the LSOAs across England. Thirdly, the impact of discrepancies between the number of meter points and household counts from different data sources was examined in detail. These tests gave confidence in the models results ahead of them being used to explore the plausibility of the results in Chapter 9.

8.1 Generating Outputs

A gas and electricity consumption index was calculated for each LSOA by dividing the recorded consumption in each LSOA by its benchmark consumption figure as predicted by the model. A full step by step guide to calculating these indices is given in Appendix 3. These indices give an immediate figure to Local Authorities which indicates whether a LSOA has higher or lower than expected consumption levels and thus whether the LSOA may benefit from energy efficiency interventions. These indices were calculated using the equation below:

Consumption Index = (DECC Recorded Consumption/Benchmark)*100

Where 100 = Consumption as expected, >100 = Consumption greater than expected, <100 Consumption less than expected

A value of 100 indicates that the LSOA is consuming the amount of gas and electricity as predicted by the model (the benchmark value). A value of less than 100 indicates that the LSOA is using less gas than might be expected given the size of the houses (number of rooms), household income and weather experienced, or less electricity than might be expected given the ratio of homes heated by gas, household income and house size. Such homes might therefore be more energy efficient. A value above 100 indicate the LSOA is consuming more energy than expected, and indicates that there may be potential for Local Authorities to intervene and reduce energy consumption. The magnitude of the deviation from the benchmark may indicate where action might be taken first. For example, a consumption index of 300 indicates that consumption in the LSOA is three times what would be expected given the conditions within that LSOA. These indices provide information on the ‘relative’ consumption in each LSOA. For example, a high-energy consuming LSOA may have an index less than 100 if it is consuming less than would be expected given the average number of rooms per house in the LSOA (for an example for gas and electricity consumption in Leicester see Appendix 4 and 5). These indices have been calculated across the whole country and therefore allows for ‘like for like’ comparisons of relative energy consumption across LSOAs and between Local Authorities.

As well as providing a statistic that can be used to assess an area, the consumption indices were used to generate maps that can be studied at the national, regional, LA, or LSOA level. Examples of these maps are shown in figures 8.1 and 8.2 and are explored further in Chapter 9. Figures 8.1 and 8.2 show the results of gas and electricity consumption indices for Leicester and were created in ArcGIS. The colour scheme and layout were designed to reflect the energy efficiency ratings for buildings in the display energy certificates (DECs), with green indicating energy efficiency (the average consumption in the LSOA is lower than is expected from the modelling results), while red indicates inefficiency (the average consumption in the LSOA is greater than expected from the modelling results) (for a guide to DECs see DCLG 2008a/b). It is intended that these maps give a very clear indication to Local Authorities as to where their efforts might be concentrated to improve the energy efficiency of the housing stock and the household.

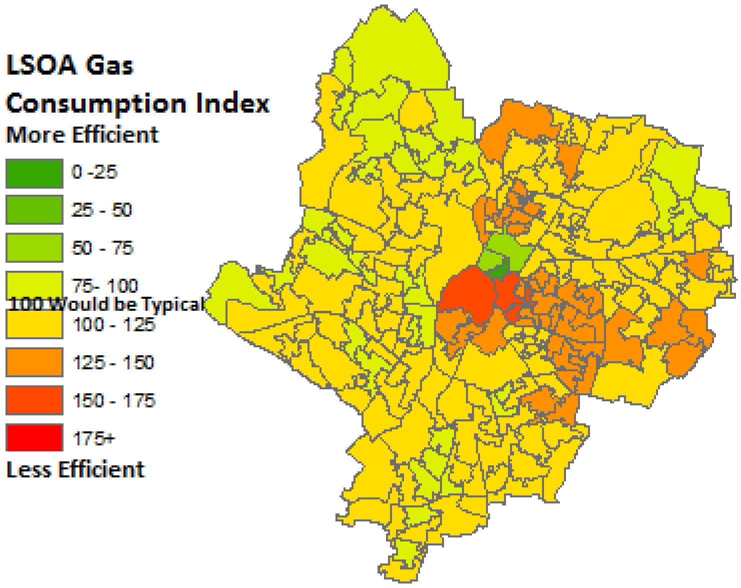


Figure 8.1 Example of Outputs for the City of Leicester Domestic Gas Consumption

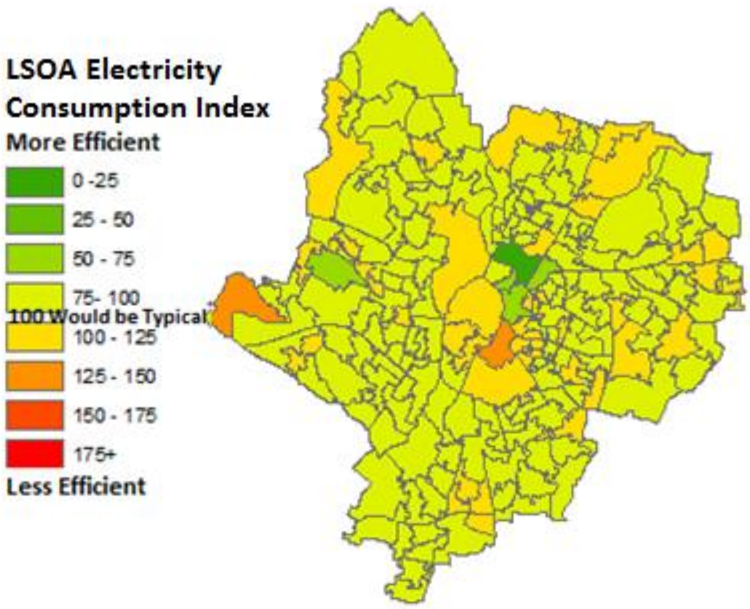


Figure 8.2 Example of Outputs for the City of Leicester Domestic Electricity Consumption

8.2 Testing How the Results Change Over Time

The consumption indices were tested to see how these vary over the three year period. This was to test how robust these outputs are. If the indices were to change rapidly from year to year they would not be suitable for Local Authority policy to measure improvements in energy efficiency. Energy efficiency improvements would be reflected by a drop in energy consumption whilst the benchmark would remain stable (this would reduce the value of the consumption index), whilst variations in the consumption index changes are investigated here to determine the extent to which the indices vary due to inconsistencies in the underlying data. To begin with, Table 8.1 shows the correlation co-efficients in the gas consumption indices for 2008, 2009 and 2010, with the scatter graphs showing the relationship between 2008 and 2009 index in Figure 8.3 and the relationship between the 2009 and 2010 indices in Figure 8.4. The co-efficients are above 0.9, which is very strong and the scatter graphs show a tight fit around the y=x line. This suggests there is a strong relationship between the gas consumption indices over the three year period.

Table 8.1 Correlation Co-Efficients of LSOA Gas Consumption Indices (2008-2010)

	2008	**2009**	**2010**
2008	1		
2009	0.942	1	
2010	0.939	0.944	1

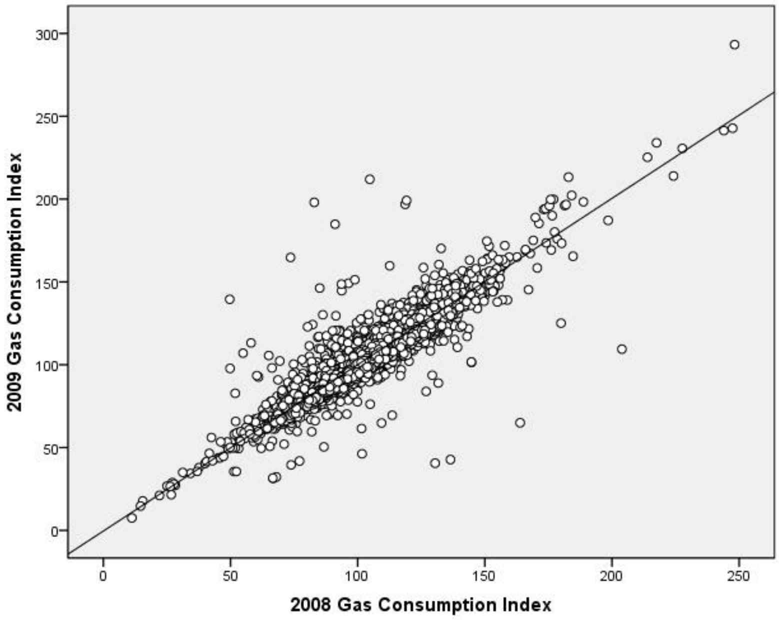


Figure 8.3 Plot of 2008 LSOA Gas Consumption Index against 2009 LSOA Gas Consumption Index

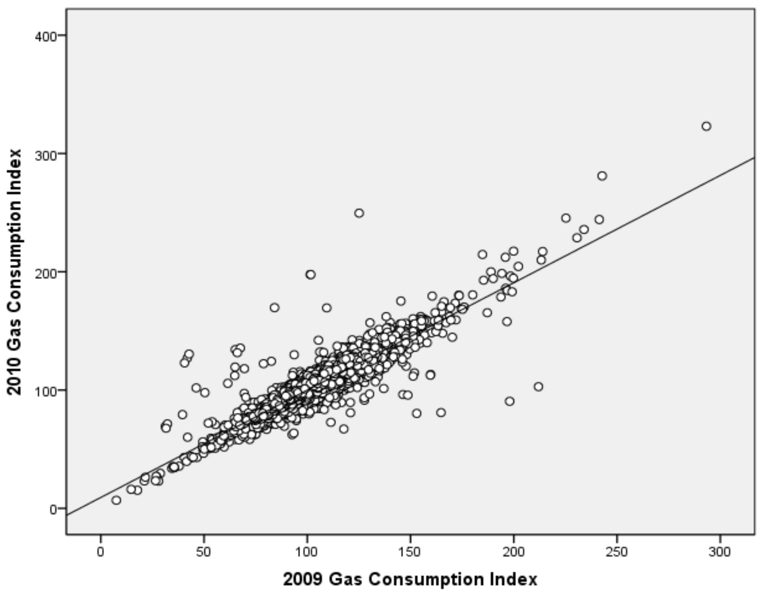


Figure 8.4 Plot of 2009 LSOA Gas Consumption Index against 2010 LSOA Gas Consumption Index

From Table 8.2, it can be seen that the change in the gas consumption indices between any two consecutive years is, on average, approximately zero. The descriptive statistics for both time change years follow a similar pattern, with a mean and median approximately zero but with long tails on either side of the distributions as shown in figures 8.5 and in 8.6. The high kurtosis values indicate that a large proportion of the data points are concentrated around the mean. What these statistics show is that the majority of LSOAs have relatively small changes to their gas consumption indices between 2008 and 2010, but there are a small number of LSOAs for which these indices change dramatically between years which may at first glance appear implausible (e.g. one LSOA decreasing from 212 to 103 between 2009 and 2010). From Table 8.3 it can be seen that only 0.3% of LSOAs have a year on year change of greater than 20 points.

Table 8.2 Gas Consumption Indices Percentage Change Descriptive Statistics

Statistic	**Change 2008 - 2009**	**Change 2009 - 10**
Mean	0.06	0.15
Median	-0.38	0.11
Standard Deviation	4.78	5.24
Highest Decrease	-68.92	-54.27
Highest Increase	180.86	205.06
Interquartile Range	4.70	5.14
Skewness	5.12	9.21
Kurtosis	147.26	292.56

Table 8.3 Number of LSOAs by Change in Gas Consumption Indices

Deviation Greater Than	**2008-09**	**2009-10**
±1	24640 (83%)	25198 (79%)
±5	5443 (17%)	6229 (19%)
±10	755 (2%)	849 (3%)
±20	115 (0.3%)	85 (0.3%)
±25	72 (0.22%)	60 (0.19%)
±50	20 (0.06%)	20 (0.06%)
±75	11 (0.03%)	10 (0.03%)
±100	2 (0.006%)	3 (0.06)

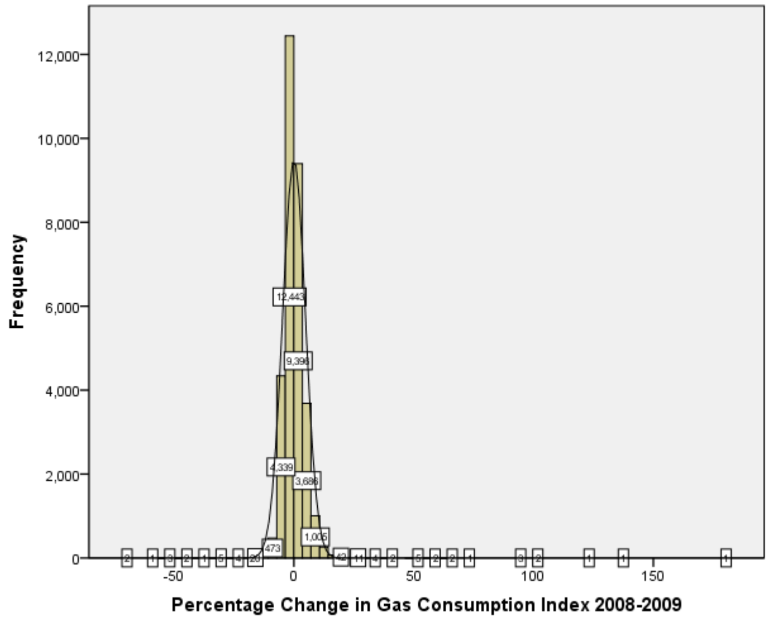


Figure 8.5 Distribution in LSOA Gas Consumption Index Change 2008-2009

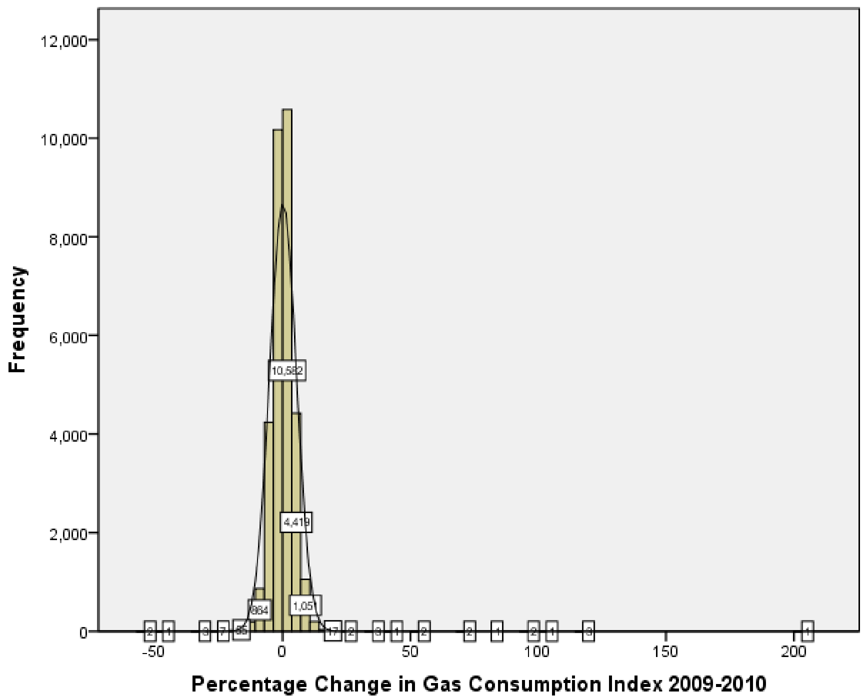


Figure 8.6 Distribution in LSOA Gas Consumption Index Change 2009-2010

Focusing on the LSOAs with changes in gas consumption indices of ±25 gave a smaller sub-sample of 72 LSOAs for 2008-2009 and 60 LSOAs for 2009-2010. From examining the data for these LSOAs, it was found that there were 13 LSOAs that have fluctuations in their gas consumption indices in excess of 40 points between the three years of data. For all 13 of these LSOAs the number of gas meters listed for 2009 is significantly different to the figures listed in 2008 and 2010. This suggests the data for 2009 is unreliable or distorted by new homes on the gas grid. Investigation of these LSOAs revealed different patterns of disclosure and merging of LSOAs for the gas consumption figures in 2009 than is used for 2008 and 2010 which has a significant impact on the gas consumption figures reported for 2009. The most extreme example is for South Cambridgeshire 008C, which had an index increase in 115 (138%) between 2008 and 2009, followed by a decrease of 143 (54%) between 2009 and 2010. The number of gas meters is listed as 138 in 2008 and 146 in 2010, yet the number of gas meters in 2009 is just 3. Other LSOAs change between 2008 and 2009 is also likely to be a result of a sharp increase in the number of gas meters such as West Berkshire 022A which has an increase in the number of gas meters from 287 in 2008 to 710 in 2009 and then appears to stabilise, with 711 gas meters reported in 2011. This may be a plausible change since it is possible large housing developments account for this change. Other meter changes however may be a result of changing disclosure patterns, and changing classifications of commercial properties as domestic properties.

One final variable that impacts on the gas consumption index is the change in income, and there are four LSOAs in London (City of London 001B, Barnet 033B, Barnet 038B, and Barnet 033F) and Oxford 008, that experience dramatic changes in Experian reported median household income between 2009 and 2010 of over £20000 whilst all other variables remain relatively stable that leads to changes in the gas consumption index. These income changes do appear implausible, but there are a lack of alternative data sources to investigate this further at present.

As with the gas consumption indices, changes in the electricity consumption indices were investigated. Table 8.5 shows the correlation co-efficients in the electricity consumption indices for 2008, 2009 and 2010, with the scatter graphs showing the relationship between 2008 and 2009 index in Figure 8.7 and the relationship between the 2009 and 2010 indices in Figure 8.8. The relationship between these consumption indices is strong, though not as strong as with the gas consumption indices.

Table 8.4 Correlation Co-Efficients of LSOA Electricity Consumption Indices (2008-2010)

	2008	**2009**	**2010**
2008	1		
2009	0.881	1	
2010	0.882	0.909	1

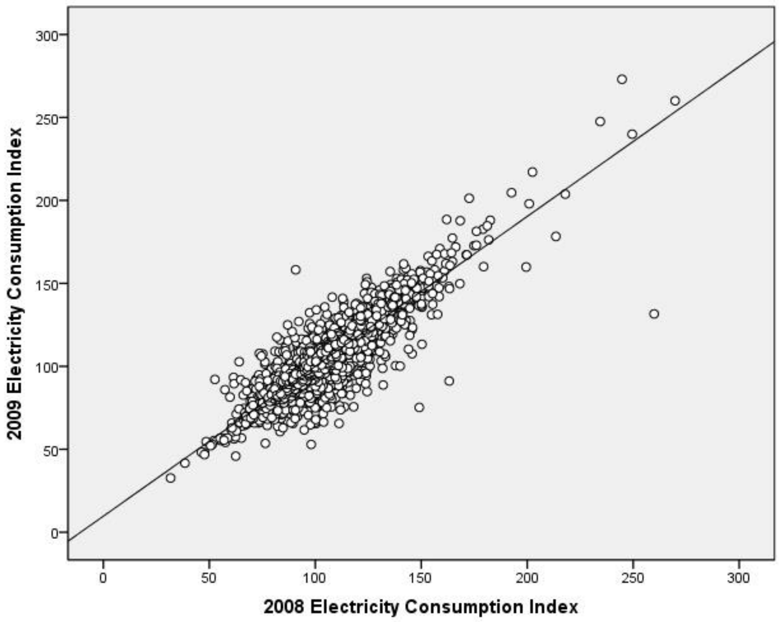


Figure 8.7 Plot of 2008 LSOA Electricity Consumption Index against 2009 LSOA Electricity Consumption Index

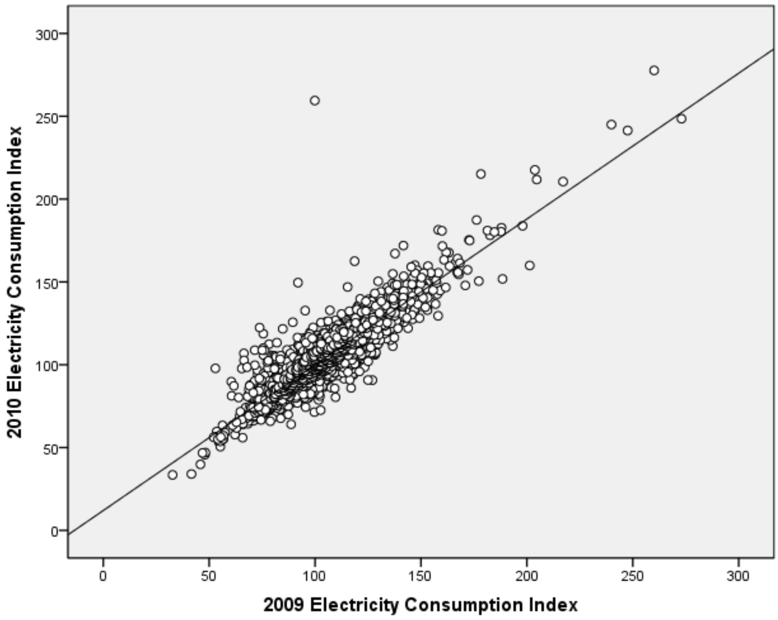


Figure 8.8 Plot of 2008 LSOA Electricity Consumption against 2009 LSOA Electricity Consumption Index

The average change in electricity consumption indices over time was approximately zero (see Table 8.6) however there are LSOAs with extreme changes from year to year (e.g. a decrease of 128 (50%) between 2008 and 2009, and an increase of 160 (160%) between 2009 and 2010). These distributions are displayed in Figures 8.9 and 8.10. There were 80% and 79% of LSOAs with a change in electricity consumption index of greater than 1 from 2008-2009 and 2009-2010 respectively (see Table 8.4). In Table 8.5 it is shown that over 90% of the LSOAs were between -8.5 and 8 for changes in the electricity consumption index for both years. These are slightly wider than for the gas consumption indices.

Table 8.5 Electricity Consumption Indices Descriptive Statistics

Statistic	**% Change 2008 - 2009**	**% Change 2009 - 10**
Mean	0.12	0.13
Median	0.15	0.06
Standard Deviation	5.22	4.65
Highest Decrease	-49.56	-29.27
Highest Increase	75.00	159.84
Interquartile Range	5.62	5.29
Skewness	0.17	2.39
Kurtosis	9.10	59.38

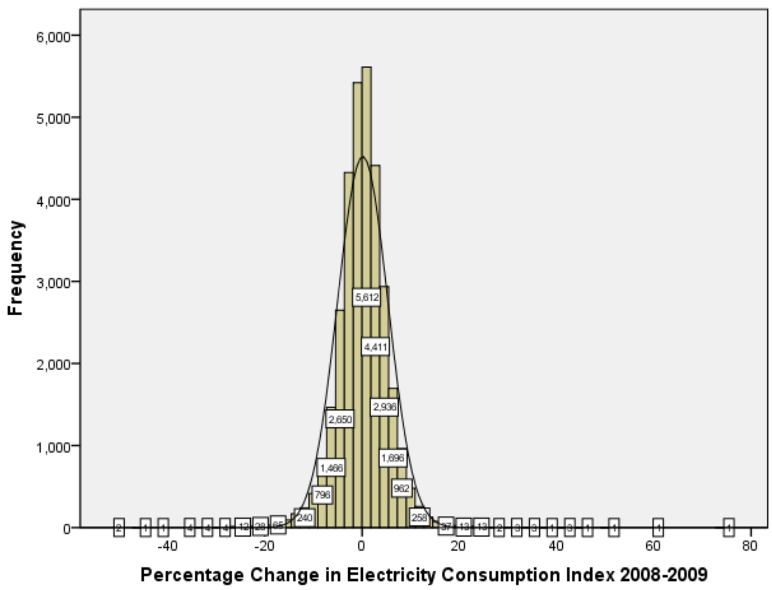


Figure 8.9 Distribution in the LSOA Electricity Consumption Index Percentage Change 2008-2009

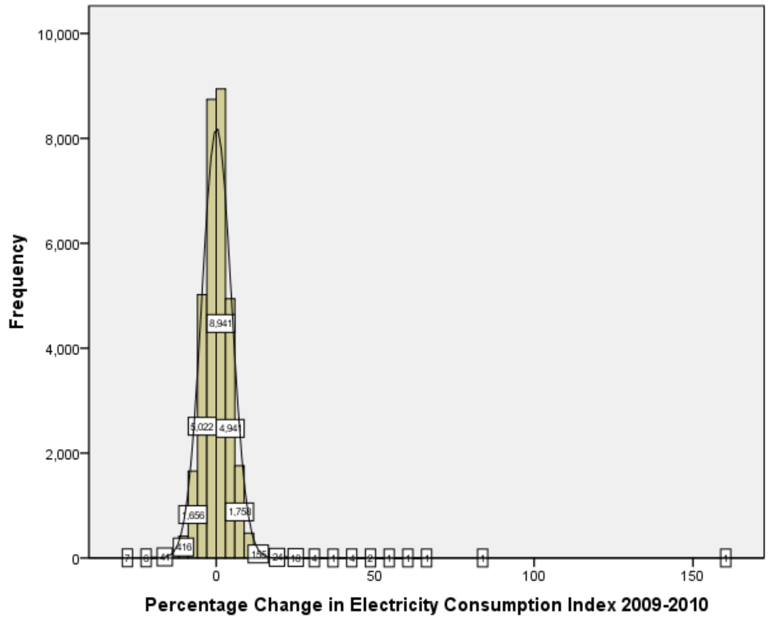


Figure 8.10 Distribution in LSOA Electricity Consumption Index Percentage Change 2009-2010

Table 8.6 Number of LSOAs by Change in Electricity Consumption Indices

Change in Index Greater Than	**2008-09**	**2009-10**
±1	26168 (80%)	25742 (79%)
±5	8284 (26%)	2950 (9%)
±10	1715 (5%)	1021 (3%)
±20	179 (0.6%)	92 (0.3%)
±25	95 (0.29%)	43 (0.13%)
±50	4 (0.01%)	2 (0.02%)
±75	1 (0.003%)	1 (0.003%)
±100	1 (0.003%)	1(0.003%)

Between 2008 and 2009 there is one LSOA with a change in electricity consumption index of greater than 100 (Basingstoke and Deane 010A, decrease of 128). Examination of the underlying data revealed an increase in the number of electricity meters from 505 to 878, with per meter consumption falling from 4149kW h per year in 2008 to 3331kW h per year in 2009. These figures stabilised in 2010 as did the consumption index. What these figures also show is a fall in the ratio of gas to electricity meters from 2.23 gas meters per electricity meter to 1.53 in 2009. Again this stabilised in 2010. For this LSOA, it would appear there was a one-off jump in the index. This may be as a result of incorrect data recorded for 2008, or that the data for 2008 is genuine and that there has been the construction of off-gas properties (such as high rise flats) between 2008 and 2009.

Between 2009 and 2010 the LSOA Aylesbury Vale 012B experiences an increase in its electricity consumption index by 160, having had a decrease of 2 the previous year. Examination of the data showed income and per meter consumption remained relatively constant whilst there was a large increase (150%) in the ratio of gas to electricity meters between 2009 and 2010. Other examples of LSOAs which experienced fluctuating changes to their electricity consumption indices over the three year period were seen in Reading 016C, Thanet 015C, and Kingston-Upon-Thames 002B. Reading 016C's underlying data showed that in 2008 and 2010 the LSOA has almost a 1:1 ratio of gas meters to electricity meters, yet in 2009 it is recorded as having 0 gas meters, therefore this greatly skews its results for 2009 and in 2010 the LSOA 'returns' to the consumption index it was assigned in 2008. Thanet 015C experiences a drop in per meter consumption by 85% between 2008 and 2009, followed by an 87% increase between 2009 and 2010. For Kingston-upon-Thames 002D, there is a 15% decrease in median household income between 2008 and 2009, followed by an 18% increase between 2009 and 2010. There are no LSOAs which experience an electricity consumption change by more than 25 in the same direction in both periods, and for those which experience a change specific to one time-period, it is again a combination of income, per meter consumption, and gas to electricity meter ratio changes.

As with the gas consumption figures, these potential problems affect a small proportion of LSOAs (less than 0.3% of LSOAs). Therefore as with the gas consumption statistics the decision was taken not to exclude any LSOAs. Any final output should include the underlying statistics as it is then easy to spot changes that affect the consumption indices.

With a longer time span of data to evaluate it is possible that this statistical method could be expanded to not only identify areas with higher (and lower) than expected domestic energy consumption in the present but also how this changes over time as a result of policy intervention and overall national trend.

8.3 Checking the Discrepancy in Household Numbers

The investigation of how gas and electricity consumption indices change over time indicated that there were some significant differences in the number of households underlying the different datasets. There is no reliable method for determining whether gas consumption is from domestic, or small/medium sized commercial properties (see chapter 5), and it is estimated that two million small and medium sized business premises are incorrectly classified as domestic properties. A large concentration of industrial properties could skew the consumption indices of LSOAs that include high proportions of non-domestic properties being included. The following steps were taken to better understand variations in household count:

1. Using a count of the number of households from council tax bands from the Valuation Office Agency ([VOA] 2011) as the definitive number of households and comparing these to the meter counts for electricity and gas meters (from DECC) in each LSOA.
2. Calculating the ratio of gas and electricity meters to number of houses and examining the descriptive statistics
3. Correlating the ratio of gas and electricity meters to number of houses against the appropriate ratings from the original regression equation (with all qualifying LSOAs) to check for non-random errors.
4. Filter out LSOAs in a step-by-step process based on the percentage of meters to household counts. Each step applies increasingly strict exclusion criteria. There is a re-running the regression model building at each step.
5. Calculate the percentage change of the consumption indices from each iteration compared to the original model rating generated from including all qualifying LSOAs

6. Assess the extent to which filtering changes the outputs of the statistical modelling, and determine whether the discrepancies from number of households and electricity/gas meters impacts on the ability to assess the efficiency of each LSOA.

The following section presents the findings at each stage of these iterations and concludes with how to proceed forwards having assessed the potential impacts of discrepancies between the house counts from council tax bands and the number of gas and electricity meters reported by DECC in LSOAs.

8.3.1 Distributions and Correlations

One LSOA (Greenwich 030A) has 30 times the number of house counts as there are for both electricity and gas meters and was disregarded from the analysis as this is a clear outlier. All other LSOAs were included in the analysis. The descriptive statistics in Table 8.7 and 8.8 show that on average there is a ratio of 0.87:1 gas meters to electricity meters, with electricity meters to council tax houses being at a 1:1 ratio. This is a plausible result given that it is expected that every house would have an electricity meter, but not all houses would be expected to have a gas meter. The distribution shown in Figure 8.11 shows a long tail below the mean for gas consumption, reflecting the varying proportions of off-gas properties in a LSOA, whilst Figure 8.12 shows a distribution of electricity meters to council tax meters symmetrically around the mean, which may indicate a misclassification of properties as domestic, and these deviations from a 1:1 ratio were investigated further.

Table 8.7 Descriptive Statistics of Ratio of Gas Meters to Council Tax Houses

Mean	Standard Deviation	IQR	Skew	Kurtosis
0.87	0.18	0.14	-2.4	7.15

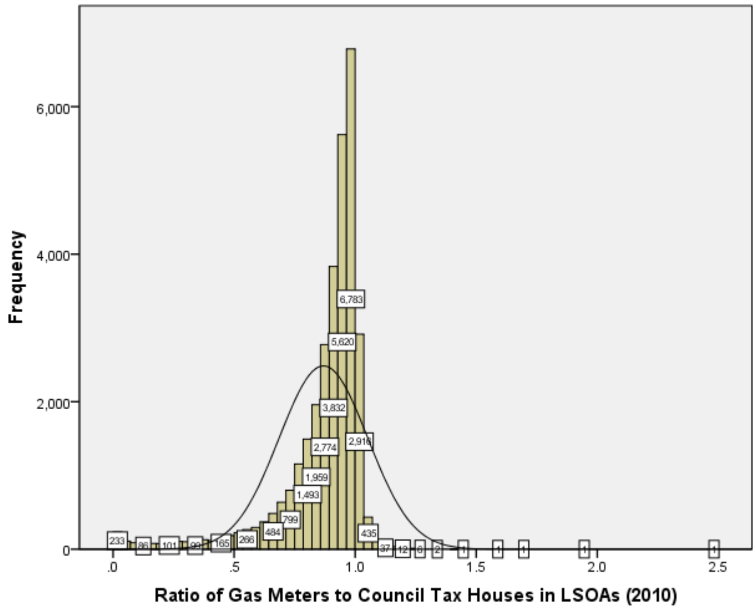


Figure 8.11 Histogram of Ratio of Number of Gas Meters to Council Tax Houses

Table 8.8 Descriptive Statistics of Ratio of Number of Electricity Meters to Council Tax Meters

Mean	Standard Deviation	IQR	Skew	Kurtosis
1	0.52	0.04	-0.66	42

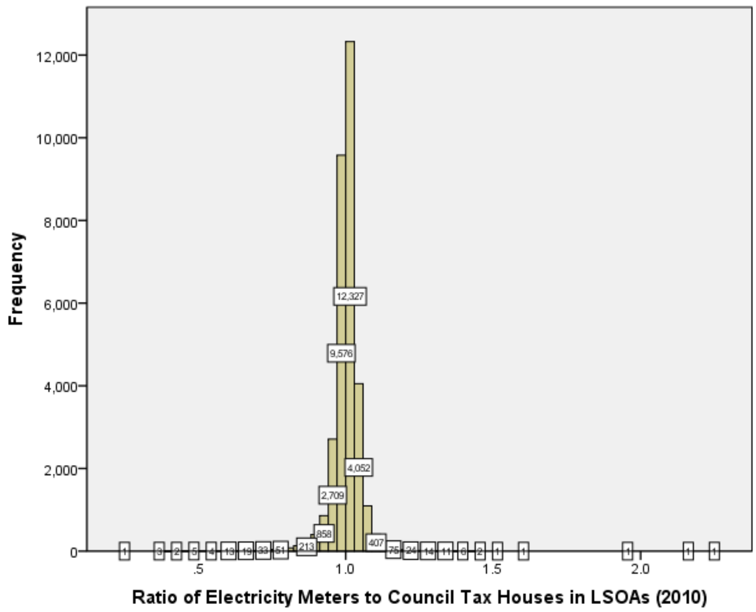


Figure 8.12 Histogram of Ratio of Number of Electricity Meters to Council Tax Houses

Table 8.9 Correlation between Ratio of Energy Meters to Council Tax Household Counts Against Consumption Indices

	Gas Meter Errors	**Gas Meter Errors (>1)**	**Electricity Meter Errors**
Gas Consumption Index	-0.016	-0.052	-0.182

From Table 8.9 it is shown that the correlation co-efficients are negative which suggests as the proportion of errors rises, then the consumption index falls. This is more pronounced in the electricity meter errors but these correlation co-efficients are relatively weak, and this is highlighted by examining the R^2 values (from squaring the correlation co-efficient). The R^2 values indicate that for electricity meter errors these figures suggest that errors in the number of electricity meters accounts for 3.3% of the variation in the gas consumption index. The corresponding figure for gas meters is 0.03%. This is contrary to the hypothesis that LSOAs with a higher number of misclassified non-domestic properties as high consuming domestic properties would lead to those LSOAs having a higher consumption index as the correlation results suggest there is not a strong relationship between discrepancy of meters compared to council tax house counts and the relative gas consumption in a LSOA.

8.3.2 Filtering LSOAs

To identify the impacts on the consumption indices resulting from LSOAs where the discrepancy between the number of meters and count of houses is the greatest, the model was re-constructed with those LSOAs removed. This process involved filtering out LSOAs where the number of meters deviated from the number of houses as indicated by the council tax records by a specified percentage (see Table 8.10). The same analysis was applied using gas and electricity meter discrepancy. Consumption indices were calculated using the new models. Because there is a theoretical justification for the percentage of gas meters in a LSOA to be less than 100% of the total number of houses (due to off-gas grid properties), the gas criteria only applies to LSOAs where there are more gas meters than households but not in instances where gas meters are less than the recorded number of houses. Electricity meter errors were chosen to be a symmetrical band around 100% since it is assumed that every household should have a connection to the electricity grid (DECC 2012a).

Table 8.10 Steps of Filtering LSOAs based on Ratio of Energy Meters to Council Tax Household Count

Step	Percentage of Gas Meters to Council Tax Houses	Percentage of Electricity Meters to Council Tax Houses
1	All	all
2	0-150%	50%-150%
3	0-125%	75%-125%
4	0-110%	90%-110%
5	0-105%	95%-105%
6	0-102.5%	97.5%-102.5%

LSOAs that fall outside of the maximum error criteria were removed before multiple regression models were re-calculated. The subsequent changes in the consumption index values were then calculated. Tables 8.11 and 8.12 show the changes to the fit of the gas and electricity models respectively, and the descriptive statistics of the changes to the relevant consumption indices. The Table lists the absolute values of the changes to the indices (with the maximum and minimum percentage changes in brackets).

Table 8.11 Gas Model Fits after Steps of LSOA Filtering

Criteria	Model R^2	N	Mean Index Value	Deviation from Original Consumption Indices[2]				
				Average	Standard Deviation	IQR	Max	Min
All LSOAs	0.658	31957	100	n/a	n/a	n/a	n/a	n/a
Gas Meters (GM) < 150% Council Tax Houses (CTH)	0.658	31952	100.1	0.01	0.01	0.01	-0.03 (-0.03%)	0.28 (0.13%)
GM < 125% CTH	0.659	31941	100.1	0.01	0.02	0.02	-0.05 (-0.04%)	0.40 (0.19%)
GM < 110% CTH	0.659	31825	100	0.00	0.02	0.03	-0.11 (-0.07%)	0.29 (0.13%)
GM < 105% CTH	0.661	31527	99.98	-0.02	0.05	0.07	-0.41 (-0.17%)	0.35 (0.29%)
GM < 102.5% CTH	0.662	30919	99.93	-0.07	0.09	0.12	-0.77 (-0.38%)	0.84 (0.54%)

Table 8.12 Electricity Model Fits after Steps of LSOA Filtering

Criteria	Model R^2	N	Mean Index Value	Deviation from Original Consumption Indices				
				Average	Standard Deviation	IQR	Min	Max
All LSOAs	0.736	32480	100	n/a	n/a	n/a	n/a	n/a
Within 50% of Council Tax Houses (CTH)	0.740	32459	99.98	-0.02	0.04	0.04	-1.54 (-0.6%)	0.26 (0.17%)
Within 25% of CTH	0.747	32274	99.93	-0.07	0.09	0.09	-3.08 (-1.19%)	0.31 (0.27%)
Within 10% of CTH	0.751	30989	99.85	-0.15	0.12	0.11	-4.36 (-1.68%)	0.34 (0.29%)
Within 5% of CTH	0.740	27477	99.80	-0.20	0.16	0.14	-4.86 (-1.87%)	0.46 (0.41%)
Within 2.5% of CTH	0.731	19701	99.69	-0.31	0.20	0.20	-2.60 (-1.64%)	0.20 (0.38%)

[2]Deviation from Original Efficiency Rating = New Rating (from new model benchmarks after applying filtering criteria) – Original Rating (from original model benchmarks)

None of the applied filtering changed the variables that were included in the model and the R^2 values never deviated by more than 2% of the original value of the model. The maximum change in any LSOA gas consumption index was a decrease of 0.03% off the original value, and a 1.87% decrease in the electricity consumption index. Applying the filtering criteria at 2.5% for the discrepancy between electricity meters and council tax houses left just 60% of the LSOAs in the analysis. Since this excludes a large number of LSOAs without leading to a practical change to the outputs it was decided that filtering LSOAs in this way was not a necessary step and therefore it was appropriate to benchmark consumption in LSOAs with a greater number of gas and/or electricity meters than number of houses from council tax records and generate benchmark and consumption indices for every LSOA in England.

8.4 Conclusion

Gas and electricity consumption indices for every LSOA were calculated by comparing the benchmark figures generated from the regression models with the recorded consumption from the DECC figures. These indices could be used by Local Authorities to identify where they should intervene to improve the energy efficiency of the housing stock (such as identifying LSOAs for the Green Deal) or to reduce consumption levels towards the benchmark level. Comparing the consumption indices for the three years of available data (2008, 2009, 2010) shows a stable relationship for the overwhelming majority of the LSOAs over the three years and that those areas with large swings in their consumption indices for gas consumption are due to the underlying DECC data, particularly LSOAs with disclosure. Identifying LSOAs that potentially contain incorrectly classified commercial properties as domestic properties through applying an exclusion criteria of the ratio of electricity meters to VOA council tax households did not significantly alter the results and it was decided that filtering out LSOAs because results appear to be 'implausible' would not be useful to Local Authorities, and instead Local Authorities would be given the underlying data to fully inform their decision concerning those LSOAs with large year-on-year deviations in energy consumption indices (Appendix 6 provides guidance to Local Authorities on how to interpret the results for LSOAs, particularly with large year-on-year changes in consumption indices). What has been demonstrated in this chapter is that there is potential for updating benchmarks for each LSOA on an annual basis and providing Local Authorities with data for assessing the impact of their energy efficiency strategies.

9. APPLYING THE MODELLING RESULTS: PLAUSIBILITY TESTS

This chapter describes work carried out to examine the plausibility of the results generated from the statistical models. The aim of these tests was to demonstrate that the outputs have practical applications for the intended audience – Local Authorities, and to ensure that these results are not simply due to spurious statistical associations and are therefore plausible. The chapter is organised as a number of plausibility tests. First the results from follow up interviews that were conducted with the 5 Local Authority representatives who agreed to remain engaged in the research project are described. Secondly, plausibility assessments that were carried out by performing walk-by surveys in LSOAs in the City of Leicester to establish the physical characteristics of those LSOAs that had extreme high or low energy consumption compared to their benchmark. Thirdly, the relationship between high concentrations of both social and privately renting households, and domestic energy consumption relative to the benchmark was explored. Fourthly, the chapter evaluated a plausibility test of Milton Keynes is detailed, where it is to be expected that a higher proportion of LSOAs within this Authority would have low gas consumption relative to their benchmark levels. Finally, the modelling results are used to rank Local Authorities, and explore potential reasons for these rankings demonstrating how these results can be used by Local Authority and Central Government to assess the relative performance of Local Authorities.

9.1 Plausibility Test 1: Local Authority Feedback

Five follow-up interviews were carried out with Local Authority representatives. This was done to establish the opinions of those who the outputs of this work were intended to be used by. Local Authority representatives who agreed to participate in the follow-up study from the initial interviewees (see Chapter 4) were used to evaluate how these results could be used positively and constructively to shape domestic energy efficiency policies. Each representative was presented with maps specific of their authority area and a two-page summary (see Appendix 4 and 5, with full data listed in Appendix 7) that outlined the methods and data used. The Local Authorities were consulted to gauge their opinions on: i) the output (e.g. layout, appearance, usability and applicability to local energy efficiency schemes), ii) clarity in the methodology used to generate the results, and iii) the plausibility of the results generated for their local area (determining if there were any unexpected outcomes that might suggest a fault in the model). The consultations were carried out in May and June 2012, 12-18 months after the initial contact. The interviews lasted approximately one hour. Notes were recorded along with annotations on information distributed to the representatives (see Appendix 8 for an example of the interview schedule). The representatives who took part in the study are listed in Table 9.1.

Table 9.1 Representatives who participated in consultation meetings

Council	Council Type	Job Title
City Council	Unitary Authority	Home Energy Advice Manager
City Council	Unitary Authority	Home Energy Team Leader
City Council	Lower Tier	Energy and Climate Change Team Leader
City Council	Metropolitan Authority	Fuel Poverty and Affordable Warmth Officer
District Council	Lower Tier	Planning and Sustainability Officer

The remainder of this section reflects on the findings from these consultation meetings.

9.1.1 Data and Method

The first part of the interview concentrated on the data sources and the method used to generate results and outputs. These were deemed reasonable and sensible by all of the representatives. It was noted that LSOA level was ‘probably as sharp as [the data] can be’ by the Home Energy Team Leader. The Home Energy Advice Manager felt that LSOAs being made up of 500-900 properties was a ‘good resolution’. LSOAs were favoured by the Fuel Poverty and Affordable Warmth Officer as their Authority Ward boundaries had changed in 2005 and it was the consistency of LSOA boundaries that was important to developing long term energy policies.

The use of a regression model was praised by the Home Energy Advice Manager, who stated that ‘it has to be kept simple’, adding ‘what we want is practical application of theory and research so anything like this should be run past practitioners’. This gives a strong justification to involving Local Authorities in the development of the method in this thesis. The variables in the model were seen as reasonable and sensible by all the Authorities, but there were questions raised over the exclusion of property age by four of the five authorities, and type of property by three Authorities (the latter of which was shown not to be an important predictor of LSOA domestic energy consumption once household size had been taken into account – see chapter 7), for property age the results from the model appeared to identify the oldest (and therefore likely the most energy inefficient) properties when examining results for LSOAs in which recorded gas consumption exceeded its benchmarked level by the greatest amounts. The age of the housing stock was not included in the modelling process because these data were not available at LSOA level for the whole of England. However as discussed in earlier chapters, if older houses are refurbished it is expected that they would have lower energy consumption relative to the benchmark. The relatively high consuming older properties are therefore most likely to be in need of insulation measures and should be highlighted to Local Authorities and therefore should not be accounted for in the benchmark.

9.1.2 Locally Specific Results from the Statistical Model

The second section of the interview focused on the results produced by the model. In checking the plausibility of results for their local area, the Home Energy team Leader believed that for the gas consumption figures the model had identified areas of: poor quality housing stock, fuel rich households, and areas of recent new build housing developments. The results for all the urban authorities showed a clear pattern of red LSOAs (indicating gas consumption in excess of the benchmark figures) around the City Centres, where traditionally the oldest and most inefficient properties are to be found, as suggested by anecdotal evidence from the interviewees.

The Home Energy Advice Manager explained '[we] would expect slightly above average figures for the urban centre, made up of older Victorian properties…people are using more gas to keep warm in energy inefficient homes'. The Energy and Climate Change Team Leader stated that the gas model had identified areas of old Victorian houses which are occupied by a mixture of affluent households and university students. Other reasons given for LSOAs with higher than expected gas consumption were explained as 'rail worker cottages, old poor quality housing but the residents are becoming more affluent'. The Fuel Poverty and Affordable Warmth Officer suggested that 'private landlords [who are] not all looking after their properties' and 'single brick stone wall terraces' accounted for the majority of the LSOAs with higher than expected gas consumption in their Authority. The councils were able to give plausible explanations for why LSOAs were highlighted as being higher gas consumers than the benchmark. These examples highlight that: a) councils are aware that older properties are more likely to be energy inefficient, and that b) accounting for the age of the housing stock in the modelling process would reduce the impact these results have in guiding local domestic energy reduction strategies. It is precisely these older houses that provide the greatest opportunity for reducing heating demands and therefore domestic gas consumption. Including house age into the benchmarking process would compensate for the very thing that might usefully identify thermally inefficient houses.

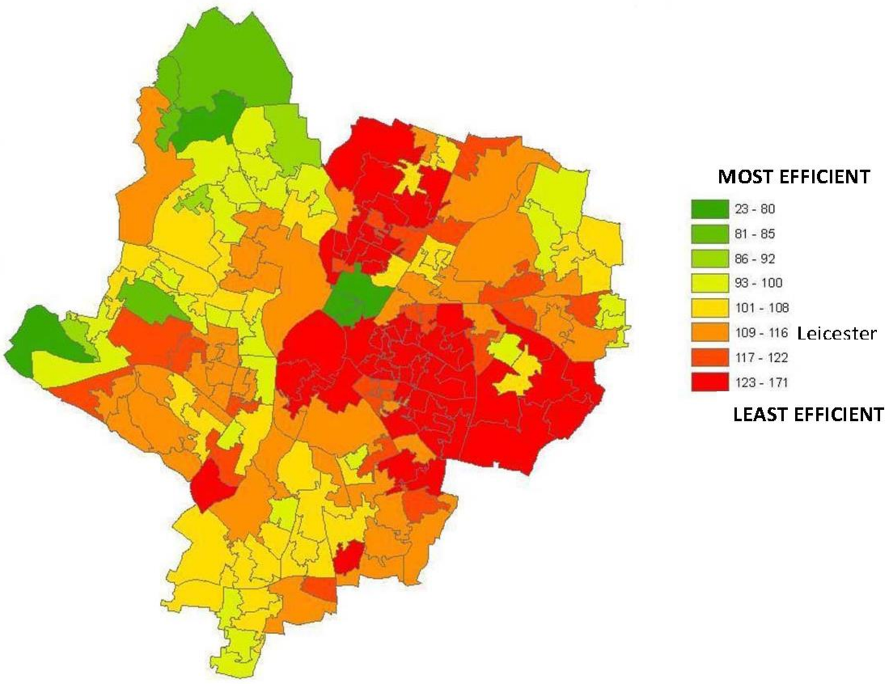
Another important finding from this consultation exercise was that all of the Authorities found the gas results easier to interpret than the electricity results. As the Energy and Climate Change Team Leader explained, 'benchmarking electricity consumption is difficult; there are so many appliances and gadgets'. The reasons offered as to why certain LSOAs had electricity consumption in excess of the benchmark figure were stated with far less conviction than for the gas consumption figures from all of the Local Authorities questioned. The only suggestion stated with any real confidence came from the Fuel Poverty and Affordable Warmth Officer, who hypothesised that LSOAs using far in excess of the benchmark level of electricity could be comprised of households connected to the gas grid but using storage heating. However it was clear that Local Authorities were mainly focused on the figures for gas consumption, whilst electricity consumption was a fleeting interest. This suggests a lack of knowledge about the nature of domestic electricity consumption patterns by Local Authorities and confirms the hypotheses suggested in chapter 2 that domestic electricity consumption is harder to predict on an individual (or even at LSOA level) due to the rise of electrical appliances and consumer goods driven by behaviours and consumer preferences. This reflects the wider political emphasis on space heating demands in housing, with (the growing) electricity consumption often neglected (Leaman *et al* 2012). It is hoped that these benchmarks might provide a new way of looking at the problem, with the consumption indices providing new insights into areas with greater than expected electricity consumption.

9.1.3 Application of Results for Local Authority Energy Policy

The final part of the Local Authority consultation meetings focused on how these gas and electricity consumption indices could be applied to Local Authority domestic energy consumption reduction policy. Figure 9.1 shows an example of the outputs for the City of Leicester. The Home Energy Team Leader felt that the simple colour range made the physical output easy to identify neighbourhoods with exceptionally high levels of domestic energy consumption, and believed that these areas could be investigated further regarding policy options to reduce this consumption level.

These results are experimental and should be used for research purposes only.

GAS	LEICESTER	NATIONAL
AVERAGE	113	100
HIGHEST	139	330
LOWEST	23	7



PRELIMINARY FINDINGS – GAS CONSUMPTION

- Leicester as a Local Authority is less efficient than the national average
- 37 of Leicester's LSOAs (20% of the Authority) are at, or below their benchmarked gas consumption level
- 110 LSOAs (59% of the Local Authority) are 10% or more above the benchmark level
- 32 LSOAs (17% of the Local Authority) is 30% or more above the benchmark level

Figure 9.1 Example of Outputs Distributed to Local Authorities

Of agreement from the Local Authorities was the ability to relate policy interventions to their relevant wards was of particular importance to three of the Local Authorities as this was particularly important for elected councillors. As mentioned in chapter 3, LSOAs were constructed with the intention of providing stable boundaries and fit within Ward boundaries and are the spatial scale at which data is released at. The ability to match LSOAs to Wards through the Neighbourhood Statistics (see ONS 2010a) would enable Local Authorities to justify to elected councillors and residents why work is being carried out in specific wards as councillors are elected to serve residents in wards. Figure 9.2 shows an example of how LSOAs in Leicester relate to the respective ward boundaries.

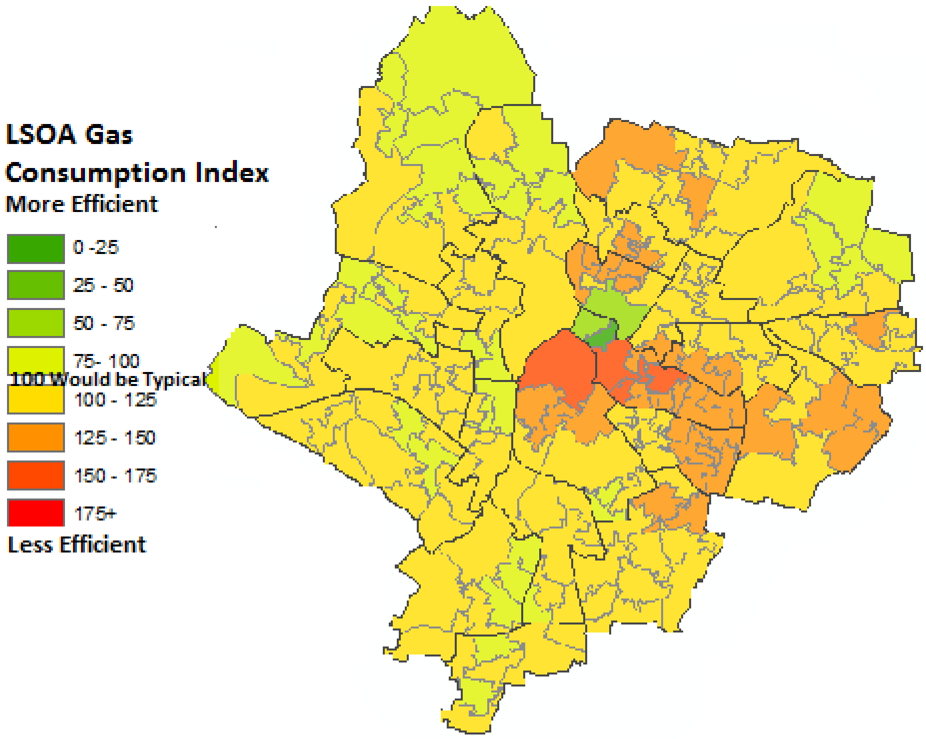


Figure 9.2Example of Leicester LSOA Outputs with Ward Boundaries Overlaid

The Home Energy Team Leader stated that the results 'could grow into significant detail if it can be used to target LSOAs' adding that 'identifying owner-occupiers within these red LSOAs could be vital in promoting the Green Deal to owner-occupiers within these areas'. The Energy and Climate Change Team Leader highlighted that 'with the Green Deal on the horizon, this might help focus attention of areas to target'. This was more explicitly stated by the Fuel Poverty and Affordable Warmth Officer who explained: 'We could use this when targeting wards for decent homes, the free insulation scheme'. The Home Energy Advice Manager hoped for a development of the 'over-time aspect', indicating that LSOAs which fall down the rankings (i.e. their consumption relative to their benchmark increases over time) could be a justification for intervention in those areas. This is an important concept, since whilst the Local Authority representatives recognised their currently 'over consuming' areas are predominately made up of 'old' housing, if their houses are then subject to refurbishment such as solid wall and loft insulation then the energy efficiency performance of these houses would improve and this should lead to a reduction in space heating demands. This is another reason why it is not sensible to identify inefficient housing by house age alone. The numerical nature of the results could also promote evidence-based policy strategies, an example of this is given by the Planning and Sustainability Officer who hoped these results could be used to 'persuade others of the issues'. In this Authority there is a lack of political support for energy efficiency drives and domestic energy reduction policy, and the representative also hoped that the quantitative indicators of poorly performing houses 'gives an impact that cannot be ignored'.

The flexibility of these outputs to identify areas with domestic energy consumption in excess of their benchmarked figure was seen as an advantage over using the current criteria of using income deprivation to identify low income housing for CESP grants. The Home Energy Team Leader explained that Local Authorities 'want to use indices of multiple deprivation for CESP funding but DECC's criteria is based purely on income deprivation', going on to add that the results presented here could be used to target LSOAs but also to 'back up and justify why we are focusing on these areas'. This view is also shared by the Fuel Poverty and Affordable Warmth Officer who explained that 'Councils are trying to work out the Green Deal and this could be a useful tool. We still need to know where to target our resources'. The Home Energy Advice Manager explained that 'councils need to be targeting the right properties but there is a political element and [most in need] areas can be overlooked as other areas have not had any schemes run on them'. It is hoped that this method could be used to justify to councillors why certain areas are in need of interventions for reducing domestic energy demand. Overall, from consultation with Local Authorities the outputs produced have addressed concerns raised in the academic literature (see Fudge *et al* 2012) and from Local Authorities themselves that they do not have the technical capabilities to identify areas for potential carbon reductions, and this method focuses on the improvements Local Authorities can make to the energy performance of the householders and housing stock in their boundaries, identifying LSOAs to promote energy efficient behaviour.

9.2 Plausibility Test 2: Exploring Leicester LSOAs on the Ground

It is recognised that while the encouragement of Local Authority staff is positive, they may be reluctant to criticise the plausibility of locally specific results within their boundaries. In an attempt to gather more evidence, LSOAs in Leicester were explored on foot to obtain a first-hand account of the housing stock. Leicester was deemed to be a suitable choice, being a medium-sized city located within 15 miles of Loughborough University. It also the city used for the EPSRC 4M project which funds this PhD. Five LSOAs were chosen based on the following criteria:

- The highest gas consumption relative to the benchmark
- The highest electricity consumption relative to the benchmark
- The lowest gas consumption relative to the benchmark
- The lowest electricity consumption relative to the benchmark
- Both electricity and gas consumption are closest to the benchmark

The questions posed in this plausibility test were:

- What visual indicators exist to highlight the potential discrepancies between benchmark and actual consumption levels?
- What geographical areas are associated with energy consumption levels in excess of what would be expected?

- Do the models overlook factors which may explain energy consuming behaviours that are immediately obvious from visually examining the area?

Potential visual indicators are listed in Table 9.2.

Table 9.2 Site Visit Assessments

Indicator	Potential Impact
Double Glazing	Absence of measure likely to indicate lack of other energy efficiency measures
Evidence of Conservation Areas	Restrictions on development of housing
Solar Panels, Micro Wind	Less energy consumed from national gas and electricity grid
Estimated Age of House	Older housing likely to have lower insulation levels
High number of cars, lights on, windows open during working hours	Home working, unemployment, students (daytime heating and different than expected heating patterns)
Discrepancies in housing types from 2001 Census and Reality	Underlying data is unreliable

The walk-by surveys were conducted on a Tuesday and Thursday in June 2012 between the hours of 10am and 3pm. Weekdays were chosen over weekends as this was assumed to better reflect 'standard' working practices of the occupants. Information was recorded in a field diary and photographs taken to record physical observations of the area. The selection of the LSOAs immediately highlighted interesting patterns when comparing gas and electricity consumption indices. The LSOA with the lowest electricity consumption relative to benchmark ranks as the 4th highest gas consumption relative to benchmark, whilst the highest electricity consumption relative to benchmark has the 5th lowest gas consumption relative to benchmark. At the national level, the correlation co-efficient between the gas relative to benchmark and electricity consumption relative to benchmark is 0.7, so these were typical. Information on the site visits are shown in Table 9.3, including statistical analysis and geographically mapped in Figure 9.2.

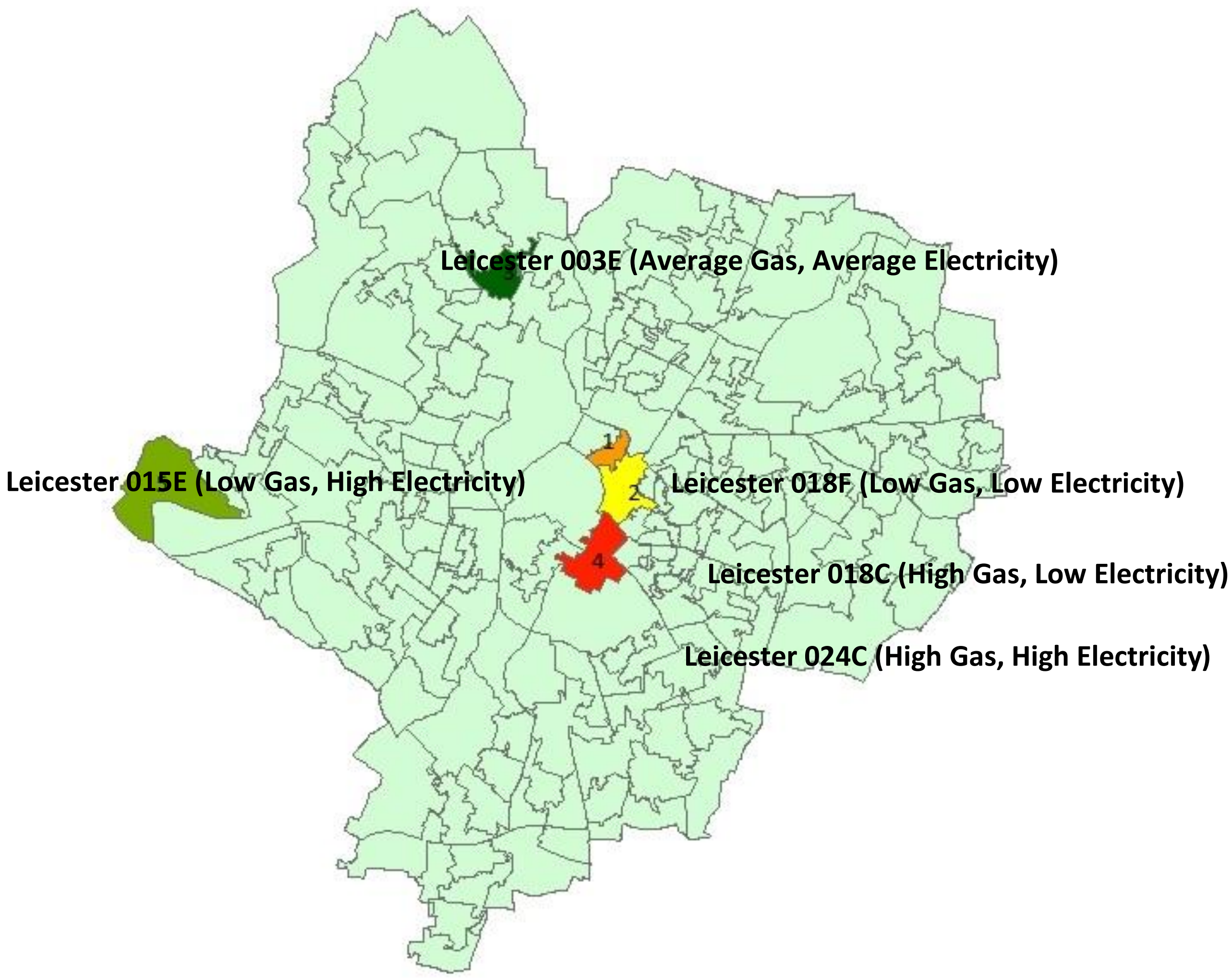


Figure 9.3 Geographical Locations of LSOAs in Leicester for Analysis

Table 9.3 Statistics on LSOAs Visited

Statistic	Site 1: Leicester 018F	Site 2: Leicester 018C	Site 3: Leicester 024C	Site 4: Leicester 015E	Site 5: Leicester 003E
Gas Rating (%)	26 (rank 1)	151 (184)	143 (179)	79 (4)	99 (38)
Electricity Rating (%)	73 (3)	63 (1)	120 (186)	139 (187)	102 (138)
Gas Consumption (kW h per year)	2485	15983	16593	10,584	14,244
Electricity Consumption (kW h per year)	2502	2540	4261	4,971	3,595
Dominant Tenure Type	Social Renting (80%)	Social Renting (78%)	Owner Occupier (32%) Social Renting (23%) Private Renting (42%)	Owner Occupier (53%) Social Renting (41%)	Owner Occupier (41%) Social Renting (52%)
Dominant House Types	Flat (79%)	Terrace (22%) Flat (69%)	Flat (59%) Terrace (31%)	Semi-Detached (69%)	Semi Detached (53%)
Average Number of Rooms	3.86	3.82	4.16	4.79	4.91
Heating Degree Days (1986-2004)	2196	2203	2175	2270	2217
Median Household Income (£ per year)	16832	16775	20184	22016	17880
Ratio of Gas Meters to Electricity Meters	0.69	0.37	0.75	0.91	0.94
Ratio of Gas Meters to Council Tax Houses	0.74	0.39	0.88	0.99	0.98
Ratio of Electricity Meters to Council Tax Houses	1.06	1.06	0.66	0.90	1.04

9.2.1 Summary of Results from Visiting LSOAs

Site 1, which had the lowest gas consumption index was overwhelmingly made-up of 3-4 storey flats and social housing (featuring signs reserved for Leicester City Council vehicles and the St.Matthew's Housing Association services – see Figures 9.4 and 9.5). In contrast, site 2 which had the highest gas consumption index was made up of high-rise flats and terraced houses (see Figure 9.6). It is expected that it is the terraced houses that are connected to the gas grid and therefore driving the high gas consumption index (the statistics indicate 69% of the properties are flats and 63% of the properties do not have a connection to the gas grid). Of note was the lack of solid wall insulation on these houses. What was also observed in this LSOA was the level of human activity, both in terms of pedestrian traffic in a residential area (which was not observed in any of the other LSOAs studied), and the sighting of people entering and leaving homes (therefore likely greater levels of daytime heating), as well as the relatively old age of the housing stock that is likely to account for the relatively high levels of gas consumption in this LSOA.

Figure 9.4 Evidence of Social Housing Apartments in Site 1

Figure 9.5 Dominant Housing Type in Site 1

Figure 9.6 Contrasting Tenure Types in Site 2

Site 2 is what Local Authorities described as a ‘typical city centre LSOA’ and therefore matched what may be expected by the model results (that site 1 has a low gas consumption index while site 2 has one of the highest gas consumption indices in Leicester), which contrasts with site 1 which was an area relatively modern (post 1960) flats dominated by social housing. Both sites had similar electricity consumption indices and there were no indicators from these site visits that would suggest why this would be the case.

Site 3 contained the highest gas and electricity consumption indices. The proximity of this LSOA to the two Universities in Leicester and the relatively high (42%) proportion of privately renting households suggest this is an area of student occupation. Site 3 was an LSOA made up large Victorian houses converted into multiple occupancy housing, and purpose built flats and it is this combination of a likely high student population and pre-1930 housing that indicates plausible high gas consumption indices. As well as from visiting site 4, another area with a high electricity consumption index, there were no visual indicators as to why these two LSOAs had among the highest electricity consumption indices in Leicester.

Figure 9.7 Street Scape of Site 4. Solar Panels Are Visible on the Rooftops of Houses

Site 4 did have a presence of solar panels and its make-up of post-1990 semi-detached houses would indicate that its relatively low gas consumption index is a plausible finding (see Figure 9.7). This is because Site 4 had the most 'modern' housing stock of the five sites visited (and therefore built to stricter building regulations for energy efficiency) and the lowest level of human behaviour (and so likely lowest levels of daytime occupancy). Site 5, which had 'at benchmark' values for both gas and electricity consumption was a mix of owner-occupier and social renting, as well as a mix of house types and ages (though post-war semi-detached were the most common – see Figure 9.8). There was a presence of solar panels on one house and there was little daytime activity. However there were no visual indicators to suggest why this LSOA would have a lower electricity consumption indicator than that of site 4, or above that of sites 1 and 2.

Figure 9.8 Typical Street Scape of Site 5

9.2.2 Evaluating of Walk-By Surveys in Identifying Energy Efficiency

The walk-by surveys allowed an investigation into the general environment of the LSOAs and it was possible to assess the plausibility of the results from the modelling process given the physical characteristics from visiting these areas. Visually it was possible to get an indication of house age and if there were any legislative barriers to renovations of the housing stock (e.g. conservation areas) as well as assessing if there was any up-take of renewables such as solar panels. For the days in which the LSOAs were visited, it was possible to gain an indication of the level of day-time occupancy through visual indicators including the number of cars, lighting, evidence of students, and any evidence of pensioner communities. What was not possible from site visits was to 'fill in the gaps' from the statistical data. It was not possible from visual indicators to determine if houses had already experienced energy efficiency interventions, or judge householders energy consumption attitudes. The small sample size and one-off nature of the visit means it is not possible to determine the extent of day-time occupancy in these LSOAs. Therefore whilst the site visits presented an opportunity to gain an understanding of the 'extreme'

LSOAs in Leicester, it is not a method that can fully assess the true plausibility of the results generated by the statistical study. What these site visits have shown is that while visually inspecting LSOAs at the extremes for the gas and electricity indices in a City can, to a small extent, support the plausibility of the gas consumption indices, there were no visual indicators to determine if the electricity results were plausible.

9.3 Plausibility Test 3: Tenure and Consumption

The next tests of plausibility focus on how the proportion of types of tenure, and the age of housing stock in LSOAs impact on domestic energy consumption relative to the benchmark figures by grouping LSOAs according to the proportion of social, and private renting households. From chapter 7, it was shown that for 2008 the proportion of socially renting houses in a LSOA has a correlation co-efficient of -0.547 with the raw figures for domestic gas consumption, however the correlation between the proportion of social housing in LSOAs and gas consumption relative to the benchmark is -0.074. Tenure types were not included in the model but it is anticipated that social renting householders will have relatively lower median incomes which has been accounted for in the model, Table 9.4 that 93% of LSOAs have a proportion of less than 60% of social renting houses and that 67% of LSOAs have a proportion of social rented housing that is less than 20%. An equivalent analysis of private renting housing was not considered, given that 84% of LSOAs have less than 20% of private rented properties, and 99.8% of LSOAs have less than 60% private rented properties. Given the large variations in sample sizes, and the discrepancy in the standard deviation between the population group (all LSOAs) and the 80-100% group, it was decided running statistical tests to assess this difference would not be appropriate.

Table 9.4 Number of LSOAs in Each Grouping of Social Renting Proportions (2010)

Proportion of Homes in LSOA that are Either Private or Social Rented	Number of LSOAs with stated proportion that are Socially Rented	Number of LSOAs with stated proportion that are Privately Rented
0%-20%	20490	27375
20%-40%	6308	3875
40%-60%	3542	569
60%-80%	1417	61
80%-100%	115	1

Table 9.5 and Table 9.6 present the indices of gas and electricity consumption relative to the benchmark levels averaged across the groupings of LSOAs by proportion of social renting houses. From the Tables it can be seen that the LSOAs with a higher proportion of social renting, above the 80% level, on average, have lower gas consumption relative to the benchmark than the national average of all LSOAs, which would be expected given the advantages and opportunities for efficiency interventions and installations in the social housing stock. However this is not a conclusive finding as it was not possible to assess statistical significance and the large standard deviation and interquartile range suggest that this is not a clear-cut finding. For the electricity consumption figures there was insufficient evidence to suggest the increasing proportion of social housing has any impact on the level of electricity consumption relative to the benchmark figure for LSOAs.

Table 9.5 Descriptive Statistics of the Gas Consumption Index Relative to Benchmark in Sub-Sections of Social Renting Proportions (2010)

Proportion of Social Housing in LSOA	Mean	Median	Standard Deviation	Interquartile Range
All LSOAs	100	100	13	15 (92.7 – 107.5)
0%-20%	101	100	13.75	16 (92-108)
20%-40%	101	100	12	14 (93-107)
40%-60%	99	99	12	13 (92.5 -105.5)
60%-80%	96	97	14	15 (88.5 – 103.5)
80%-100%	84	90	24	26 (78-102)

Table 9.6 Descriptive Statistics of the Electricity Consumption Index Relative to Benchmark in Sub-Sections of Social Renting LSOA Proportion Groupings (2010)

Proportion of Social Housing in LSOA	Mean	Median	Standard Deviation	Interquartile Range
All LSOAs	100	100	11	12 (106 – 94)
0%-20%	100	99	10	11 (93.5-104.5)
20%-40%	101	101	10	13 (94.5 – 107.5)
40%-60%	102	102	12	14 (95 – 109)
60%-80%	100	99	14	17 (91.5-108.5)
80%-100%	94	93	17	20 (83-103)

9.4 Plausibility Test 4: Exploring Lower than Expected Consumption

Further exploration into the plausibility of the results generated by the model focused on analysis of the gas consumption indices in LSOAs in Milton Keynes. Milton Keynes has been identified as an area of 'known' relatively energy efficient housing due to its relatively recent and rapid development in the second half of the 20th Century. Milton Keynes serves as a case study for energy efficiency of housing by Summerfield *et al* (2010b) when testing income effects. Milton Keynes offers a unique opportunity for study as it is almost exclusively comprised of post-1960 housing, which is expected to be more thermally efficient due to progressively stricter building regulations (Milton Keynes Borough Council 2011, DECC 2012a).

The Local Authority (Milton Keynes Borough Council 2011:2) states that ‘Milton Keynes has grown from a collection of small towns and villages into a significant sub-regional centre in less than 40 years’ and it is this relative ‘newness’ of the housing stock that makes it an ideal area to serve as a test area. DECC (2012a) state that it is only since 1985 that energy efficiency requirements were explicitly stated in the building regulations, minimum standards for cavity wall and loft insulation were first included in the 1966 English Building Regulations (Dowson *et al* 2012). Milton Keynes therefore should have a greater proportion of LSOAs with gas consumption less than its benchmarked level compared to other similar sized Authorities. The Borough has a lower proportion of pre-1945 (and particularly pre-1919) housing which are associated with the lowest levels of thermal efficiency (DECC 2010a, 2012, Dowson *et al* 2012) and has been a site of various domestic energy efficiency projects since 1980 (Milton Keynes Borough Council 2011).

Table 9.7 Local Authority LSOAs exceeding 100 for Gas Consumption efficiency ratings (2010)

LA NAME	Former Government Office Region	Number of LSOAs	Number of LSOAs with Gas Rating >100	Percentage of LSOAs with Gas Rating > 100
Milton Keynes	South East	139	15	11%
Bath and North East Somerset	South West	113	30	27%
Solihull	West Midlands	133	48	36%
Derby	East Midlands	147	59	40%
Camden	London	133	57	43%
York	Yorkshire and the Humber	118	57	48%
Salford	North West	144	81	56%
North Tyneside	North East	129	82	64%
Luton	East	121	87	72%

From Table 9.7, comparing Milton Keynes with similar sized Authorities (chosen as the Local Authority in each Government Office Region with the closest number of LSOAs as Milton Keynes) from across the 10 former Government Office Regions in England shows that Milton Keynes has a much lower proportion of LSOAs (11%) with gas consumption exceeding their benchmark figures than the representative urban areas from the other 10 regions. This is an important finding, and demonstrates plausibility in the results of the model given that Milton Keynes, with a significant proportion of post-1960 (and therefore higher potential energy efficiency in the physical housing stock) has a smaller number of LSOAs with higher domestic gas consumption than would be expected. The gas consumption indices for the Milton Keynes Local Authority are shown in Figure 9.9.

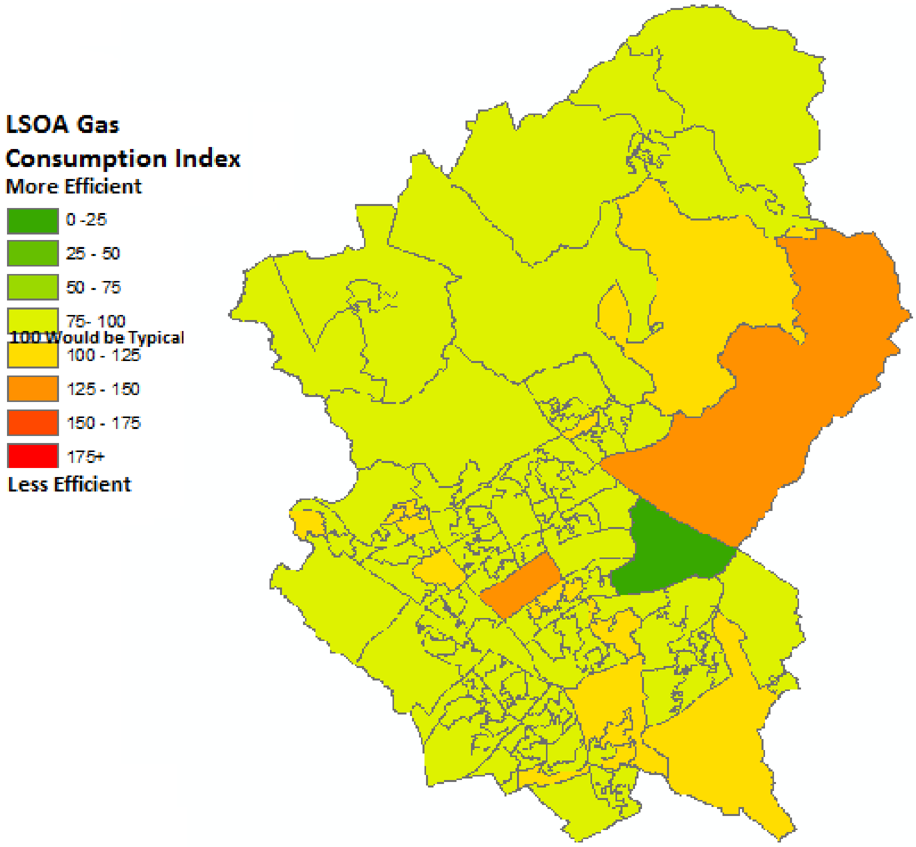


Figure 9.9 Gas Consumption Indices for Milton Keynes LSOAs (2010)

9.5 Plausibility Test 5: Exploring Local Authorities' Performance

This section presents a demonstration of how Central Government can monitor and measure the performance of Local Authorities in reducing their domestic energy demands. The method of measuring Local Authority energy performance is to measure the proportion of LSOAs in Local Authorities with higher than expected gas and electricity consumption. This measure was chosen over taking averages as it measures the areas within the Local Authority boundaries in need of intervention rather than an average 'consumption relative to benchmark' rating for Local Authorities. This is the same indicator as used in the Milton Keynes study. This section then identifies reasons for why these patterns of Local Authorities with a large proportion of LSOAs with higher than expected domestic energy consumption occurs.

9.5.1 Analysis of New and Expanded Towns

To explore how the proportion of LSOAs with levels of domestic gas and electricity consumption in excess of their benchmark figures differs between Local Authorities, an analysis of the differences between Local Authorities that contain new and expanded towns, and those that do not was carried out. New Towns were centrally planned housing development projects in England between 1945 and 1970 largely to rehouse displaced populations following damage to London during the Second World War (Fothergill *et al* 1983, DCLG 2006c). Expanded Towns followed a similar pattern but were developed in partnership with Local Authorities (Fothergill *et al* 1983). Table 9.8 lists the New Town Local Authorities, and Expanded Town Local Authorities are listed in Table 9.9. It is anticipated that, like Milton Keynes, the New and Expanded Town Local Authorities will have a lower proportion of LSOAs with gas consumption in excess of the benchmark figures than the 'pre-existing' Local Authorities.

Table 9.8 List of ‘New Town’ Local Authorities (Source: DCLG 2006c)

Description	**Local Authority Name**	**Town(s)**
New Towns 1946-1960	Basildon	Basildon
	Bracknell Forest	Bracknell
	Corby	Corby
	Crawley	Crawley
	Harlow	Harlow
	Dacorum	Hemel Hempstead
	Sedgefield	Newton Aycliffe
	Easington	Peterlee
	Stevenage	Stevenage
	Welwyn Hatfield	Welwyn Garden City
New Towns 1961-64	Telford and Wrekin	Telford
	Redditch	Redditch
	Halton	Runcorn
	West Lancashire	Skelmersdale
	Sunderland	Washington
New Towns 1967-70	Central Lancashire	Preston
	Milton Keynes	Milton Keynes
	Northampton	Northampton
	Peterborough	Peterborough
	Warrington	Warrington

Table 9.9 List of 'Expanded Towns' Local Authorities (Sources: Hansard 1973, Fothergill *et al* 1983)

Description	**Local Authority Name**	**Town(s)**
Expanded Towns 1960 - 1980	Ashford	Ashford
	Aylesbury Vale	Aylesbury
	Babergh	Long Welford, Sudbury
	Basingstoke and Deane	Basingstoke
	Blyth Valley	Cramlington
	Braintree	Braintree, Witham
	Breckland	Thetford
	Burnley	Burnley
	Cannock Chase	Rugeley
	Central Bedfordshire	Houghton Regis, Sandy
	Cherwell	Banbury
	Daventry	Daventry
	Halton	Widnes
	Hastings	Hastings
	Huntingdonshire	Huntingdon, St Neots
	King's Lynn and West Norfolk	King's Lynn
	Macclesfield	Macclesfield
	Milton Keynes	Bletchley
	North Cornwall	Bodmin
	North Hertfordshire	Letchworth
	North Somerset	Weston-Super-Mare
	North Tyneside	Killington
	Plymouth	Plymouth
	Rushmoor	Farnborough
	South Kesteven	Grantham
	St Edmunsbury	Haverhill
	Swindon	Swindon
	Tamworth	Tamworth
	Test Valley	Andover
	Vale Royal	Winsford
	Walsall	Brownhills
	Wellingborough	Wellingborough
	West Lindsey	Gainsborough
	Wychavon	Droitwich

Table 9.10 presents the descriptive statistics for the gas consumption figure. Figure 9.10 orders Local Authorities by the proportion of LSOAs in the Local Authority with a gas consumption index of greater than 100, highlighting the 'New Town' Local Authorities in red.

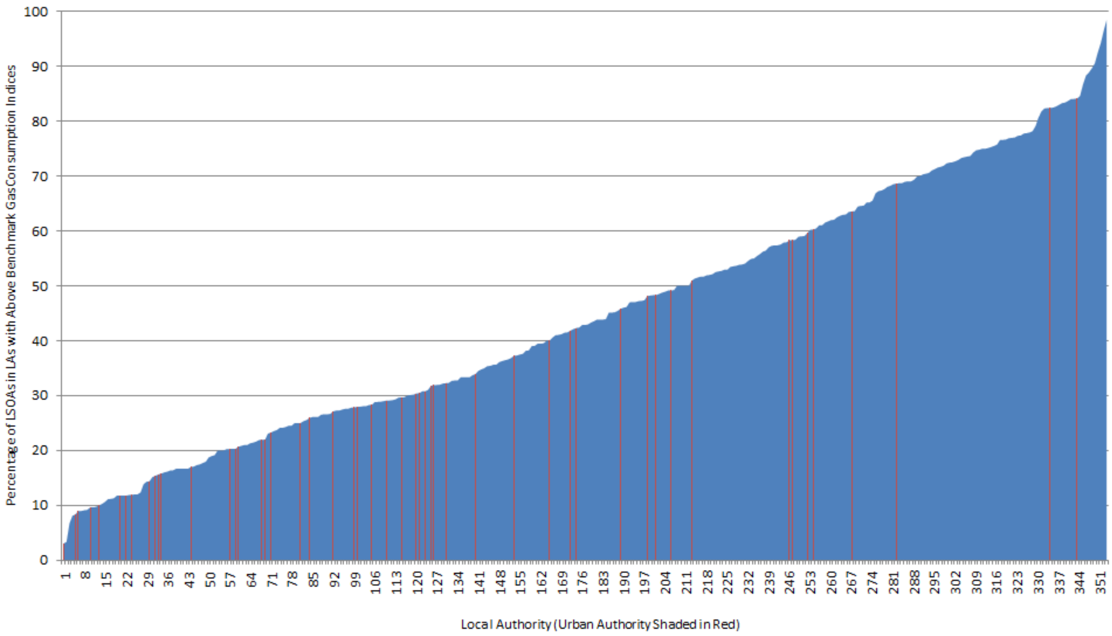


Figure 9.10 Local Authorities Ranked by Above Benchmark Gas Consumption Indices (New Towns Highlighted)

The corresponding distributions of gas consumption 'above benchmark' LSOAs for 'pre-existing town' and 'New/Expanded' Local Authorities are shown in Figures 9.11 and 9.12 respectively. The statistics indicate that on average Local Authorities that do not contain new towns have, a greater proportion of LSOAs with gas consumption in excess of their benchmark compared with those LSOAs containing new towns, and have a greater variability (as indicated by the higher standard deviation and wider interquartile range) in these proportions of higher than expected consuming LSOAs. A t-test shows that there is a statistically significant difference between the mean values of these two groups of Local Authorities at the 0.05 level (t_{352}=4.74, p<0.001). This confirms expectations that Local Authorities containing relatively recent (e.g. post 1945) housing developments would have relatively more thermally efficient housing stock, and therefore have a lower proportion of LSOAs of high gas consumption relative to the benchmark level.

Table 9.10 Comparing Proportion of LSOAs with Higher than Expected Gas Consumption in New/Expanded Towns and Pre-Existing Settlements

	Number of Local Authorities	**Mean Proportion of LSOAs where CI>100**	**Median Proportion of LSOAs where CI>100**	**Standard Deviation**	**Interquartile Range**
Pre-Existing	302	46.81%	46.09%	22.63%	39% (26.5-65.5)%
New/Expanded	51	32.61%	29.11%	19.26%	29% (14.6-43.6)%

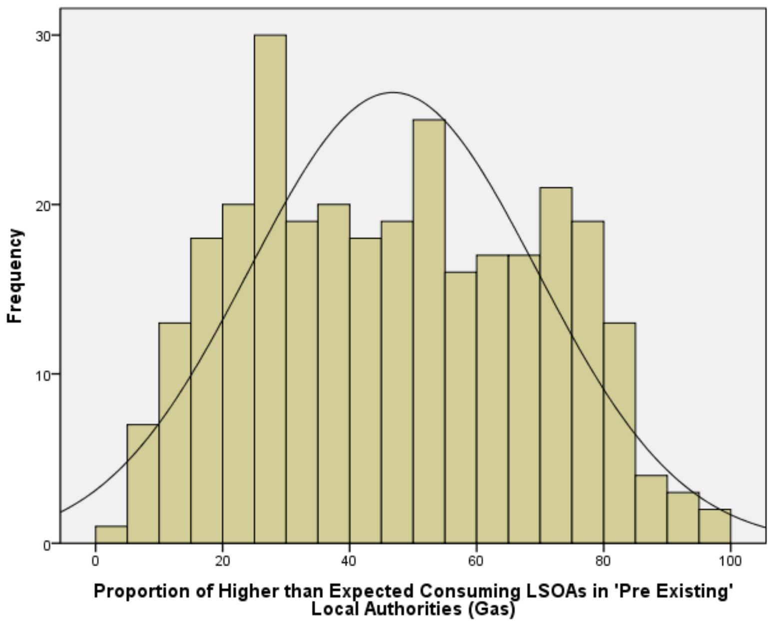


Figure 9.11 Histogram of Proportion of LSOAs with Higher than Expected Gas Consumption in 'Pre Existing' Local Authorities

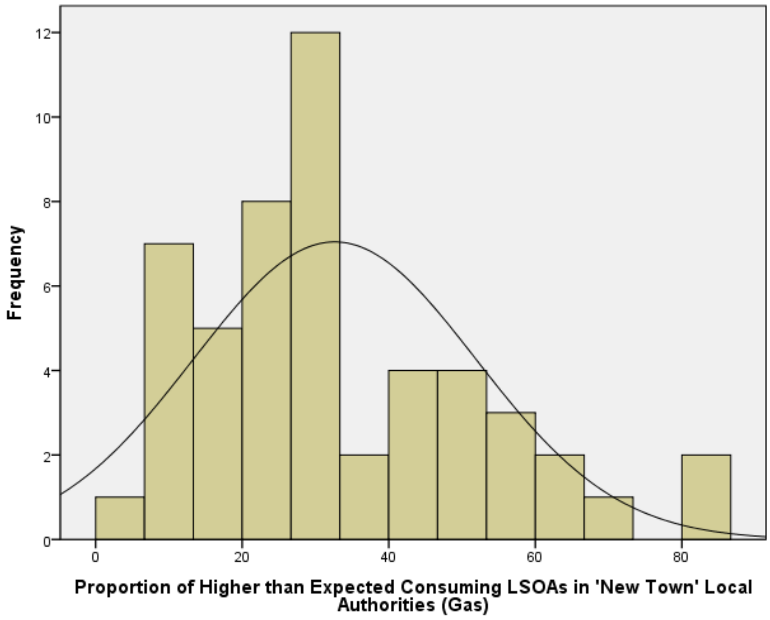


Figure 9.12 Distribution of LSOAs by Proportion of Higher than Expected Gas Consumption in 'New Town' Local Authorities

Table 9.11 displays the corresponding statistics for the proportion of LSOAs with electricity consumption in excess of the benchmark between the 'Pre-Existing' and 'New/Expanded' Local Authorities. Figure 9.13 orders Local Authorities by the proportion of LSOAs in the Local Authority with an electricity consumption index of greater than 100, highlighting the 'New Town' Local Authorities in red.

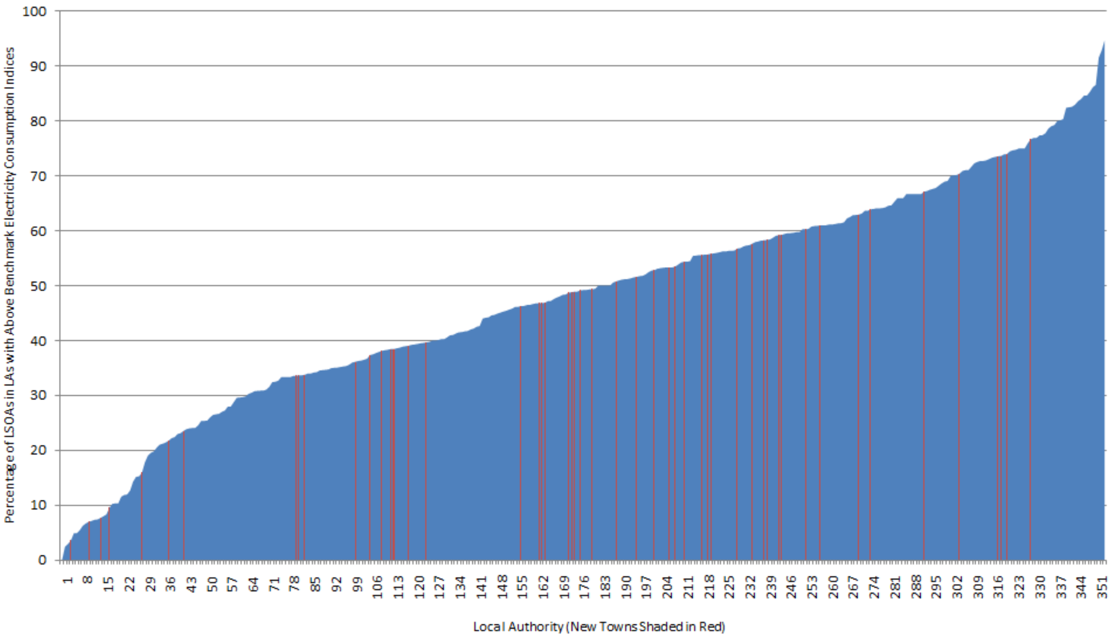


Figure 9.13 Local Authorities Ranked by Above Benchmark Electricity Consumption Indices (New Towns Highlighted)

The corresponding distributions are shown in Figures 9.14 and 9.15 for New Town and Pre-Existing Local Authorities. Unlike with the gas figures, there is a much smaller difference (1 percentage point) between the means in the proportion of LSOAs with greater electricity consumption than expected between the two groups of Local Authorities. As expected, the t-test does not show that this is statistically significant (t_{352}=0.349, p=0.73). The 'Pre-Existing' category has a larger standard deviation and interquartile range but this is to be expected given the larger number of Local Authorities in this category.

Table 9.11 Comparing Proportion of LSOAS with Higher than Expected Electricity Consumption in New/Expanded Towns and Pre-Existing Settlements

	Number of Local Authorities	**Mean Proportion of LSOAs where CI>100**	**Median Proportion of LSOAs where CI>100**	**Standard Deviation**	**Interquartile Range**
Pre-Existing	302	48.13%	49.07%	20.37%	29% (35.5-64.5)%
New/Expanded	51	47.17%	49.37%	17.77%	20% (39-59)%

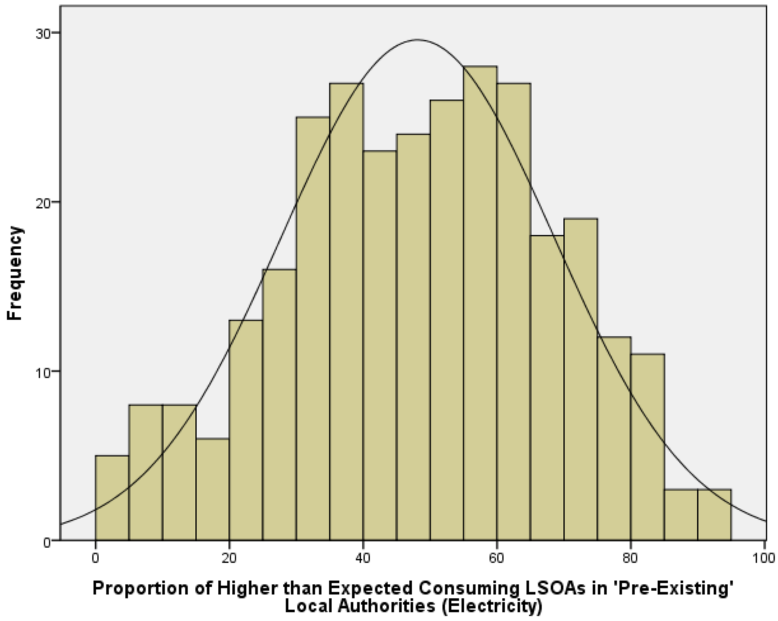


Figure 9.14 Proportion of LSOAs with Higher than Expected Electricity Consumption in ‘Pre-Existing’ Local Authorities

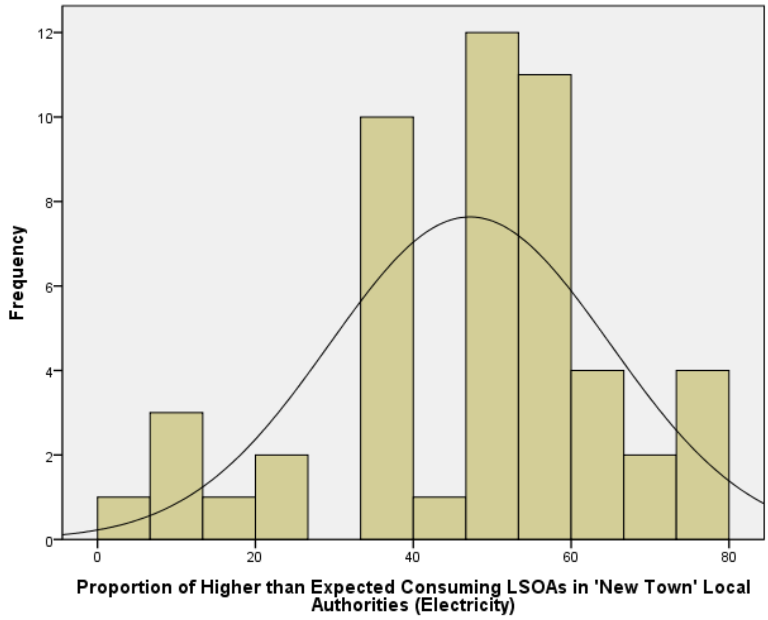


Figure 9.15 Proportion of LSOAs with Higher than Expected Electricity Consumption in 'New and Expanded Town' Local Authorities

From these statistics, it is shown that the 'New Town' Local Authorities (which contain new or expanded towns) do have a lower proportion of LSOAs with gas consumption that is higher than would be expected. What these findings raise is that the model's results are plausible, and suggest that house age is currently a reasonable indicator of potential energy efficiency of the housing stock.

9.5.2 Analysing the Rural-Urban Divide

DEFRA (2009) provide a guide to rural-urban classification in England based on population and housing densities across the Local Authority area (see Table 9.12). There is a general classification splitting Local Authorities between rural and urban classifications, and then a further split into six sub-categories (three each between the rural and urban classifications). These classifications are set out in Table 9.12. On the one hand, academic literature in chapter 2 suggests that densely populated areas (predominantly urban) benefit from heat sharing (particularly in apartment blocks), and potential urban heat island affects, but also contain higher quantities of thermally inefficient industrial era terraced housing. The 2009 DEFRA report suggests that on every indicator, from health to education, urban areas show a much wider variance in their scores, but on average have worse scores than rural authorities. This work tests to see if these relationships are relevant when evaluating domestic energy consumption. Tables 9.13 and 9.14 show the rankings of Local Authorities based on the proportion of LSOAs within their boundaries with higher than benchmarked gas consumption. Figure 9.16 ranks Local Authorities by this proportion for gas, and Figure 9.19 for the corresponding electricity rankings. The urban authorities are highlighted in red. Tables 9.15 and 9.16 show the corresponding rankings for electricity consumption. Additional information highlights if these Authorities are classified as either rural or urban and if the Authority contained a New or Expanded Town. These results are mapped for the UK in Figure 9.17, with Figure 9.18 showing the London Boroughs for gas consumption, and in Figures 9.20 and 9.21 for electricity.

Table 9.12 Rural-Urban Classification of English Local Authorities (Source: DEFRA 2009)

Broad Classification	Sub-Classification	Criteria	Number of Local Authorities (pre 2009 boundaries)
Urban	Major Urban	Local Authorities with either a minimum of 100,000 people or a minimum of 50% of their total population resident within a major urban area (i.e. an urban area with at least 750,000 population)	76
	Large Urban	Local Authorities with either a minimum of 50,000 people or a minimum of 50% of their total population within a large urban area (i.e an urban area with between 250,000 and 750,000 population)	45
	Other Urban	Local Authorities that have less than 26% of their population living in rural settlements (including larger market towns - regarded for this exercise as urban areas with between 10,000 and 30,000 population) and do not have a substantial quantity or proportion of their population living in major or large urban areas	55
Rural	Significant Rural	Local Authorities with more than 26% but less than 50% of their population in rural settlements and larger market towns	53
	Rural 50	Local Authorities with at least 50% but less than 80% of their population in rural settlements (including larger market towns)	52
	Rural 80	Local Authorities that have at least 80% of their population resident in rural settlements (including larger market towns)	72

Table 9.13 Top 10% Ranked Local Authorities for Proportion of LSOAs with Higher than Expected Gas Consumption

Local Authority Name	Government Office Region	Proportion of Inefficient Gas LSOAs	New/Expanded Town	Rural/Urban Classification
Basingstoke and Deane	South East	3.03%	Yes	Rural
Bridgnorth	West Midlands	3.33%	No	Rural
Salisbury	South West	6.67%	No	Rural
Fareham	South East	8.11%	No	Urban
Telford and Wrekin	West Midlands	8.33%	Yes	Urban
Mid Bedfordshire	East of England	8.97%	Yes	Rural
North Wiltshire	South West	8.97%	No	Rural
Redditch	West Midlands	9.09%	No	Urban
Westminster	London	9.17%	No	Urban
Gosport	South East	9.62%	No	Urban
Stevenage	East of England	9.62%	Yes	Urban
Kensington and Chelsea	London	9.71%	No	Urban
Plymouth	South West	10%	Yes	Urban
Weymouth and Portland	South West	10.26%	No	Urban
Tewkesbury	South West	10.64%	No	Rural
South Northamptonshire	East Midlands	11.11%	No	Rural
South Gloucestershire	South West	11.18%	No	Urban
West Oxfordshire	South East	11.29%	No	Rural
Cherwell	South East	11.76%	Yes	Rural
Stratford-on-Avon	West Midlands	11.76%	No	Rural
Mid Suffolk	East of England	11.76%	No	Rural
Swindon	South West	11.76%	Yes	Urban
Shrewsbury and Atcham	West Midlands	11.86%	No	Rural
Huntingdonshire	East of England	11.88%	Yes	Rural
Barrow-in-Furness	North West	12%	No	Urban
Vale of White Horse	South East	12%	No	Rural
South Cambridgeshire	East of England	12.35%	No	Rural
Taunton Deane	South West	13.85%	No	Rural
Eastleigh	South East	14.29%	No	Urban
Milton Keynes	South East	14.39%	Yes	Urban
North Dorset	South West	15.15%	No	Rural
Crawley	South East	15.38%	Yes	Urban
Test Valley	South East	15.63%	Yes	Rural
Wychavon	West Midlands	15.79%	Yes	Rural
Torridge	South West	16%	No	Rural

Table 9.14 Bottom 10% Ranked Local Authorities for Proportion of LSOAs with Higher than Expected Consumption

Local Authority Name	**Government Office Region**	**Proportion of Inefficient Gas LSOAs**	**New/Expanded Town**	**Rural/Urban Classification**
Harrow	London	98.54%	No	Urban
Castle Point	East of England	96.49%	No	Urban
Brent	London	94.25%	No	Urban
Southend-on-Sea	East of England	92.52%	No	Urban
Redbridge	London	90.57%	No	Urban
Waltham Forest	London	89.66%	No	Urban
Haringey	London	88.89%	No	Urban
Spelthorne	South East	88.33%	No	Urban
Barnet	London	86.67%	No	Urban
Runnymede	South East	84.62%	No	Urban
Easington	North East	84.13%	Yes	Rural
Epsom and Ewell	South East	84.09%	No	Urban
Trafford	North West	84.06%	No	Urban
Lewisham	London	83.73%	No	Urban
Enfield	London	83.43%	No	Urban
Mole Valley	South East	83.33%	No	Urban
Newham	London	83.02%	No	Urban
Croydon	London	82.73%	No	Urban
South Bucks	South East	82.5%	No	Rural
Sunderland	North East	82.45%	No	Urban
Bradford	Yorkshire and the Humber	82.41%	No	Urban
Leicester	East Midlands	82.35%	No	Urban
Mansfield	East Midlands	81.82%	No	Urban
Rother	South East	80.7%	No	Rural
Hillingdon	London	79.14%	No	Urban
Slough	South East	78.21%	No	Urban
Allerdale	North West	77.97%	No	Rural
Havering	London	77.85%	No	Urban
Brentwood	East of England	77.78%	No	Rural
Bexley	London	77.4%	No	Urban
Stockport	North West	77.37%	No	Urban
Barking and Dagenham	London	77.06%	No	Urban
Gateshead	North East	76.98%	No	Urban
Epping Forest	East of England	76.92%	No	Urban
Tendring	East of England	76.67%	No	Rural

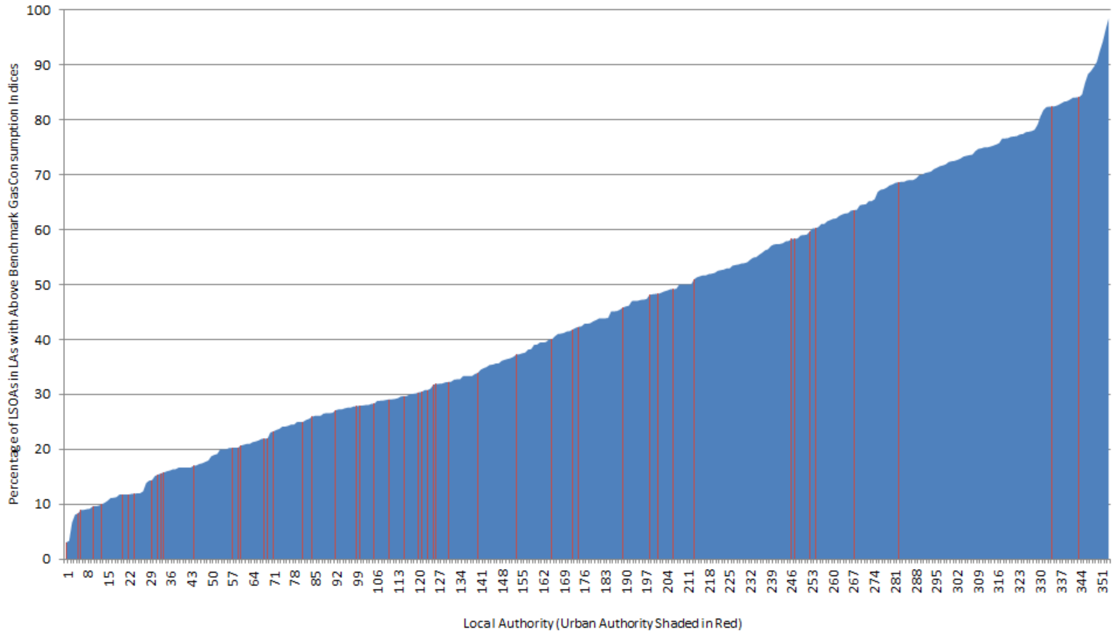


Figure 9.16 Local Authorities Ranked by Above Benchmark Gas Consumption Indices (Urban Authorities Highlighted)

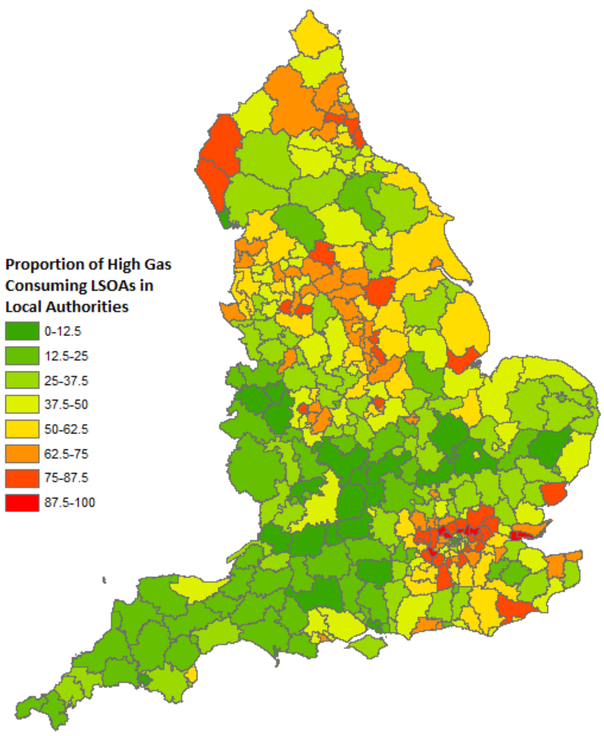


Figure 9.17 Geographical Distribution of Proportions of LSOAs with Higher than Expected Gas Consumption in English Local Authorities

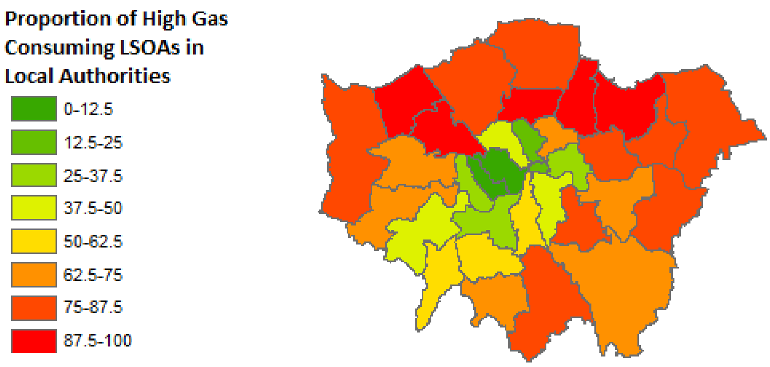


Figure 9.18 Geographical Distribution of Proportions of LSOAs with Higher than Expected Gas Consumption in London Local Authorities

Table 9.15 Top 10% Ranked Local Authorities for Proportion of LSOAs with Higher than Expected Electricity Consumption

Local Authority Name	**Government Office Region**	**Proportion of Higher than Expected Electricity Consuming LSOAs**	**New/Expanded Town**	**Rural/Urban Classification**
Alnwick	North East	0%	No	Rural
Wansbeck	North East	2.44%	No	Rural
Chester-le-Street	North East	2.94%	No	Urban
Sedgefield	North East	3.57%	Yes	Rural
Wear Valley	North East	4.88%	No	Rural
South Tyneside	North East	4.9%	No	Urban
Derwentside	North East	5.45%	No	Rural
Bolsover	East Midlands	6.25%	No	Rural
Tynedale	North East	6.67%	No	Rural
North Tyneside	North East	6.98%	Yes	Urban
Teesdale	North East	7.14%	No	Rural
Chesterfield	East Midlands	7.35%	No	Urban
Durham	North East	7.41%	No	Rural
Blyth Valley	North East	7.69%	No	Rural
Richmondshire	Yorkshire…	8%	No	Rural
Hambleton	Yorkshire…	8.33%	No	Rural
Easington	North East	9.52%	Yes	Rural
Stockton-on-Tees	North East	10.26%	No	Urban
Hartlepool	North East	10.34%	No	Urban
Ryedale	Yorkshire…	10.34%	No	Rural
Barnsley	Yorkshire…	11.56%	No	Rural
Islington	London	11.86%	No	Urban
Redcar and Cleveland	North East	11.96%	No	Urban
Darlington	North East	12.7%	No	Urban
Gateshead	North East	14.29%	No	Urban
Norwich	East of England	15.19%	No	Urban
Lambeth	London	15.25%	No	Urban
Sunderland	North East	15.96%	No	Urban
Wandsworth	London	17.82%	No	Urban
North East Derbyshire	East Midlands	19.05%	No	Rural
Camden	London	19.55%	No	Urban
Hammersmith and Fulham	London	19.82%	No	Urban
Weymouth and Portland	North West	20.51%	No	Urban
North Kesteven	East Midlands	21.05%	No	Rural
Castle Morpeth	North East	21.21%	No	Rural

Table 9.16 Bottom 10% Ranked Local Authorities for Proportion of LSOAs with Higher than Expected Electricity Consumption

Local Authority Name	Government Office Region	Proportion of Inefficient Gas LSOAs	Rural/Urban Classification
Castle Point	East of England	94.74%	urban
Adur	South East	92.86%	urban
Thurrock	East of England	91.58%	urban
Havering	London	86.58%	urban
Blackpool	North West	86.17%	urban
Barking and Dagenham	London	85.32%	urban
Epping Forest	East of England	84.62%	urban
Fenland	East of England	84.62%	rural
Tandridge	South East	84.00%	rural
Woking	South East	83.61%	urban
Rochford	East of England	82.98	urban
Wyre	North West	82.61	urban
South Bucks	South East	82.5	rural
Sevenoaks	South East	82.43	rural
Broxbourne	East of England	80.36	urban
Bexley	London	80.14	urban
Spelthorne	South East	80	urban
Swale	South East	79.27	rural
Reigate and Banstead	South East	79.07	urban
Newham	London	78.62	urban
Restormel	South West	77.78	rural
Hertsmere	East of England	77.42	rural
Guildford	South East	77.38	rural
Runnymede	South East	76.92	urban
Great Yarmouth	East of England	76.92	rural
Cannock Chase	West Midlands	76.67	rural
Mole Valley	South East	75.93	urban
Rossendale	North West	75	urban
Wycombe	South East	75	rural
Kennet	South West	75	rural
Southend-on-Sea	East of England	74.77	urban
Wolverhampton	West Midlands	74.68	urban
Arun	South East	74.47	urban
Tamworth	West Midlands	74	urban
Stroud	South West	73.91	rural

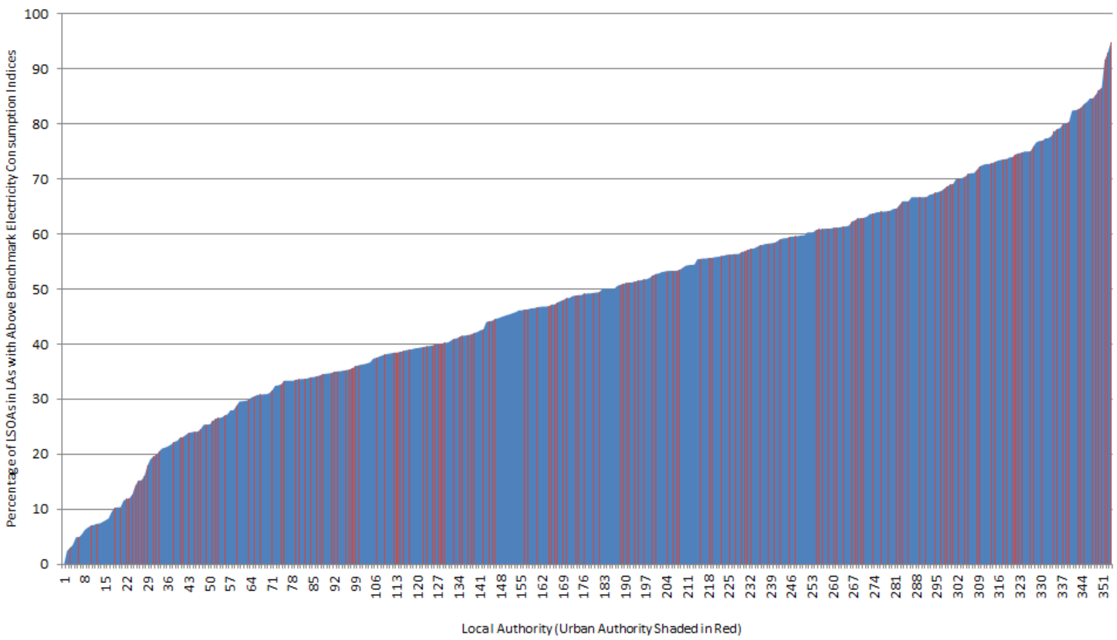


Figure 9.19 Local Authorities Ranked by Above Benchmark Electricity Consumption Indices (Urban Authorities Highlighted)

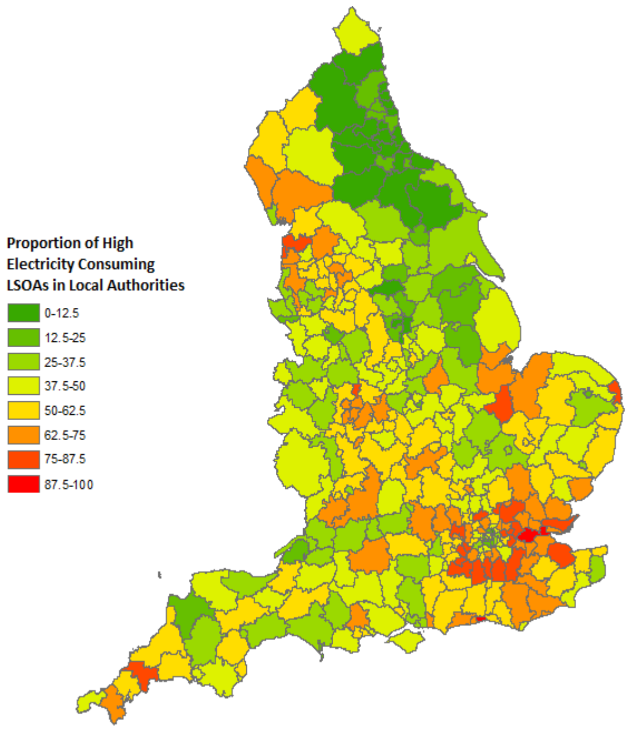


Figure 9.20 Geographical Distribution of Proportions of LSOAs with Higher than Expected Electricity Consumption in English Local Authorities

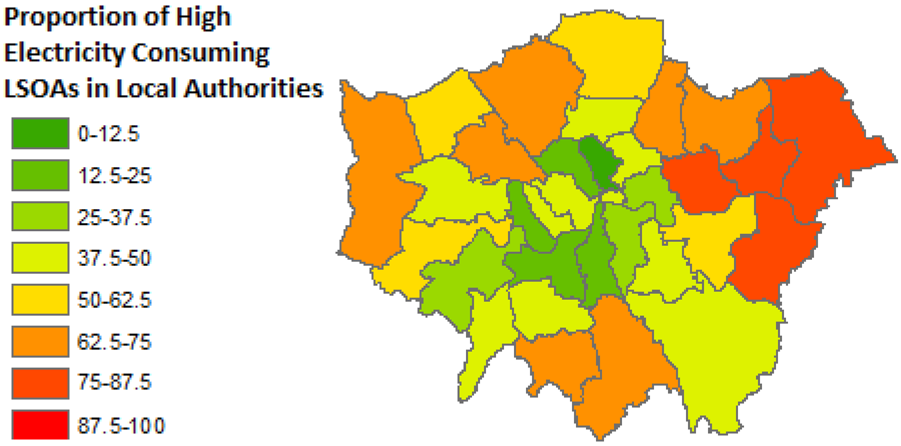


Figure 9.21 Geographical Distribution of Proportions of LSOAs with Higher than Expected Electricity Consumption in London Local Authorities

From Tables 9.13 and 9.14 it appears that there are a higher proportion of urban areas in the bottom 10% of the rankings (i.e. the Local Authorities with the greatest proportion of LSOAs with gas consumption in excess of the benchmarked figure). The urban areas that are in the top 10% are mostly those which experienced rapid post-war development as part of the New Towns movement. These results make intuitive sense as those Local Authorities in Urban Areas largely developed before 1945 are likely to be made up of older, less thermally efficient housing stock than those which experienced large scale housing development in the 1960s. This is explored in more detail below. Table 9.17 lists the descriptive statistics for the LSOAs with gas consumption in excess of the benchmark. The distributions are shown in Figures 9.22 and 9.23. The corresponding figures for electricity consumption are shown in Table 9.18 and Figures 9.25 and 9.26.

Table 9.17 Descriptive Statistics of the Proportion of LSOAs in Local Authorities with Gas Consumption in Excess of the Benchmark Figure

	Number of Local Authorities	**Mean Proportion of LSOAs where CI>100**	**Median Proportion of LSOAs where CI>100**	**Standard Deviation**	**Interquartile Range**
Rural	177	37%	33%	19%	28 (19-47)
Urban	176	52%	54%	24%	39 (36-75)

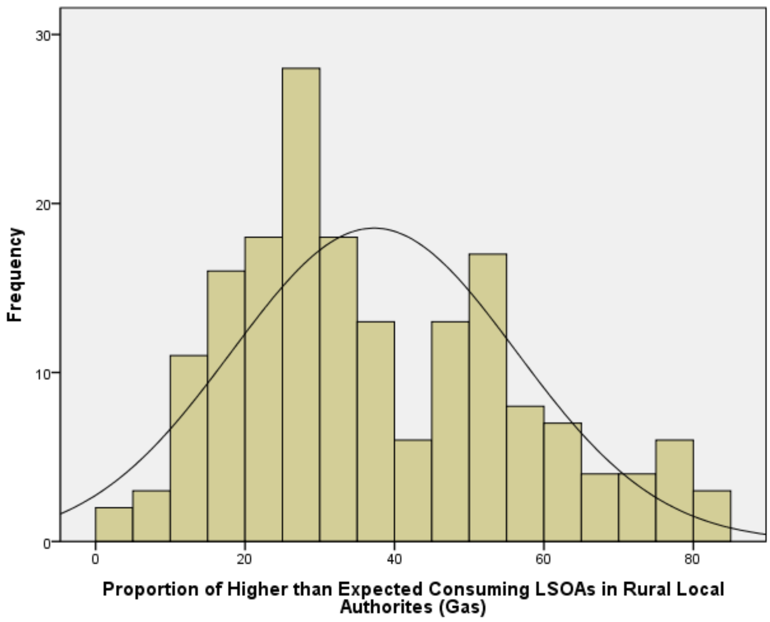


Figure 9.22 Proportion of LSOAs with Higher than Expected Gas Consumption in Rural Local Authorities

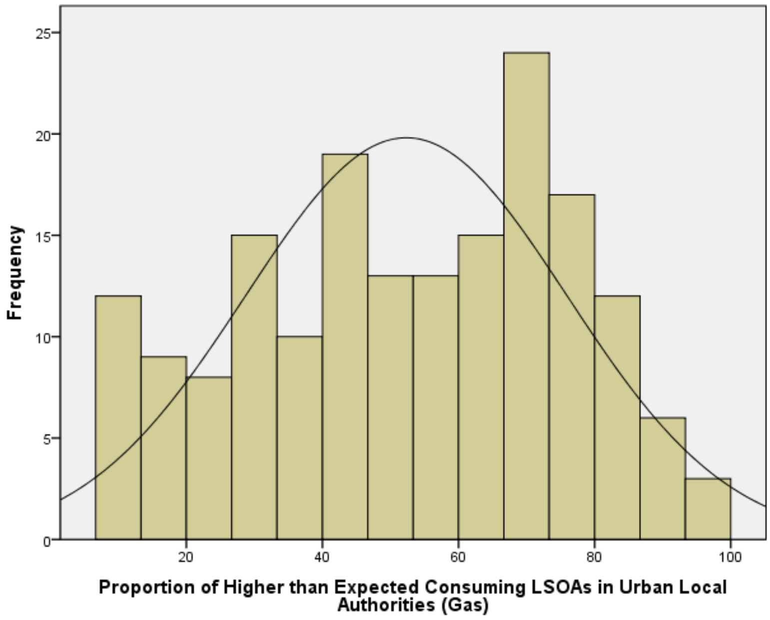


Figure 9.23 Proportion of LSOAs with Higher than Expected Gas Consumption in Rural Local Authorities

The descriptive statistics in Table 9.17 show that Urban Authorities, on average, have a greater proportion of LSOAs with higher than expected domestic gas consumption and that the standard deviation of this distribution is also greater. This corresponds with the theories identified in the ONS rural/urban report, which suggests that urban Local Authorities experience greater variability in a range of indicators, and on average perform worse than rural counterparts (ONS 2011b). From the results of the t-test, it can be seen that the difference in the means between these indicators for high gas consuming LSOAs are statistically significant (t_{335}=-6.595, $p<0.001$). The boxplots visually highlighting the differences between these samples is shown in Figure 9.24.

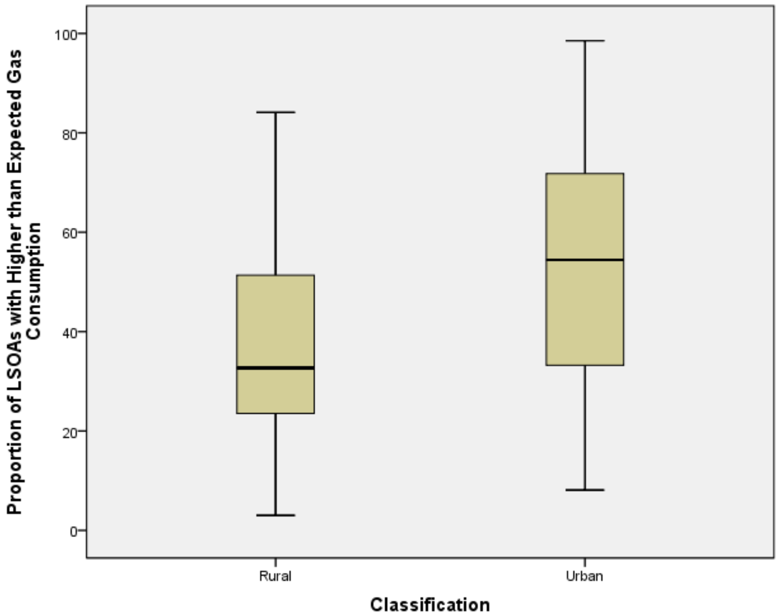


Figure 9.24 Boxplot Showing Differences in Means and Spread of Proportion of LSOAs with Higher than Expected Gas Consumption in Rural and Urban Areas

Table 9.18 Proportion of LSOAS with Higher than Expected Electricity Consumption in Local Authorities by Rural-Urban Divide

	Number of Local Authorities	Mean Proportion of LSOAs where CI>100	Median Proportion of LSOAs where CI>100	Standard Deviation	Interquartile Range
Rural	177	46.72%	48.94%	19.42%	26 (36-62)
Urban	176	49.27%	49.38%	20.54%	29 (35-64)

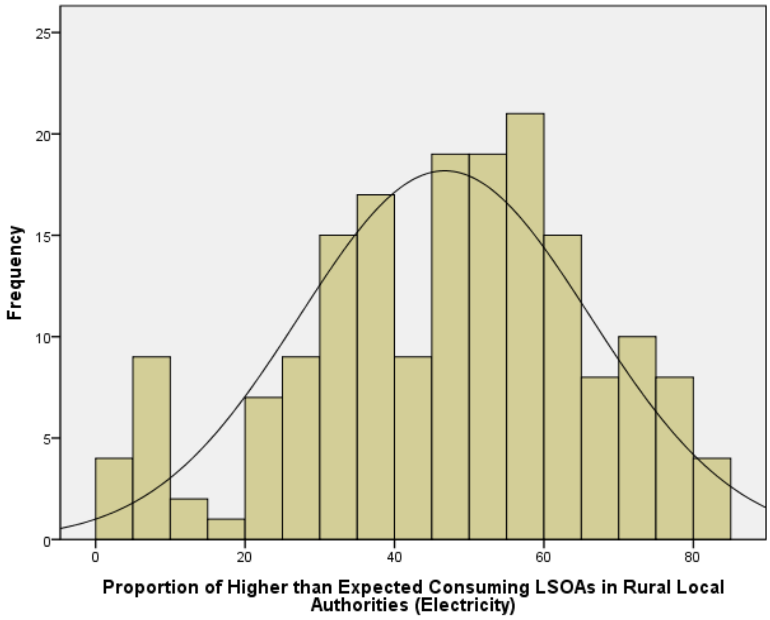


Figure 9.25 Proportion of LSOAs with Higher than Expected Electricity Consumption in Rural Local Authorities

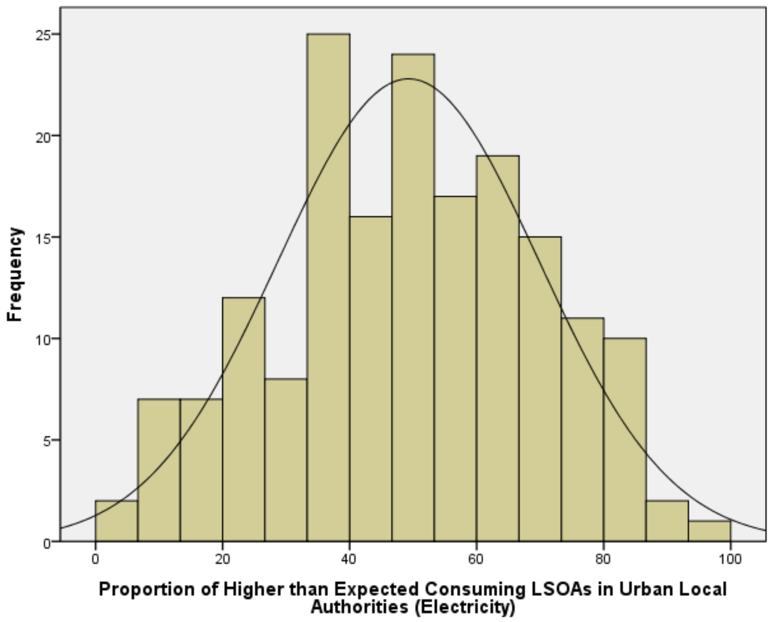


Figure 9.26 Proportion of LSOAs with Higher than Expected Electricity Consumption in Urban Local Authorities

Splitting Local Authorities into rural and urban sections reveals that urban authorities on average have a higher proportion of above benchmark gas and electricity LSOAs. However the differences between rural and urban Local Authorities are less pronounced for electricity consumption than they are for gas consumption, with the means much closer together as shown in Table 9.18. A t-test indicates that there is no statistically significant difference in the mean values for LSOAs with higher than expected electricity consumption between rural and urban areas (t_{351}=-1.195, p=0.233). This is visually shown in Figure 9.27.

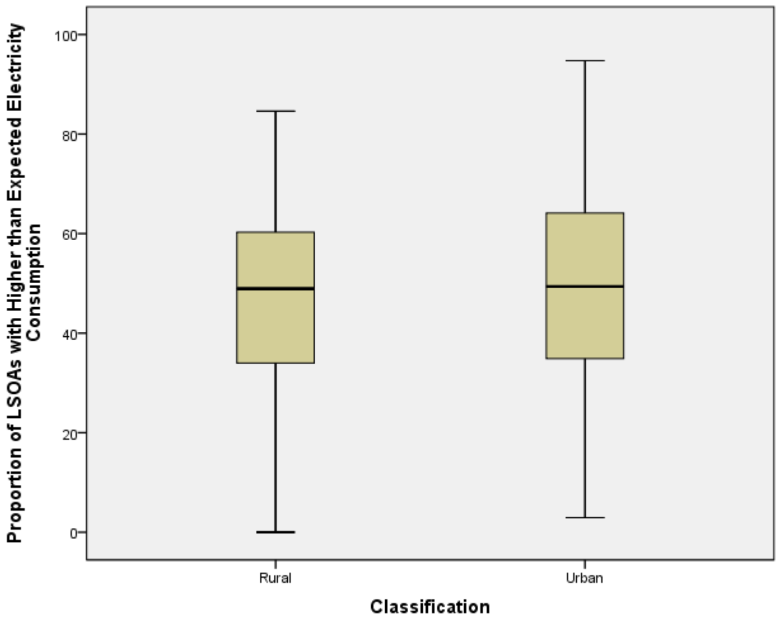


Figure 9.27 Boxplot Showing Differences in Means and Spread of Proportion of LSOAs with Higher than Expected Electricity Consumption in Rural and Urban Areas

Using the further sub-sample categorisation indicates Major Urban Local Authorities on average have a greater proportion of higher than expected gas and electricity consuming LSOAs within their boundaries than the other five classifications (see Tables 9.19 and 9.20). By contrast with the general trend in rural and urban Local Authorities, the sub-sample of Other Urban areas has, on average, the lowest proportion of LSOAs with higher than expected gas consumption. The differences between these mean values of proportion of LSOAs by the sub-sample rural/urban classifications is statistically significant ($F_{347,5}$=19.98, p<0.001). Running a Bonferroni post hoc analysis, as advocated by Moore *et al* (2009) on the average proportion of LSOAs that have gas consumption in excess of the benchmark level in Local Authorities shows that the differing rural and urban categories shows that the groupings with statistically significant differences are between Major Urban and all other categories. All other pairs of groupings are not statistically significantly different with the exception of Large Urban and Rural 80 ($p<0.001$). This can be seen visually in Figure 9.28. What can be concluded from this is that it is the large urban areas that have statistically significant differences in the proportion of LSOAs with higher than expected gas consumption compared with the other classifications of Local Authorities.

Table 9.19 Proportion of Higher than Benchmark Consuming LSOAs by Gas Consumption in Rural/Urban Local Authority Sub-Groups

	Number of Local Authorities	**Mean Proportion of LSOAs where CI>100**	**Median Proportion of LSOAs where CI>100**	**Standard Deviation**	**Interquartile Range**
Major Urban	76	63%	69%	21%	26 (55-81)
Large Urban	45	50%	55%	23%	35 (37.5-72.5)
Other Urban	55	30%	40%	21%	31 (24.5-55.5)
Significant Rural	53	41%	33%	19%	27 (20-46)
Rural 50	53	39%	34%	21%	33 (20-51)
Rural 80	72	33%	31%	17%	26 (18-44)

Table 9.20 Proportion of Higher than Benchmark Consuming LSOAs by Electricity Consumption in Rural/Urban Local Authority Sub-Groups

	Number of Local Authorities	**Mean Proportion of LSOAs where CI>100**	**Median Proportion of LSOAs where CI>100**	**Standard Deviation**	**Interquartile Range**
Major Urban	76	51%	53%	22%	30 (38-68)
Large Urban	45	48%	48%	21%	30 (33-63)
Other Urban	55	48%	51%	18%	23 (39-62)
Significant Rural	53	50%	50%	17%	23 (39-51)
Rural 50	53	46%	46%	21%	28 (32-60)
Rural 80	72	45%	48%	20%	26 (35-61)

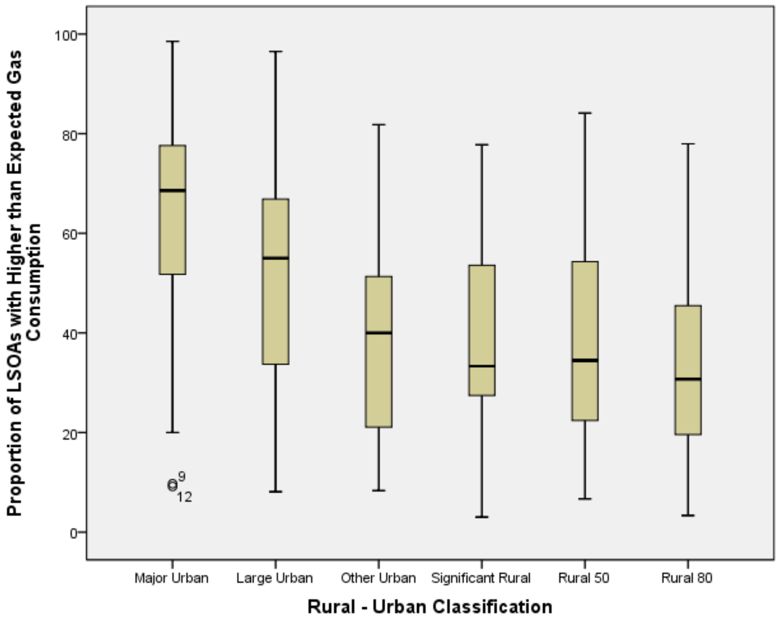


Figure 9.28 Box Plot of the Proportion of LSOAs with Higher than Expected Gas Consumption in Rural and Urban Local Authority Sub-Groups

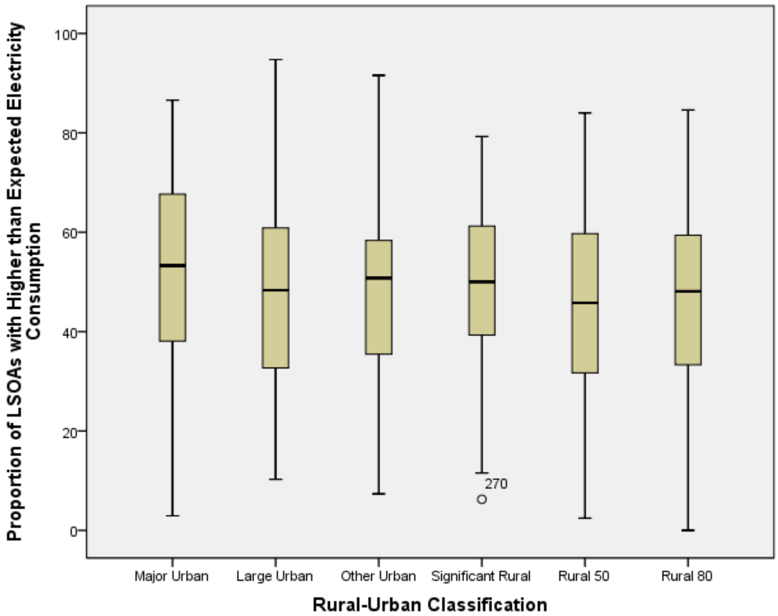


Figure 9.29 Box Plot of the Proportion of LSOAs with Higher than Expected Gas Consumption in Rural and Urban Local Authority Sub-Groups

Running the ANOVA test for differences in means for proportions of LSOAs with higher than expected electricity consumption did not reveal a statistically significant difference between means of the groupings ($F_{347,5}$= 1.04, p=0.397), and this is visually represented in the box plots of Figure 9.29. This continues with the theme running through this thesis that it is harder to predict, and to account for, differences in the LSOAs that have higher than expected electricity consumption. Electricity consumption continues to appear to be less dependent on the character of the area and of the physical housing stock than gas consumption at present. This analysis suggests that Local Authorities in Major Urban Areas that do not contain a New or Expanded Town have, on average, a greater proportion of LSOAs with higher than expected gas consumption relative to the benchmark levels. For Central Government, it is perhaps these Local Authorities that should be given priority for funding to address the over-consuming LSOAs.

9.6 Conclusion

The results and outputs from the multiple regression models were tested for applicability and plausibility. Feedback from Local Authorities was, crucially, able to link the outputs of the model to policies such as the Green Deal and Energy Company Obligation, demonstrating that the outputs have applications for Local Authority energy policy. The discussion from Local Authorities gave confidence in the results of the gas consumption that these results were plausible, often identifying areas of old housing within inefficient boundaries, as well as areas known to have higher than average consumption levels. The case studies of Leicester LSOAs supported this, with the LSOA with the highest gas consumption index containing solid wall terraced housing, whilst the LSOA with the lowest gas consumption index made up of purpose built flats under Local Authority control. Expanding this analysis to Milton Keynes showed that the model was able to identify Milton Keynes, as a Local Authority, with 89% of its LSOAs having lower than expected gas consumption, which is expected given the relatively young age of the Local Authority. Expanding this to encompass all of the Local Authorities that have experienced developments under the 'New Towns' movement showed that there is a statistically significant difference in the proportion of LSOAs with lower than expected gas consumption between Local Authorities containing New or Expanded Towns and those that do not. Exploring Local Authorities showed that major urban areas had higher proportions of LSOAs with higher than expected gas consumption compared with the other classifications of Local Authorities, which may be indicative of the lower quality housing stock in large urban areas that experienced rapid industrial development. It is envisaged that as greater proportions of the existing housing stock undergo energy efficiency renovations the link between house age and relative gas consumption becomes weaker, and therefore the model's results will be vital in identifying those LSOAs in need of further interventions to reduce domestic gas consumption.

Exploratory findings in this chapter show an indifference towards the electricity consumption results, both in terms of what the results showed, and the potential applications for policies. This is perhaps to be expected given the overwhelming focus on reducing space heating demands and therefore domestic gas consumption in the academic and policy literature. Local Authorities showed less interest in their electricity consumption figures and had less understanding of, and ideas for why the patterns of results exist. Site visits in Leicester were also unable to give visual indications as to why LSOAs would have higher or lower than expected electricity consumption. Electricity consumption patterns were less defined than the gas consumption, with no statistically significant difference between rural and urban Local Authorities, or between Local Authorities containing New and Expanded Towns and those that do not. Given the rising electricity consumption in the domestic sector there is a need for a mechanism to identify areas with higher than expected electricity consumption for policy intervention.

10. DISCUSSION OF FINDINGS, RECOMMENDATIONS FOR FUTURE RESEARCH, AND CONCLUSIONS

This thesis began with a discussion of the UK Government's 2050 climate target, whereby the UK had set itself the challenging target of reducing its CO_2 emissions by 80% relative to 1990 levels by 2050 (HM Government 2008). It was established that the domestic sector currently accounts for almost 25% of the UK's carbon emissions, and 30% of the total final energy demands (Kannan and Strachan 2009). It is also clear that this energy demand is growing, particularly with regards to electricity consumption (Utley and Shorrock 2008). The starting point for this thesis was the recognition that while currently there exists technical knowledge on reducing domestic energy demands through technical interventions to improve the thermal efficiency of the housing stock, and the energy efficiency in electrical appliances, there has yet to be a large-scale drive towards greater levels of energy efficiency in the domestic sector.

In attempting to reduce energy consumption (and therefore carbon emissions) in the domestic sector, DECC began in 2005 to publish sub-national domestic gas and electricity consumption statistics for use by Local Authorities, but has not accounted for the variation in domestic energy consumption. In this chapter, the aim of the PhD, which was, '**to identify the key factors that explain the variation in domestic gas and electricity consumption and, applying this knowledge, develop a model for Local Authorities to target areas of housing that is most likely to benefit from energy efficiency measures',** is revisited. The progress made against each of the five research objectives is noted, and the findings and methods are critiqued. The chapter is structured accordingly: Section 10.1 revisits each research objective in order to critically assess the contribution of this research to existing knowledge of domestic energy demands and carbon reduction strategies, and highlight the contribution of this thesis against the overall stated aim. Section 10.2 then explores the direct and indirect implications of this research for wider academic and non-academic debates around domestic energy reduction strategies, Local Authority energy policy and overall carbon reduction strategies at local levels. The chapter concludes by acknowledging the limitations of the research process and identifying a series of new questions raised by the research presented within this thesis, which, it is argued, provide a framework for future research.

10.1 Addressing the Research Objectives

To meet the aim of this thesis, a series of objectives were proposed. This section details the key findings from addressing each objective and discusses what the implications are of these findings on the wider research aim. The research objectives of this research were:

1. The *Policy Objective* was to consult with Local Authorities (LAs) in order to (i) determine the form of the model, its outcomes, and scale of applicability, and (ii) develop a more detailed understanding of the priorities and pressures LAs face, in order to make the model as usable as possible.
2. The *Data Objective* was to (i) identify nationally publically available datasets under the categories of social, demographic, technical, economic, and climatic factors; (ii) explore the uncertainty, limitations and methodological processes in the data collection, and (iii) generate descriptive statistics illustrating the spread, distribution and average values for each of these factors.
3. The *Analytical Objective* was to explore relationships between domestic energy consumption and identified datasets using statistical methods including correlation, regression and appropriate tests of significance.
4. The *Output Objective* was to use the datasets and findings from objectives 2 and 3 as significant indicators to develop a statistical model that produces benchmarks for domestic gas and electricity consumption.
5. The *Applicability Objective* was to test the model developed in objective 4 by i) illustrating the potential applications of the outputs for Local Authority energy policy, and ii) assessing the plausibility of the results through statistical testing using alternative data sources and a series of plausibility tests.

In addressing the *policy objective*, building on the policy literature and interviewing Local Authority representatives, it became clear that Local Authorities did not value the requirements of calculating reductions in CO_2 emissions as a result of their policy actions. This was seen as the largest criticism of the Local Area Agreement NI 186. Government policy appears aimed at local level interventions (such as the Localism Bill – see DCLG 2011) and, the work from DECC (see 2010a, 2012a) placed emphasis on Local Authorities to take a lead role in the efforts to reduce domestic energy demands. However, the interviews with Local Authorities revealed that these bodies lacked the resources, and at times the political will to indulge in data collecting exercises for domestic energy consumption. This highlights tension between the desire for local action on reducing energy consumption and a concentration of resources at the national level. The work of Schruers (2008) and Sovacool and Brown (2009) emphasise the benefits of 'bottom up' policies developed and enacted at a local level to aid national objectives but this is at odds with the traditional political culture in the UK of a 'one size fits all' national policy (Leach and Percy-Smith 2001, Stoker 2004). Keirstead and Schulz (2010) argued that local energy policy was under-researched, and under-represented in the Energy Policy academic journal.

Consultation with Local Authorities revealed a 'stage of transition' between schemes pioneered by the previous Labour Government (such as CERT – see DECC 2010a) and new policies introduced by the current Coalition Government such as the Green Deal (DECC 2011a). As a result these findings from Local Authority consultation supported a need to generate benchmark domestic gas and electricity consumption figures to identify LSOAs with higher than expected consumption (and also lower than expected consumption to serve as exemplars) that were not tied to specific Government schemes. It was found that there was a lack of financial, data, and technical resources for Local Authorities to conduct in-depth investigations into the nature of domestic energy consumption within their boundaries. Local Authorities instead tended to prioritise social policies such as reducing fuel poverty rather than a general energy efficiency strategy to reduce overall carbon emissions. The implication from addressing this objective was a need for a relatively simple method that used freely available, existing data to identify areas of 'potential' inefficient energy consumption patterns within small areas (LSOAs where consumption exceed the expected benchmark figure), as well as areas of potential efficiency. By doing this, Local Authorities would be able to use the results to aid in meeting current Government policy strategies as well as understanding the nature of domestic energy consumption within their boundaries. The results would also be robust enough to meet future strategies that aim to reduce energy consumption in the domestic sector. Another notable finding from addressing the policy objective was a focus, both from policy literature and from Local Authority consultation, on reducing domestic gas consumption specifically though installing insulation measures in the existing housing stock and as highlighted by Lomas (2009) and Williams *et al* (2012). Focusing solely on technical interventions and failing to account for the characteristics and attitudes of the residents will not bring about successful policy interventions. What has been overlooked in the area of domestic energy consumption reduction strategies is an understanding of occupant behaviour and in identifying areas that have higher than expected electricity consumption.

The *data objective* was achieved using Government (DECC and ONS) and commercial (Experian and MET Office) secondary data sources. The objective centred on identifying nationally available datasets that could be used for predicting variation in domestic energy consumption. These data sources were identified from the academic and policy literature, covering demographic, social, economic, technical, and climatic factors that impact on domestic energy consumption across England. This was based on the findings from previous studies on UK housing energy consumption by Yao and Steemers (2005), Druckman and Jackson (2008) and Summerfield *et al* (2010a). It what found, that even after averaging gas and electricity consumption over 500-700 houses at LSOA level, there was still a large variation in LSOA domestic energy consumption levels across England. The distribution of both fuels was positively skewed, indicating a small proportion of LSOAs with very high levels of gas and electricity consumption. Electricity consumption in particular showed a strong positive skew. Using these energy consumption data in their raw form provided a good indication of those LSOAs in England with higher absolute domestic energy consumption levels; however it hides the potential for energy reduction because locally specific factors are not taken into account. Examination in the distributions of the ‘predictor’ variables (i.e. the social, economic, demographic, technical and climatic factors that influence domestic energy consumption) showed a wide range of distributions across the various factors. It was unclear which of these variables would have the greater impact on domestic energy consumption. It was possible to obtain heating degree-days data that approximated the base year against which the gas consumption data is weather corrected (a 17 year average of 1988 to 2004); however this was only available at 5kmx5km grid squares and required manipulation using GIS to convert the data to LSOA level. In the future, Government departments may consider publishing this data at LSOA level for Local Authority use as Heating Degree Days became an important factor in the gas consumption model subsequently produced.

The *analytical objective* focused on using the data from the data objective which described the social, demographic, economic, technical, and climatic variations in LSOAs to develop statistical models that would enable Local Authorities to identify LSOAs within their boundaries where they could enact policies that would feasibly lead to a reduction in domestic energy consumption. To meet the assumptions of multiple linear regression, square root transformations were applied to the LSOA domestic gas and electricity consumption figures to reduce the skew of the distribution. Correlation analysis reduced the potential number of inputs for the models to 11 (by applying a cut off figure of $|r|>0.2$). The average number of rooms per house in a LSOA had the strongest association with both domestic gas consumption ($r=0.731$) and domestic electricity consumption ($r=0.605$). Accounting for the average number of rooms, and having ensured pairs of independent variables with a correlation co-efficient of $|r|>0.7$ were not included in the model enabled two linear multiple regression models to be constructed, with R^2 values of 0.653 and 0.731 when modelling LSOA gas and electricity consumption respectively. Using the stepwise entry method and stopping variable entry once additional variables added less than 0.01 to the R^2 leads to the inclusion of three variables in the models. For gas consumption these were: average number of rooms, median household income and heating degree days for the gas consumption model. For electricity consumption these were: average number of rooms, ratio of gas to electricity meters, and median household income. The key finding here is that three variables were able to account for approximately 65% of the geographical variation in LSOA domestic gas consumption, and 73% of domestic electricity consumption. Accounting for these variables would distinguish between over-consuming, possibly energy inefficient LSOAs and those that were high consumers (as a result of colder weather or larger housing, higher income, or housing with electrical heating). Crucially these models were deliberately kept simple in terms of number of inputs, and the type of modelling method used. This simplicity was seen as crucial for non-technical audiences such as Local Authorities by Makridakis and Wheelwright (1989), and had practical applications in studies of Italian electricity consumption by Bianco *et al* (2009). Where this research goes beyond Bianco *et al* and other studies on domestic energy consumption by Weber and Perrels (2000), Druckman and Jackson (2008), Olonscheck *et al* (2011), and Wiesmann *et al* (2011) is the focus on accounting for variation in demographic, social, economic, technical and climatic factors specifically for practical applications for local domestic energy reduction policies. Previous studies in this field had focused on understanding which factors accounted for variation in energy consumption at an individual household level. Whilst focusing on the individual household level enables the understanding of how individuals may respond to a specific intervention, by extending the analysis to LSOA level provides the benefits of: economy of scale to contractors who wish to focus on large areas, averaging individual idiosyncrasies. This is highlighted by comparing the results from this thesis with the NEED study of DECC (2011c), and the wide-spread availability of data which is not available at an individual household level.

The *Output Objective* took the predicted values from the regression models and used these as 'benchmark' levels of consumption. 'Relative consumption' indices were then calculated by dividing the DECC recorded consumption figures by the benchmark level and multiplying by 100. Thus it was possible to create an index that could easily identify

LSOAs with domestic energy consumption in excess of the benchmark figure. Using data from 2008, 2009 and 2010 these indices were re-calculated by re-running the regression analysis, and crucially in the context of this work the results for all three years followed similar patterns. These patterns gave strong indications that these results were not spurious to 2008, and demonstrated that there is potential to use these outputs over time to monitor the changes in domestic energy consumption in LSOAs relative to the benchmark figure. Statistically testing the outputs against discrepancies between the number of meters recorded by DECC, and VOA records of housing, showed the model was robust enough to overcome the greatest limitations in the DECC energy consumption data (whereby there are errors in the classification of domestic gas meters). Feedback from Local Authorities suggested that the outputs generated, the models developed, and the data sources used, fit the needs of local energy policy given resource constraints facing local councils.

From the *applicability objective* it was possible to establish that the results generated in this thesis had practical applications. Local Authorities were able to relate the use of the results to current UK Government policy requirements. This was a crucial finding, as Local Authorities were able to demonstrate how they would use these results in relation to the Green Deal and ECO schemes. The Local Authority feedback sessions built confidence in the plausibility of the results, given that the respondents could rationalise the findings with knowledge of the houses in each LSOA. The applicability objective was not just concerned with Local Authority feedback though, and the results would not be applicable to Local Authority schemes if the results themselves lacked plausibility. Assessment of five LSOAs in Leicester indicated that the results were plausible given the physical characteristics of the area but this method of walk-by visits was inconclusive on a wider scale. Therefore to overcome this, statistical testing of the model results was undertaken to identify areas of known energy efficiency, such as Milton Keynes. Milton Keynes's relatively new housing stock almost exclusively comprised of post-1960 housing, was expected to be more thermally efficient due to progressively stricter building regulations enforced during the construction of the City (Milton Keynes Borough Council 2011, DECC2012a). The model was able to correctly identify Milton Keynes as a City of lower domestic gas consumption than would otherwise be expected.

The final part of the applicability objective demonstrated how Central Government could use the results of this thesis to rank Local Authorities. The proposed comparison of Local Authority performance in this thesis is to assess Local Authorities by their proportions of LSOAs with domestic energy consumption in excess of their benchmark. This is a response to the critiques by Stoker (2004) and Howell and Nakhle (2008) about the way in which Local Authority performance is traditionally measured in the UK, specifically the culture of 'target setting' from the Central Government. Here this research extends on the academic literature by consulting with Local Authorities to determine how this target culture relates specifically to energy policy. The finding from surveying 11 Local Authorities is that there is a need to go beyond setting general CO_2 emission reduction targets for Local Authorities from a national level. The Authorities interviewed preferred to measure their performances based on the number of energy efficiency schemes they implemented, but there was also a consensus on the need for comparisons between Local Authorities. The performance monitoring proposed here meets the desires for Central Government to measure the performance of Local Authorities, whilst promoting local action. This is something that has been championed by the Coalition Government through the 2011 Localism Bill. However Lowndes and Pratchett (2012:38) warn that 'this [the Localism Bill] development may be as much the corollary of savage public spending cuts and the need to externalise responsibility for performance failure as the outcome of a principled commitment to more autonomous local governance'. With this in mind, this research aims to ensure Local Authorities are given adequate resource and informations to fulfil their responsibilities despite potential further spending cuts.

10.2 Meeting the Domestic Energy Challenge: Local Authority Action

The mixed-methods approach used in this research enabled the designing of an evidence based strategy for Local Authorities to use when setting local domestic energy reduction targets. More specifically, this would help Local Authorities to identify areas in which to focus their resources and efforts to achieve these targets. The statistical approach taken in this thesis enabled a new model to be developed that described the variation in domestic gas and electricity consumption in England. The qualitative approach ensured that the results were presented in a format that Local Authorities could apply to their own targets, and to those set by National Government.

Previous quantitative studies in the academic literature focusing on variation in domestic energy consumption, such as Summerfield *et al* (2010a), had focused on measuring the consequences of changing levels of energy prices and temperature on domestic energy consumption over time but did not investigate how these relationships vary across space. Further research had been required to understand how domestic energy consumption varied across space in the UK, and this thesis has extended the previous study by Wiesmann *et al* (2011). Although the research in their paper focused on Portugal, its approach in conducting a cross-study analysis for the impacts of demographic, social, economic, technical and climatic factors on household electricity consumption. The approach taken by the Weismann *et al* (2011) study is extended to focus on England, and to analyse domestic gas consumption. In the UK, a similar approach is taken by DECC for the NEED analysis (DECC 2011c). Despite DECC's position as a Government Department enabling them to obtain information on four million individual households, the results from their statistical models only explained approximately 30% of the geographical variation in energy use. Aggregation to LSOA level in this research is a concern highlighted by Morley and Hazas (2011:2046) who state 'Thus to understand how variation in energy consumption arises, micro-level studies that go beyond averages to represent variations at the many points they occur are needed.' However this research argues that by aggregating to LSOA level, and taking averages of 500-700 'socially homogenous' houses, it was possible to account for 65% and 73% of the geographical variation in LSOA domestic gas and electricity consumption respectively using simple multiple linear regression. Results for individual households, such as those from the NEED study have limited application for policy implementation, as highlighted by further DECC publications outlining the Green Deal strategy, which emphasises the need to identifying clusters of housing for economies of scale benefits for refurbishment contractors (DECC 2011a). This viewpoint of how the Green Deal may operate is shared by five of the Local Authority respondents in this study.

The regression models accounted for technical, economic and climatic factors and this method generated stronger statistical results than had previously been obtained from studies of individual housing. The original contribution of this thesis is that, not only does it advance the academic knowledge by combining technical and non-technical factors to understand domestic energy consumption variations, but also meets the demands of Local Authorities in the context of current UK Government policy. The thesis contributes to the academic debate by approaching energy reduction in the domestic sector by taking a policy perspective on where spatially Local Authorities can achieve domestic energy savings, rather than on what savings could theoretically be achieved from energy efficiency interventions. This addresses concerns over the Green Deal focus on technical efficiency interventions (Dowson *et al* 2012). This was done by using freely available data, in an approach that is simple to interpret for non-technical audiences, and in a format that enables partner organisations to target relatively large areas of housing therefore benefitting from economies of scale (Makridakis and Wheelwright 1989, Williams *et al* 2012). This is a clear and succinct guide for where Local Authorities may be best suited to targeting their efforts to reduce domestic energy consumption in this manner was something that had previously been lacking in this field.

Perhaps the most notable finding, which had not been part of any of the original research objectives, was that domestic electricity consumption is distinct in terms of trends, patterns, attitudes, responses and policy focus compared to domestic gas consumption.

Local Authorities were able to identify potential reasons for the pattern in their gas consumption indices and were more engaged with the policy options to deal with them. By contrast electricity consumption figures were given little attention by the Local Authority representatives and there was little engagement in policy options to deal with excessive electricity consumption. This is unsurprising given that the policy focus at present in the UK is focused on improving the thermal efficiency of the current housing stock, and therefore strongly oriented towards domestic gas demands.

From the experiences of this thesis it was easier to test the plausibility of the gas consumption figures due to the anticipated relationship between gas consumption relative to the benchmark, the energy efficiency of the housing stock and the age of the housing stock. There is a strong focus on modelling savings from technical interventions in the housing stock; heating systems; and efficiency of electricity appliances in the academic literature (Boardman 2004, Firth and Lomas 2009, Dowson *et al* 2012). These studies provide theoretical savings from energy efficiency interventions. For example, the Firth and Lomas (2009) study suggests that 40% reduction in energy demand from insulating walls and lofts, replacing boilers and low energy electrical appliances. These studies approach energy consumption from a technocratic perspective but do not consider energy behaviours that lead to theoretical savings not being achieved. As stated by Greening (2000) and Sorrell (2007), large scale *rebound* effects such as the preference of higher internal temperatures rather than reducing energy consumption, and the increased heating in rooms previously under heated negate the impact of energy efficiency improvements. This thesis recognises the need for technical interventions to reduce domestic energy consumption, but also the unintended rebound consequences. The consumption indices developed in the thesis accounts for income, and house size, and by doing this is able to distinguish between high consumers that require large heating demands to heat larger house area, and those which may be lower consumers, but have higher energy demands than would be expected. Local Authority performance over time could be judged on the changes in consumption index over time, rather than based on energy reductions in comparison to theoretical savings from efficiency interventions.

From consultation with Local Authorities, and from the debates in the academic literature, what is overlooked and poorly understood is the behavioural aspects behind electrical appliance use (Mullainathan and Alcott 2010, Leaman *et al* 2010). Given the current knowledge, the discrepancies between domestic electricity consumption and gas consumption, and that policies are weighted heavily in favour of reducing domestic gas consumption, it is perhaps vital that in the future there is a shift towards reducing domestic electricity demands. This is a stance taken by Leaman *et al* (2010). Currently there appears little focus on reducing electricity demands yet electricity use is a growing percentage of domestic energy use and in overall UK Carbon Emissions and is therefore becoming increasingly important (Utley and Shorrock 2008, Kannan and Strachan 2009). However the political agenda in the UK focuses strongly on national supply-side changes to decarbonise electricity consumption, making up the bulk of the *Pathways to 2050* proposals (HM Government 2050).

The main proposals for reductions in household electricity demands focus on a roll-out of smart meters to influence householder behaviour (DECC 2010a) and providing information of electrical appliances through efficiency labelling (EEA 2008). This thesis agrees with the viewpoint of Fischer (2008:102) who states that 'much-consuming customers react differently from little-consuming ones, and middleclass groups from working-class groups' to information feedback. Sunikka-Blank *et al* (2012:143) contributes that 'Policy instruments such Smart Meters are based on the rational choice models that assume that people make rational decisions, but in practice, there seems to be irrational economic behaviour.' This thesis considers these viewpoints and contributes by creating mechanisms to identify groups of households with higher than expected electricity consumption. The understanding of the economic, social, demographic and technical variations would enable Local Authorities to differentiate between those with higher than expected consumption due to technical inefficiencies (such as running older-style appliances) and those with access to the latest technology but with electricity intensive behavioural patterns. This would aid Local Authorities to tailor the information they provide to these households and policy formulation to reduce electricity demands and attempt to reverse the current electricity consumption culture. This goes beyond the prevailing preference to provide technical solutions to what Sunikka-Blank *et al* (2012:144) define as an 'acceptance of energy wasting behaviour that is passed on to the next generation'.

10.3 Moving Forward: Limitations and Future Work

While this thesis has contributed to the wider academic and policy debates, there are limitations with the method and data undertaken with this project. As discussed as part of the output objective, limitations in the DECC sub-national gas and electricity consumption data were evaluated to ensure the model's outputs were robust enough to overcome the discrepancies between the number of domestic energy meters and houses as recorded by the VOA. What have not been addressed thus far in the thesis are the remaining limitations of the study. These limitations are as follows:

- There were discrepancies between the number of properties classified as 'domestic' in the DECC data, and the listed household counts by council tax bands from the VOA for the year 2010. DECC highlight this by indicating up to two million small and medium sized commercial premises may be incorrectly classified as domestic properties. LSOAs with a large proportion of misclassified properties may therefore have inaccurate per meter energy consumption figures and consumption indices. If misclassifications in the data are inconsistent between years, this could potentially cause large swings in the consumption index values for a particular LSOAs and incorrectly suggest improvements in energy efficiency (or sudden increases in energy consumption).
- Many of the variables used in this study were obtained from the 2001 Census, which is now over 10 years out of date. This could potentially undermine the research where LSOAs have experienced housing development and demolition over the past 10 years (which would impact on the statistics for average number of rooms and house type). What these data may hide is the true relationship

between these variables and domestic energy consumption that were not picked up in the correlation and regression analysis because the data is out of date.

- The heating degree day data used in the modelling is an approximation of the weather correction used in the gas consumption figures. This has implications for comparisons over time if the weather correction method used in the gas consumption figures is changed.
- The median household income data is from Experian. These data are not certified as official statistics and are based on modelling techniques as opposed to recorded income data.

Proposed future work to begin to address these limitations is as follows:

- In addressing the misclassification of commercial properties as domestic properties in the underlying data, any outputs disseminated to Local Authorities would include the consumption index, independent variables, underlying consumption figure, and the number of gas and electricity meters for each LSOA. Local Authorities would then be able to use this information, and their own local knowledge, to assess extreme results. As further years of DECC subnational energy consumption are released it would be possible to analyse LSOAs over a greater time-scale and visit LSOAs with large swings in the consumption index to establish the underlying causes for this.
- Addressing the use of 2001 Census data for analysing variation in 2008, 2009 and 2010 energy consumption would include updating the analysis to include data from the 2011 census. Local Authorities could be given an 'overlap' period of 3 years (i.e. 2010, 2011, 2012) where a consumption index is calculated using both 2001 and 2011 census data. Those LSOAs with large deviations in these consumption indices would be investigated in more detail to understand the underlying cause (e.g. large scale housing developments).
- Extend the study to include a longer time-series of data. Currently benchmarks are re-calculated year-on-year based on updated versions of the variables that were

included in the regression model for 2008. What is not clear is how the relationship between domestic energy consumption, and these variables might change over time (e.g. efficiency strategies may weaken the link between LSOA per meter gas consumption and median household income). There may be a need to re-run the entire analysis and change the nature of the regression equations in the future, perhaps as new census data becomes available.

- There is consideration of reducing the computational requirements for Local Authorities in calculating the consumption indices for their LSOAs. Exploring the plausibility of using benchmark gas and electricity consumption figures for one year and comparing subsequent DECC energy consumption data against these benchmarks (which remain constant) could provide a simpler alternative to the annual re-calculated benchmarks presented in this thesis. Guidance to both methods is given in Appendix 5.

Recommendation for Government to improve the clarity of the DECC sub-national energy consumption statistics are as follows:

- Greater clarity from DECC over the nature of disclosure in the sub-national gas and electricity consumption data by relaxing the disclosure criteria for LSOA energy consumption (from the current criteria of at least 6 households). Alternatively the removal of LSOAs from the dataset that cannot be disclosed will give the actual consumption for the LSOAs that would otherwise be ‘merged’.
- An indication on which LSOAs are affected by the misallocation of commercial properties as domestic properties. This may be by comparing records of households from council tax records with the number of domestic electricity and gas meters in each LSOA. A list of the number of properties in each LSOA which exceed the 73000 kW h per year gas consumption cut-off to be classified as a domestic property would also be of use for further research in this field and for policy makers to better understand the characteristics and potential problems within their boundaries.

In addition, it would be beneficial to policy makers, and other interested bodies to have the following datasets made available for use:

- The collection and release of median household income data for LSOA level. This data may already be collected in assessing household eligibility for certain welfare benefits or income tax records. By disseminating at LSOA level to model energy consumption may be sufficient to alleviate fears of disclosure of individual person and household income data and provide a reliable indicator of household income as opposed to the modelled data from Experian.
- Providing either: a) an up-to-date variable on the average number of rooms, or b) publishing a variable that has better precision on the physical size of housing. The suggestion is for 'average floor area'. This would be an improvement over the use of 'average number of rooms' from the 2001 census.
- The publication of a variable at LSOA level that would match up to the weather correction in the per meter gas consumption data. Alternatively the publication of uncorrected gas consumption data could be published alongside annual heating degree day figures at LSOA level. This would enable for the accounting of temperature changes both spatially and temporally.

These variables could be included in the DECC sub-national energy consumption datasets. DECC has shown willingness to include demographic variables from the 2001 census as part of the energy consumption data releases. This thesis has highlighted the importance of additional and alternative data sources for Local Authorities to consider when analysing domestic energy consumption within their boundaries. Generating benchmarks and indices would be much easier for LAs if data was provided in this format.

In addressing the limitations, and from the general findings of the thesis, there are further questions that have arisen from this study. The first set of questions concern limitations in the statistical data used in the project. Firstly, given that the data sources used were taken from the 2001 Census which was at least 7 years old compared to the earliest year for which LSOA energy consumption data was available (2008), how would using data from the 2011 Census impact on the modelling results? Secondly, the multiple regression models account for 65% and 73% of the geographical variation in LSOA domestic gas and electricity consumption respectively. There is a further challenge to develop a greater understanding, and identify the factors accounting for this remaining variation. The data used in this project had been obtained from Government sources, and from commercial sources that had been used in previous Government analysis. This limited the study to variables that had been collected and published by, or promoted by, UK Government departments. Most pressingly, how would the inclusion of a national dataset (either at, or easily converted to LSOA level) of existing insulation levels in housing impact on the results that the model produces? Are there LSOAs with relatively high energy efficiency installations (e.g. high proportion of cavity walls filled) and with high levels of domestic gas consumption relative to the benchmark? What can Local Authorities do with this knowledge? Incorporating LSOA-wide energy performance certificate information into the testing of the results may reveal important information about households with energy ‘wasteful’ behaviours, and in the case of inefficient housing with lower than expected gas consumption may indicate incidences of fuel poverty.

The second set of questions concern the context within which this research was carried out. Firstly, the model was used to identify LSOAs with gas and electricity consumption in excess of the benchmark. What has not been established is what reasons explain those LSOAs which significantly deviate from the national trend. A question which arises in the study of Morley and Hazas (2011:2046) on household energy consumption variations concerns understanding how energy consumption varies across households. Here they state:

> ‘Thus to understand how variation in energy consumption arises, micro-level studies that go beyond averages to represent variations at the many points they occur are needed. And in turn, a practice theory approach should help make this data more meaningful to society-wide patterns of demand’.

While this research highlights the importance of understanding the underlying distribution of energy consumption within each individual LSOA, it overlooks how this understanding of individual households can be used to inform policy applications. What the findings of this thesis do therefore is begin to bridge the gap between nationally focused and individual household focused research to give practical applications for policy implementation.

The results here have been produced in conjunction with feedback from English Local Authorities using UK Government data in the context of UK Government policy. What has not been considered is; are these results applicable to an international context? One of the findings from presenting this research at academic conferences in Paris and the USA is the differences in political climate, and the data that is available. This international transferability of knowledge in domestic energy consumption is raised by Olonoscheck *et al* (2011) in their study of energy efficiency renovations of German houses, and emphasised by the EEA (2008) in promoting European-wide schemes for reducing household electricity consumption.

10.4 Future Uses for the Model

Throughout this research the focus has primarily been on the ways in which Local Authorities could apply the results, in particular the consumption indices, in developing their own Local Authority energy policies. The model has applications for the following scenarios:

- For use by policy makers to identify LSOAs to bring to 'benchmark' levels of consumption. A recurring theme of the research is for Local Authorities to identify 'above benchmark' consuming LSOAs to enact energy efficiency policies such as the Green Deal, and ECO, to reduce energy consumption to levels that would be expected.
- Policy makers may also use these results to encourage and persuade residents in LSOAs with high consumption indices to purchase more efficient appliances or change energy behaviours by providing feedback to these areas.

- To monitor LSOA consumption indices over time. This use of the model would enable the success of implemented policies to be tracked over time. It is anticipated that an LSOA targeted for efficiency interventions would see its consumption index reduce over time, whilst other LSOAs with no interventions may see their consumption indices increase over time.
- Identifying exemplar LSOAs which demonstrate ‘best practice’ and to understand why energy consumption is relatively lower in these areas. The experiences of these LSOAs may be replicated elsewhere across the Local Authority and beyond.
- For use by policy-makers to justify why interventions are prioritised to certain LSOAs within their boundaries and not to others. For Local Authorities it may be of importance to have an evidence-based strategy to highlight why one LSOA receives greater resources for energy efficiency measures than others.
- Enabling community groups to highlight their position (i.e. as an area of high consumers of electricity or gas) to obtain funds and other resources for their own measures (such as community renewables or community intervention strategies). Similarly, community groups may wish to highlight themselves as ‘exemplars’ in reducing energy consumption (and maintaining below benchmark levels of energy consumption).
- For companies to obtain information over which areas of housing to target to market energy efficiency measures, in particular to home-owners in wealthier areas that are unlikely to qualify for ECO schemes. Releasing results at LSOA level would give these companies a market (of 500-700 households) with potential to benefit from energy efficiency interventions. These results would help direct marketing resources more effectively than a blanket campaign across an entire locality.
- Provide a mechanism for Governmental Departments (e.g. DECC, DCLG) to compare performances of Local Authorities. Local Authorities may be assessed on the proportion of LSOAs with above benchmark consumption. This may be used by Local Authorities to campaign for extra resources, or by the National Government to assess the relative performances of Local Authorities across the country and put pressure on under-performing councils.

10.5 Conclusions

The key finding from this PhD thesis is that it is possible to use readily available statistical data, published by UK Government Departments, or used in previous UK Government statistical analyses, to generate linear multiple regression models that can explain 65% of the variation in LSOA domestic gas consumption, and 73% of the geographical variation of LSOA domestic electricity consumption. Crucially, these results have been developed with Local Authority representatives, ensuring that the data are easily for Local Authorities to collect, and that the method and the results are understood by non-technical audiences. From addressing the objectives of this research this thesis identified that there are a number of demographic, social, economic, technical, and climatic factors that influence domestic energy consumption. These factors help to explain the skew in the distributions of LSOA per meter consumption of both gas and electricity despite the consumption figures being averaged over 500-700 houses. This knowledge is important for Local Authorities to identify areas within their boundaries that may be most in need of energy efficiency and domestic energy demand reduction policies and goes beyond previous academic studies which seek to determine theoretical possibilities for technical interventions for reducing energy consumption.

This research has improved on the understanding of the factors which influence the variation in domestic energy consumption patterns across England, and, applied this to political context so that this knowledge can be used in a practical environment to bring about reductions in domestic energy consumption and aid in the UK in meeting its 2050 carbon reduction targets. Consultations with Local Authorities ensured that the work produced in this thesis has practical applications for Local Authority energy policy, and that the Local Authorities have confidence in the plausibility of the results. By comparing the benchmark values generated by the regression models against the recorded domestic energy consumption gave Local Authorities a numerical output, the consumption indices. These indices aid in the identification of LSOAs that may benefit from energy efficiency strategies and help distinguish these 'higher than expected' consumers from those areas which are high consumers due to living in larger properties, having higher incomes, being located in colder climates and being electrically heated. This is of benefit not only to the policy makers themselves, but to private contractors involved in providing resources and interventions for insulation and intervention measures.

These findings have the potential to transform the way domestic energy reduction strategies are implemented in England. Previous academic studies in reducing domestic energy consumption had focused on theoretical energy savings in individual houses from technical interventions, such as through insulation or upgrading heating systems, but there had been little research on how these findings could be used or focused by Local Governments to meet energy targets. It had been acknowledged in the academic literature and by Local Authorities that these interventions may not produce the theoretical energy savings in practice, and that from a political perspective it was difficult to judge the success of energy efficiency schemes by comparing them against the expected energy savings. With a localism agenda likely to hold Local Authorities to greater account for delivering energy consumption reduction, and Local Authorities facing unprecedented cuts to their budgets, and it is vital that there are adequate data resources for effective local level policy action. The consumption indices proposed in this research improve the understanding of variation of domestic energy consumption in LSOAs, highlight LSOAs that may benefit most from energy efficiency policies, and enable policy makers to monitor the relative successes of their interventions.

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APPENDICES

APPENDIX 1: LOCAL AUTHORITY INTERVIEW SCHEDULE

ORGANISATION:

DATE:

REPRESENTATIVE:

POSITION:

INTERVIEW SCHEDULE

Section 1: Background Questions

What is your role in this organisation?

What focus, if any does this organisation place on reducing domestic energy consumption?

How large is the team in this department?

How have the Government funding cuts affected the situation in this organisation?

Section 2: Policies

What policies have this organisation enacted in reducing domestic energy consumption?

What powers does this organisation have over the private and public housing stock?

How does this organisation interact with neighbouring councils?

How does this organisation interact with sub-regional, regional and national organisations?

How have national policies such as PAYS and the Green Deal been dealt with by this organisation?

What has motivated this organisation to enact the policies they have implemented?

Did you/have you included NI 186 in your national indicators?

Why did the organisation chose (not) to?

Section 3: Relationship with DECC

Does this organisation utilise the DECC sub-national energy consumption data?

How well does this organisation feel that the data produced by DECC serve the intended purpose?

Are you aware of the intended purpose of the data?

Is the guidance provided by DECC adequate?

How prescriptive do you feel the guidance provided by DECC is?

How does this organisation feel that the DECC data could be improved?

Are you using the data as the primary resource for policy monitoring?

How much consultation do you have with DECC?

Are there regional advisors from DECC to assist with data use?

Section 4: Other Data Sources

How reliant are you on 2001 Census data?

Are there other adequate data sources?

Are these available for the whole of England?

Do you use ONS Neighbourhood Statistics?

Is the data provided by the Government adequate for your needs?

Do you use Experian Data?

Do you find the Experian socio-economic classifications useful?

How would you classify households in your region?

Is there any value in generating classifications (for example by income groups, deprivation, social status)?

Do you collect any data yourself?

Section 5: Comparisons

How adequate do you feel the data is for making comparisons over time?

Do data ‘corrections’ such as weather correction improve or hinder data analysis?

How adequate do you feel the data available is for making comparisons against other Local Authorities?

Is comparison against other Local Authorities a useful exercise?

Section 6: Modelling Techniques and Outcomes

Do you have dedicated staff to model energy consumption?

How useful do you feel models are at predicting energy consumption?

Do you believe models serve an effective purpose in Local Government monitoring?

Section 7: Metrics/Scale

What spatial scale do you operate at?

Do you disaggregate below this?

Would you advise using data at Middle and Lower Layer Super Output Area?

When calculating outcomes by area, do you normalise for the number of people (per capita) or by the number of dwellings?

What benefits do you foresee of this choice?

Section 8: Others

How do you see the future of household energy reduction playing out?

Is there anything else you wish to add?

APPENDIX 2: LOCAL AUTHORITY CODING SCHEDULE

1. Rationale for Energy Efficiency and Carbon Reduction

- **a. Desire to be seen as a leading authority**
- **b. Legislative requirements**
- **c. Tackling fuel poverty**
- d. Meeting 'Decent Homes' requirement
- e. Save money for the council
- f. Fit with other schemes
- g. Social Benefits

2. Policy

- **a. National Policy**
- **b. Regional Policy**
- **c. County Policy**
- **d. District/City Policy**

3. Collaboration

- **a. Active Collaboration**
- **b. Benefits of Collaboration**
- c. Collaborative Funding
- d. Shared Services

4. Interaction with Community

- **a. Promotional Campaigns**
- **b. Involving Community Groups**
- **c. Community Support**
- d. Belief in Climate Change

5. Monitoring Policy Success

- **a. Use of national statistics**

b. Use of self-collected statistics

c. Use of regional statistics

d. Measuring Installments/Rennovations/Activities

e. Qualitative Monitoring

f. Scale

g. Expertise

6. Target Setting

a. National Targets

b. Local Targets

c. Installation Targets

d. No Formal Targets

7. Comparing Against other Authorities

a. Usefulness

b. Aspirations

8. Resources

a. Level of Resources

b. Government Resources

c. Private Funding

d. CERT

9. Political System

a. Changes to Schemes

b. Political Support

c. Political Hierarchy

10. Tenure/House Type

a. Social Housing

b. Private Sector

c. Off-Gas

d. Non-Traditional

11. Behavioural Change

    a. Attitudes

    b. Financial

12. Role of Council

    a. Reputation

    b. Local Knowledge

    c. Outsourcing

    d. Advice

APPENDIX 3: GUIDANCE TO THE METHODOLOGY OF CONSUMPTION INDICES

This Appendix explains the method used to calculate the consumption indices for every LSOA in England based on annually calculated benchmarks. Alternatively Local Authorities may wish to use the 2010 calculated benchmarks, which can be found here: https://lupin.lboro.ac.uk/repository.html?rep=1&pub=211005. Appendix 6 provides guidance for interpretation of the results for Local Authorities. This can be read in conjunction with Appendices 3 and 4 which provide examples for the City of Leicester.

1. SOFTWARE REQUIRED

To create the consumption indices, there is a need for the following software packages which perform the following functions: GIS, Spread Sheet, Database, and Statistical. The following programmes were used for the generation of LSOA consumption indices, and instructions are provided for these platforms. Similar functions are available for alternative software packages.

- ESRI ArcGIS (http://www.esri.com/software/arcgis)
- Microsoft Excel (http://office.microsoft.com/en-gb/)
- Microsoft Access (http://office.microsoft.com/en-gb/)
- IBM SPSS (http://www-01.ibm.com/software/uk/analytics/spss/)

2. DATA SOURCES REQUIRED

The following data sources were required for use in generating the LSOA consumption indices. These were split into the dependent and independent variables in the model. All of these data sources can be downloaded in Microsoft Excel format. Maps for converting the heating degree day data to LSOA scale, and generating the final Local Authority maps can be obtained from the UKBORDERS facility at Edina.

a. Dependent Variables:

Name of Dataset	Manipulation Required	Source	Source URL	Availability
Per Meter Gas Consumption	Data Cleaning	DECC	https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/mlsoa-and-llsoa-electricity-and-gas-estimates	Freely available to all
Per Meter Electricity Consumption	Data Cleaning	DECC	https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/mlsoa-and-llsoa-electricity-and-gas-estimates	Freely available to all

b. Independent variables:

Name of Dataset	Manipulation Required	Source	Source URL	Availability
Median Household Income	No	Experian	http://cdu.mimas.ac.uk/experian/index.htm	Freely available to academics, otherwise obtain commercial license
Average Number of Rooms	No	2001 Census	http://cdu.mimas.ac.uk/2001/index.htm	Freely available to academics, otherwise obtain commercial license
Ratio of Gas to Electricity Meters	Yes[1]	DECC	https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/mlsoa-and-llsoa-electricity-and-gas-estimates	Freely available to all
1988-2004 Average Heating Degree Day	Yes[2]	MET Office	http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/available/annual.html	Freely available to academics, otherwise obtain commercial license

[1]See Step 5

[2]See Step 6

c. Map Data

Name of Dataset	Manipulation Required	Source	Source URL	Availability
LSOA Boundaries	No	EDINA	http://edina.ac.uk/census/	Freely available to academics, otherwise obtain commercial license

3. CLEANING PER METER GAS CONSUMPTION DATA

The Per Meter Gas Consumption data require cleaning before they can be used for any analysis. This is because an LSOA must have at least six gas meters to be published. If the LSOA has less than six gas meters its data is ‘merged’ with neighbouring LSOAs. If the gas consumption cannot be designated to a specific Local Authority then it is listed as unallocated. These steps describe how these LSOAs can be unmerged by hand. This is the most time consuming part. The cleaning is described as follows using Microsoft Excel:

a. Under the column listed ‘LSOA Code’ apply the filter: contains: ‘,’
b. This filters all LSOAs with ‘merged consumption’
c. Separate LSOA codes from ‘merged’ row into new rows for each LSOA
d. Per Meter Gas Consumption is the same for all of the ‘merged’ LSOAs. Total Consumption and Number of Meters are calculated by dividing the ‘merged’ figures by the number of LSOAs ‘merged’ together.
e. ‘Unallocated’ figures could not be assigned to specific LSOAs and should be deleted from the dataset – Filter LSOA code: equals ‘Unallocated’

4. CLEANING THE PER METER ELECTRICITY CONSUMPTION

The Per Meter Electricity Consumption data require cleaning before they can be used for any analysis. This is because some LSOA economy7 consumption figures were merged with neighbouring LSOAs due to the same disclosure criteria as for the gas consumption, out into the correct LSOA, some LSOAs have zero or negative electricity consumption, and some electricity consumption data is listed as ‘unallocated’. The following steps should be followed:

a. To filter all LSOAs with merged consumption, apply the filter: contains: ‘,’
b. Separate LSOA codes from ‘merged’ row into new rows so that each LSOA has its own row
c. Per Meter Economy7 Consumption is the same for all of the ‘merged’ LSOAs. Economy7 Consumption and Number of Meters are calculated by dividing the ‘merged’ figures by the number of LSOAs ‘merged’ together.

d. Figures for the LSOA Economy7 consumption and meters must then be assigned in the relevant section to 'match up' with the LSOA's ordinary domestic figures.
f. 'Unallocated' figures cannot be assigned to specific LSOAs and should be deleted from the spread sheet. This can be done by applying the filter: LSOA code: equals 'Unallocated'

To produce final Per Meter Electricity Consumption figures for each LSOA:

a. For each LSOA sum the ordinary domestic and economy7 consumption figures to calculate a new variable 'total electricity consumption'. Sum the number of ordinary domestic and economy7 meters to calculate a new variable 'total electricity meters'.
b. Divide total electricity consumption by total electricity meters to calculate 'per meter electricity consumption'
c. Remove all LSOAs with negative or zero total electricity consumption by firstly applying the filter: 'Total Electricity Consumption > 0'

5. CREATING THE RATIO OF GAS TO ELECTRICITY METERS VARIABLE

This section describes the method for calculating the ratio of gas to electricity meters using a database. In Microsoft Access the following steps should be followed:

a. Import the Per Meter Gas Consumption spread sheet and Per Meter Electricity Consumption spread sheet into tables in the database
b. Join the two tables (database tools – relationship) based on LSOA code. Set the join type to 'include all records from Per Meter Electricity Consumption'.
c. Run a query to create a new table that includes: LSOA code, number of gas meters, and total number of electricity meters
d. Add a new column to the query table that divides the number of gas meters by total number of electricity meters to calculate 'Ratio of Gas to Electricity Meters'.

6. CREATING THE HEATING DEGREE DAY VARIABLE

The 1988-2004 Heating Degree Day data requires a number of steps. This step is the most technically demanding process and requires the use of GIS software and database software to calculate: a) the average heating degree day figure for the 17 year period and b) assign this figure to LSOAs.

a. Obtain 5kmx5km grid square Heating Degree Day for each year from 1988-2004 inclusive
b. Import all these into ArcGIS
c. Calculate the Average Heating Degree days using the Raster Calculator (Spatial Analyst tool box – Map Algebra – Raster Calculator). Sum all the Heating Degree Day layers (1988-2004) and divide by 17. This is now the Average Heating Degree Day Layer.
d. Convert average heating degree day layer into polygon (Conversion Tools – From Raster – To Polygon)
e. Import full UK LSOA boundaries shapefile into ArcGIS (source: http://edina.ac.uk/maps/)
f. Use the ArcGIS 'union' function (Arc Tool Box-Analyst Tools-Overlay-Union) to match LSOA boundaries to Average Heating Degree Day Grid Squares (the two 'input features'). The new layer will have new areas created by the overlap of LSOA boundaries and Heating Degree Day Grid codes with heating degree day values and the LSOA codes to which they are part of.
g. Import attribute table into Microsoft Access. Create a new column in the table called 'Area Weighted Heating Degree Day'. The contents of this column should be 'Grid Code' multiplied by 'Shape Area'
h. Run a query and Group by LSOA code and sum 'Area Weighted Heating Degree Day'
i. Divide 'Area Weighted Heating Degree Day' by the total LSOA area to calculate 'LSOA Heating Degree Day'

7. CREATING THE DATABASE

This step requires creating separate databases for per meter gas consumption, and per meter electricity consumption. This step is to create a spread sheet containing the independent and dependent variables for each LSOA based on the LSOA code using the query function in Microsoft Access.

a. Join the tables of per meter gas consumption, median household income, average number of rooms, and average heating degree days based on LSOA codes.
b. Create query 'Gas Consumption' including columns 'LSOA code, per meter gas consumption, median household income, average number of rooms, average heating degree days'
c. Join the tables of per meter electricity consumption, median household income, average number of rooms, and ratio of gas to electricity meters based on LSOA codes.
d. Create query 'Electricity Consumption' and include columns 'LSOA code, per meter gas consumption, median household income, average number of rooms, average heating degree days'
e. Export these queries as Spread Sheets 'Gas Consumption' and 'Electricity Consumption'.

8. CREATING THE REGRESSION MODELS

8.1 CREATING GAS CONSUMPTION MODEL

Using SPSS:

a. Import 'Gas Consumption' spreadsheet into SPSS
b. Use 'Compute Variable' function (Transform-Compute Variable) to calculate 'Square Root Gas Consumption' – Numeric Expresssion = SQRT (Per Meter Gas Consumption)
c. Create Regression Model (Analyse – Regression – Linear). Set Dependent Variable as 'Square Root Gas Consumption', Independent Variables are: Median Household Income, Average Number of Rooms, and Average Heating Degree Days.
d. Save 'Unstandardized Predicted Variables'

e. Press ‘OK’ to run regression model

8.2 CREATING ELECTRICITY CONSUMPTION MODEL

Using SPSS:

a. Import ‘Electricity Consumption’ spread sheet into SPSS
b. Use ‘Compute Variable’ function (Transform-Compute Variable) to calculate ‘Square Root Electricity Consumption’ – Numeric Expresssion = SQRT (Per Meter Electricity Consumption)
c. Create Regression Model (Analyse – Regression – Linear). Set Dependent Variable as ‘Square Root Electricity Consumption’, Independent Variables are: Median Household Income, Average Number of Rooms, and Ratio of Gas to Electricity Meters.
d. Save ‘Unstandardized Predicted Variables’
e. Press ‘OK’ to run regression model

9. CREATING THE CONSUMPTION INDICES

This section outlines how to create the consumption indices using the results of the regression model. This can be done in either statistical or spread sheet software. However this section details how to do this in SPSS and export the results as a spread sheet.

9.1 CREATING THE GAS CONSUMPTION INDICES

a. Compute Variable ‘Benchmark Gas Consumption’ figure – Numerical Expression = Unstandardized Predicted Variable*Unstandardized Predicted Variable
b. Compute Variable ‘Gas Consumption Index’ – Numerical Expression = Per Meter Gas Consumption/Benchmark Gas Consumption

9.2 CREATING THE ELECTRICITY CONSUMPTION INDICES

a. Compute Variable 'Benchmark Electricity Consumption' figure – Numerical Expression = Unstandardized Predicted Variable*Unstandardized Predicted Variable
b. Compute Variable 'Electricity Consumption Index' – Numerical Expression = Per Meter Electricity Consumption/Benchmark Electricity Consumption

9.3 ALTERNATIVE METHOD TO CONSTRUCTING CONSUMPTION INDICES

An alternative method to constructing consumption indices for LSOAs would be to use the 2010 benchmark figures. The formulas to do this are:

a. Compute Variable 'Gas Consumption Index' – Numerical Expression = Per Meter Gas Consumption/2010 Benchmark Gas Consumption
b. Compute Variable 'Electricity Consumption Index' – Numerical Expression = 'Per Meter Electricity Consumption/2010 Benchmark Electricity Consumption.

It should be noted that this alternative have not been subjected to the same plausibility and applicability tests as the 'current year benchmark' consumption indices.

These SPSS data files can then be exported as Microsoft Excel files for use in GIS and Spread Sheet software.

10. CREATING MAPS FOR LOCAL AUTHORITIES

Maps of Consumption indices (see examples in Appendices 3 and 4) can be mapped for specific LSOAs in GIS software using the following steps:

a. Obtain Map for LSOAs within Local Authority boundaries from EDINA – (2001-2011 Census Boundaries)
b. Import map boundary into ArcGIS
c. Import consumption index spread sheet into ArcGIS

d. Join the LSOA boundary layers and LSOA data layer based on LSOA code
e. Assign colour scheme through the menus: properties – graded colours – 7 equal intervals with cut-off bands of: 25, 50, 75, 100, 125, 175

APPENDIX 4: LOCAL AUTHORITY GAS OUTPUT (LEICESTER)

LOCAL AUTHORITY GAS CONSUMPTION INDEX 2010

This document indicates the relative level of domestic gas consumption within the Unitary Local Authority of Leicester in 2010. The index is based on the meter readings of the gas consumption (published by DECC) used in the domestic sector, disaggregated to LSOA level. This is compared against the benchmark that represents the expected gas consumption in the Local Authority. These indices enable the identification of LSOAs which may benefit from Green Deal, ECO, behavioural campaigns or renewable heat/energy incentives. The generation of 'benchmark' energy consumption figures use the DECC sub-national residential energy consumption statistics and account for the size of the house, median household income, housing density, and ratio of gas meters to electricity meters. A 'benchmark' average household gas consumption figure is calculated given the specific levels of these variables in each LSOA.

HOW THESE RESULTS WERE CALCULATED:

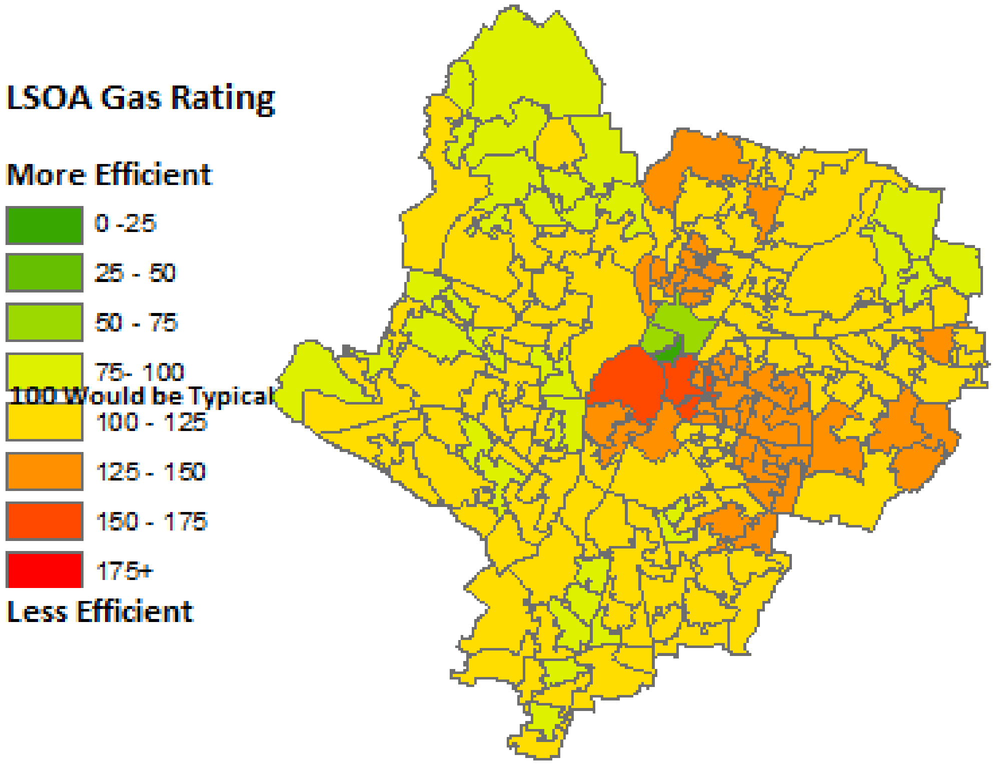
- Using a multiple regression model to account for geographical variation in median household income, the average number of rooms in the house of an LSOA, and heating degree days
- These three variables account for 67% of the variation in LSOA gas consumption in England
- Gives the formula (for 2010) of:

BMG = (26.83 + 9.01ANR + 0.61MHI +9.14HDD)^2

Where *BMG=Benchmark Gas Consumption, ANR=average number of rooms, MHI=median household income (£ 000), HDD=Heating Degree Days (1000 K-days)*

- The benchmark figure for LSOA per meter gas consumption can be obtained using predicted values from the regression model
- The index is calculated by dividing the recorded figures from DECC by the predicted values, and multiplying by 100.
- >100 = area of potential inefficiency (its actual recorded consumption value is higher than the benchmark). < 100 = area of potential efficiency (its actual recorded consumption value is below its benchmark).

GAS	LEICESTER	NATIONAL
AVERAGE	113	100
HIGHEST	139	330
LOWEST	23	7



PRELIMINARY FINDINGS – GAS CONSUMPTION

- Leicester as a Local Authority has a higher level of gas consumption than would be expected
- 37 of Leicester's LSOAs (20% of the Authority) are at, or below their benchmarked gas consumption level
- 110 LSOAs (59% of the Local Authority) are 10% or more above the benchmark level
- 32 LSOAs (17% of the Local Authority) is 30% or more above the benchmark level

Top 10 Lowest Gas Consumption Indices LSOAs (2010)

LSOA Code	Index 2010	Index 2009	Index 2008	Consumption (kW h) 2010	Consumption (kW h) 2009	Consumption (kW h) 2008
E01013755	23(1)	27 (1)	26 (1)	2485	2937	3131
E01013720	60(2)	56 (2)	60 (3)	6457	6340	7449
E01013754	62(3)	59 (3)	58 (2)	6552	6478	6827
E01013616	78(4)	77 (5)	79 (5)	10149	10411	11699
E01013731	79(5)	77 (4)	77 (4)	10584	10608	11569
E01013618	83(6)	82 (8)	84 (8)	10851	11118	12432
E01013726	84(7)	84 (6)	82(6)	9054	9262	9900
E01013615	85(8)	83(7)	83(7)	15129	15206	16639
E01013622	91(9)	89(10)	89 (10)	10757	10847	11862
E01013602	92(10)	93 (17)	96 (24)	11154	11416	12777

Top 10 Highest Gas Consumption Indices LSOAs (2010)

LSOA Code	Index 2010	Index 2009	Index 2008	Consumption (kW h) 2010	Consumption (kW h) 2009	Consumption (kW h) 2008
E01013644	139 (187)	141 (187)	142 (187)	18066	18926	17848
E01013748	120 (186)	123 (186)	120 (186)	17656	19443	18150
E01013712	117 (185)	115 (183)	114 (182)	25648	27394	25207
E01013746	114 (184)	117 (185)	114 (184)	15983	15853	14947
E01013745	114 (183)	115 (184)	115 (185)	21927	24579	22526
E01013744	114 (182)	111 (178)	104 (160)	21559	23864	21936
E01013766	112 (181)	106 (165)	102 (138)	25765	27996	25860
E01013645	112 (180)	107 (167)	108 (170)	15618	16590	15411
E01013646	112 (179)	106 (163)	106 (166)	16592	18553	16949
E01013711	112 (178)	110 (176)	109 (172)	20823	22200	21114

For the full list of Leicester LSOAs, including the underlying data consult Appendix 7.

APPENDIX 5: LOCAL AUTHORITY ELECTRICITY OUTPUT (LEICESTER)

LOCAL AUTHORITY ELECTRICITY CONUMPTION INDEX 2010

This document indicates the relative level of domestic electricity consumption within the Unitary Local Authority of Leicester in 2010. The consumption index is based on the meter readings of the electricity consumption (published by DECC) used in the domestic sector, disaggregated to LSOA level. This is compared against the benchmark that represents the expected electricity consumption in the Local Authority. These indices enable the identification of LSOAs which may benefit from through Green Deal, ECO, behavioural campaigns or renewable heat/energy incentives. The generation of 'benchmark' energy consumption figures use the DECC sub-national residential energy consumption statistics and account for the size of the house, median household income, housing density, and ratio of gas meters to electricity meters. A 'benchmark' average household electricity consumption figure is calculated given the specific levels of these variables in each LSOA.

HOW THESE RESULTS WERE CALCULATED:

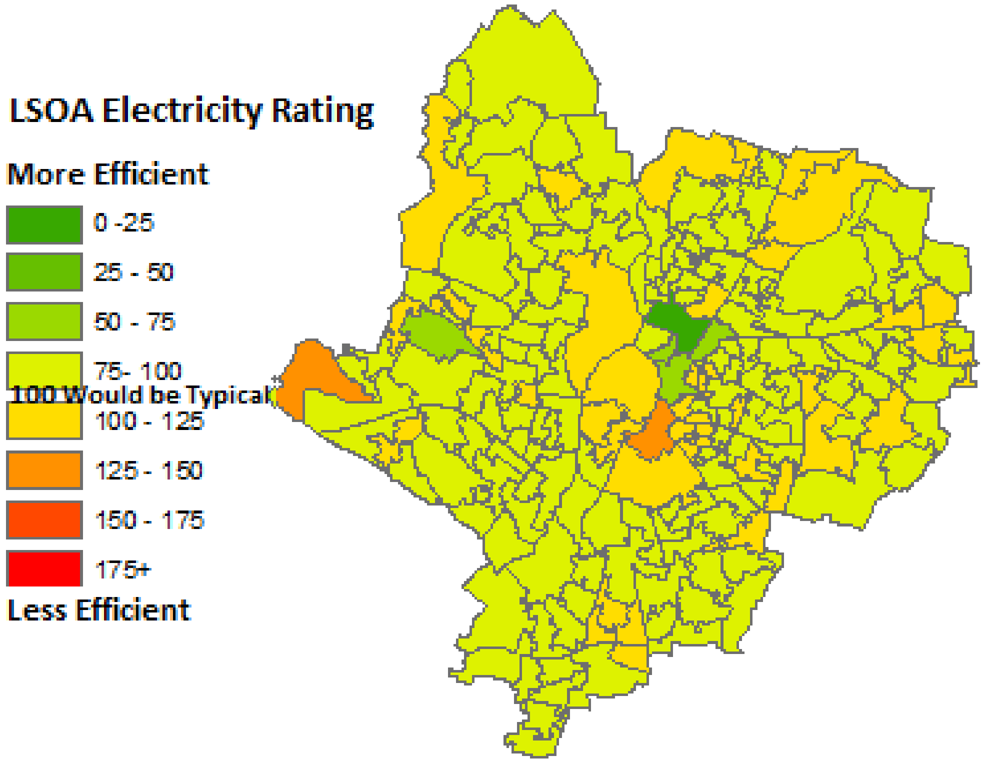
- Using a multiple regression model to account for geographical variation in median household income, the average number of rooms in the house of an LSOA, and heating degree days
- These three variables account for 74% of the variation in LSOA gas consumption in England
- Gives the formula (for 2010) of:

BME = (50.83 + 3.89*ANR* -15.40*RGE* +0.22*MHI*)^2

Where *BME=Benchmark Electricity Consumption*, *ANR=average number of rooms, RGE = Ratio of Gas to Electricity Meters, MHI=median household income (£ 000)*

- The benchmark figure for LSOA per meter gas consumption can be obtained using predicted values from the regression model
- The index is calculated by dividing the recorded figures from DECC by the predicted values, and multiplying by 100.
- >100 = area of potential inefficiency (its actual recorded consumption value is higher than the benchmark). < 100 = area of potential efficiency (its actual recorded consumption value is below its benchmark).

ELECTRICITY	LEICESTER	NATIONAL
AVERAGE	98	100
HIGHEST	139	277
LOWEST	63	33



PRELIMINARY FINDINGS – ELECTRICITY CONSUMPTION

- Leicester as a Local Authority has marginally lower than expected electricity consumption
- 144 of Leicester's LSOAs (77% of the Authority) are at, or below their benchmarked gas consumption level
- 16 LSOAs (8.5% of the Local Authority) are 10% or more above the benchmark level
- 1 LSOAs (0.5% of the Local Authority) is 30% or more above the benchmark level

Top 10 Lowest Electricity Consumption Index LSOAs

LSOA Code	Index 2010	Index 2009	Index 2008	Consumption (kW h) 2010	Consumption (kW h) 2009	Consumption (kW h) 2008
E01013746	63(1)	61(1)	63(1)	2540	2490	2599
E01013720	69(2)	68(2)	69(2)	2125	2176	2222
E01013755	73(3)	69(3)	73(4)	2502	2427	2550
E01013726	76(4)	71(4)	72(3)	2696	2510	2589
E01013715	77(5)	79 (6)	75 (5)	2679	2810	2717
E01013684	80 (6)	80(9)	82 (13)	2855	2905	2987
E01013650	80 (7)	80 (10)	81 (12)	3102	3110	3129
E01013748	81 (8)	81 (11)	79 (9)	3468	3506	3480
E01013778	82 (9)	82 (17)	80 (11)	3206	3266	3082
E01013775	83 (10)	86 (23)	86 (23)	3285	3439	3165

Top 10 Highest Electricity Consumption Index LSOAs

LSOA Code	Index 2010	Index 2009	Index 2008	Consumption (kW h) 2010	Consumption (kW h) 2009	Consumption (kW h) 2008
E01013731	139 (187)	141 (187)	142 (187)	4971	5098	5188
E01013646	120 (186)	123 (186)	120 (186)	4261	4339	4376
E01013661	117 (185)	115 (183)	114 (182)	3958	4038	4041
E01013679	114 (184)	117 (185)	114 (184)	3683	3705	3746
E01013692	114 (183)	115 (184)	115 (185)	4297	4330	4268
E01013766	114 (182)	111 (178)	104 (160)	3603	3796	3619
E01013617	112 (181)	106 (165)	102 (138)	3615	3768	3715
E01013722	112 (180)	107 (167)	108 (170)	4413	4599	4575
E01013662	112 (179)	106 (163)	106 (166)	4274	4599	4631
E01013640	112 (178)	110 (176)	109 (172)	4994	4848	4588

For the full list of Leicester LSOAs, including the underlying data consult Appendix 7.

APPENDIX 6: GUIDE TO INTERPRETING THE CONSUMPTION INDICES

The following section provides a guide to Local Authorities for interpreting consumption indices. These consumption indices highlight to Local Authorities LSOAs within their boundaries with gas and electricity consumption in excess of what might be expected and therefore these LSOAs may benefit from energy efficiency interventions. The indices can also be compared over time to monitor the impact of energy efficiency interventions over time. The examples are for interpreting the results for the City of Leicester, shown in Appendix 4 and 5. LSOA consumption indices for all England LSOAs can be found at: https://lupin.lboro.ac.uk/repository.html?rep=1&pub=211005.

1. **INTERPRETATION OF THE INDEX FOR A SINGLE YEAR**
    a. A consumption index of 100 for a LSOA indicates that this LSOA is consuming 'as expected' levels of the fuel. An index above 100 indicates this LSOA is 'over consuming' the fuel and may benefit from energy efficiency interventions, an index of below 100 indicates the LSOA is 'under consuming' the fuel and may indicate energy efficient behaviour. The further above 100 an LSOA's consumption index indicates the magnitude of the 'over consumption'. In the example of Leicester, the LSOA with the lowest gas consumption index (E01013755) consumes less than 1/3 of the gas consumption to be expected by the average house size, median income, and climate. In 2010 this LSOA has a Consumption Index (CI) of 23, less than ¼ of what would be expected. By contrast the LSOA with the highest gas consumption index (E01013644) consumes almost 40% more than would be expected given these factors (CI=139).
    b. Areas with low consumption indices (i.e. <100) may be high absolute energy consumers. This is because these LSOAs have lower consumption relative to other LSOAs with similar sized houses and incomes. Conversely areas with high consumption indices (i.e. >100) may be low absolute energy consumers. This is because these LSOAs have higher consumption relative to other LSOAs with similar sized houses, incomes, climates, and proportion of electrically heated households, and therefore this may

indicate energy inefficient housing, or energy inefficient behaviours. For an example, the electricity consumption in Leicester there are two LSOAs with similar electricity consumption but have different consumption indices. E01013748 had a consumption index of 79 in 2008 whilst E01013679 had a consumption index of 114 in 2008. Despite their respective annual per meter electricity consumption figures in 2008 being 3480 kW h and 3746 kW h respectively, one LSOA was deemed to be an under-consumer electricity, whilst the other an over-consumer.

2. MONITORING CHANGES IN CONSUMPTION INDICES OVER TIME

Data currently can be compared over a three year period (2008 to 2010). This allows users to monitor changes in relative consumption of each LSOA though this period will be extended as further LSOA gas and electricity consumption data from DECC becomes available. Suggestions of how to use these results are given below:

a. Reductions in the consumption index from year to year may indicate the successful implementation of energy efficiency strategies in that LSOA. For example in Leicester, the LSOA E01013602 has experienced year-on-year reductions in both per meter gas consumption and the gas consumption index, which may suggest energy consumption reductions independent of household income, house size and climate. Other LSOAs, such as E01013726 have experienced falls in gas consumption but not in the gas consumption index which may be as a result of reductions in median household income or the construction of smaller dwellings such as blocks of flats within the LSOA. Local Authorities would be provided with the underlying data for each LSOA to make these judgements. Example data for Leicester are provided in Appendix 7.
b. Large swings in consumption indices from year to year (e.g. a change in the consumption index by over 25 points between two years) may indicate faults with the underlying data. When this happens, the raw data for

consumption, number of meters and median income, and council tax records should be consulted for discrepancies. Discrepancies between the number of electricity meters, council tax housing records and number of gas meters may indicate the incorrect classification of commercial buildings as domestic properties (though it is valid for an LSOA to have a lower number of gas meters to electricity meters and council tax records).

APPENDIX 7: EXAMPLE OF COMPLETE DATASET FOR LEICESTER

2008

LSOA Code	LSOA Name	Per Meter Gas Consumption (kW h)	Number of Gas Meters	Per Meter Electricity Consumption (kW h)	Number of Electricity Meters	Average Number of Rooms	Median Household Income (£)	Heating Degree Days (k-days)	Ratio of Gas to Electricity Meters	Benchmark Gas Consumption (kW h)	Benchmark Electricity Consumption (kW h)	Gas Consumption Index	Electricity Consumption Index
E01013600	Leicester 003A	12819	762	3354	772	4.62	13651	2217	0.99	13494	3256	95	103
E01013601	Leicester 003B	15181	644	3832	660	5.34	15660	2217	0.98	15490	3649	98	105
E01013602	Leicester 003C	12777	810	3443	829	4.45	15327	2217	0.98	13309	3248	96	106
E01013603	Leicester 003D	12068	799	2923	846	4.40	15479	2217	0.94	13262	3284	91	89
E01013604	Leicester 003E	14244	636	3595	678	4.91	15657	2217	0.94	14388	3524	99	102
E01013605	Leicester 003F	16059	705	3469	710	5.06	22521	2217	0.99	15900	3690	101	94
E01013606	Leicester 008A	17186	683	3783	713	5.19	22731	2217	0.96	16213	3821	106	99
E01013607	Leicester 008B	17182	941	4631	1117	5.32	21933	2196	0.84	16363	4062	105	114
E01013608	Leicester 034A	17538	628	3927	622	5.31	25345	2175	1.01	16703	3850	105	102
E01013609	Leicester 034B	17588	739	3654	755	5.18	24847	2175	0.98	16285	3806	108	96
E01013610	Leicester 034C	15266	749	3425	773	5.00	19253	2175	0.97	14967	3605	102	95
E01013611	Leicester 034D	16224	653	3744	664	5.12	23619	2174	0.98	16064	3744	101	100
E01013612	Leicester 034E	18554	654	3700	673	5.37	25595	2175	0.97	17022	3936	109	94
E01013613	Leicester 031A	14866	744	3490	806	5.16	24296	2175	0.92	16159	3921	92	89
E01013614	Leicester 031B	15563	738	3376	727	5.04	22788	2175	1.02	15720	3630	99	93
E01013615	Leicester 001A	16639	554	4252	554	5.85	34962	2217	1.00	20047	4383	83	97
E01013616	Leicester 001B	11699	642	3679	688	4.53	23602	2217	0.93	14808	3572	79	103
E01013617	Leicester 004A	15095	781	4021	1038	4.73	21867	2217	0.75	14946	3942	101	102
E01013618	Leicester 001C	12432	657	3500	707	4.64	22407	2217	0.93	14801	3608	84	97
E01013619	Leicester 001D	13145	637	3269	679	4.77	14851	2217	0.94	13985	3441	94	95
E01013620	Leicester 004B	13154	607	3319	642	4.67	14205	2217	0.95	13702	3387	96	98
E01013621	Leicester 004C	12704	685	3203	735	4.47	12611	2217	0.93	12963	3268	98	98
E01013622	Leicester 004D	11862	630	3693	757	4.36	16878	2217	0.83	13329	3484	89	106
E01013623	Leicester 004E	17068	762	3861	803	5.24	28266	2217	0.95	17240	3980	99	97
E01013624	Leicester 007A	17033	513	3434	523	4.89	15840	2205	0.98	14314	3434	119	100
E01013625	Leicester 006A	16705	673	3048	665	4.62	21332	2217	1.01	14654	3424	114	89
E01013626	Leicester 007B	18439	580	3469	577	5.13	20725	2211	1.01	15759	3651	117	95
E01013627	Leicester 007C	20855	419	3316	420	5.08	22200	2211	1.00	15799	3684	132	90
E01013628	Leicester 006B	15222	681	2974	685	4.39	18923	2217	0.99	13713	3268	111	91
E01013629	Leicester 007D	19113	562	3286	546	5.16	20328	2211	1.03	15666	3611	122	91
E01013630	Leicester 007E	17662	574	3068	570	5.09	18227	2211	1.01	15225	3568	116	86
E01013631	Leicester 026A	16918	554	3559	557	5.28	17375	2175	0.99	15380	3631	110	98
E01013632	Leicester 026B	14559	732	3065	758	4.55	13196	2175	0.97	13116	3260	111	94
E01013633	Leicester 028A	14133	680	3438	706	4.81	16618	2175	0.96	14133	3473	100	99
E01013634	Leicester 028B	15455	624	3373	627	4.88	14751	2175	1.00	14050	3373	110	100
E01013635	Leicester 029A	20171	571	3806	568	5.51	26140	2175	1.01	17389	3965	116	96
E01013636	Leicester 029B	23891	490	4282	514	5.99	32247	2175	0.95	19745	4461	121	96

E01013637	Leicester 028C	14778	749	3151	816	4.80	14473	2175	0.92	13812	3502	107	90
E01013638	Leicester 026C	15596	629	3298	645	4.50	13559	2220	0.98	13217	3233	118	102
E01013639	Leicester 028D	14493	522	3708	534	5.21	17912	2175	0.98	15256	3672	95	101
E01013640	Leicester 026D	15617	643	3651	640	4.97	12741	2220	1.00	14197	3350	110	109
E01013641	Leicester 028E	17808	611	3742	606	5.32	23714	2175	1.01	16489	3819	108	98
E01013642	Leicester 030A	18744	678	3720	755	4.79	30715	2196	0.90	16442	3957	114	94
E01013643	Leicester 030B	16582	723	3331	713	5.37	23522	2175	1.01	16582	3829	100	87
E01013644	Leicester 024A	18926	767	4217	2733	3.63	18427	2196	0.28	11829	4260	160	99
E01013645	Leicester 024B	16590	261	3706	1162	4.44	9286	2175	0.22	12289	4519	135	82
E01013646	Leicester 024C	18553	853	4376	1140	4.16	20062	2175	0.75	13158	3647	141	120
E01013647	Leicester 024D	14647	217	3901	568	3.34	17590	2175	0.38	11013	3863	133	101
E01013648	Leicester 024E	16938	650	3788	671	5.05	12011	2175	0.97	14115	3444	120	110
E01013649	Leicester 030C	17646	553	4312	782	4.74	24271	2196	0.71	15212	4107	116	105
E01013650	Leicester 030D	16175	751	3129	743	5.41	25307	2175	1.01	17026	3863	95	81
E01013651	Leicester 011A	13555	682	3005	695	4.59	17201	2205	0.98	13832	3339	98	90
E01013652	Leicester 011B	15364	587	3592	601	4.97	16328	2205	0.98	14632	3522	105	102
E01013653	Leicester 011C	16280	699	3238	685	4.89	16298	2205	1.02	14407	3373	113	96
E01013654	Leicester 017A	14100	808	2555	851	4.20	17562	2203	0.95	13056	3234	108	79
E01013655	Leicester 011D	16109	736	3438	739	4.76	20051	2205	1.00	14644	3473	110	99
E01013656	Leicester 017B	18201	514	3393	512	5.01	20783	2211	1.00	15424	3571	118	95
E01013657	Leicester 017C	18522	555	3435	537	4.90	20298	2211	1.03	15058	3469	123	99
E01013658	Leicester 017D	17914	574	3064	569	5.00	22400	2211	1.01	15714	3605	114	85
E01013659	Leicester 017E	19130	580	3378	562	4.94	21739	2211	1.03	15427	3519	124	96
E01013660	Leicester 019A	16616	645	3221	667	4.93	20045	2211	0.97	15106	3620	110	89
E01013661	Leicester 019B	15821	459	4268	630	4.55	15927	2216	0.73	13639	3744	116	114
E01013662	Leicester 021A	21674	656	3625	545	5.31	22496	2216	1.20	16419	3420	132	106
E01013663	Leicester 021B	21494	514	3615	512	5.31	21875	2216	1.00	16408	3765	131	96
E01013664	Leicester 019C	12877	764	2683	816	4.20	15008	2216	0.94	12750	3194	101	84
E01013665	Leicester 019D	18387	613	3345	638	4.91	21653	2211	0.96	15322	3636	120	92
E01013666	Leicester 025A	22721	607	3803	607	5.58	26515	2216	1.00	17891	4004	127	95
E01013667	Leicester 019E	14170	673	2739	682	4.48	17407	2216	0.99	13625	3300	104	83
E01013668	Leicester 019F	20346	474	3980	595	4.77	20699	2216	0.80	14851	3864	137	103
E01013669	Leicester 025B	23106	484	3831	480	5.76	28544	2216	1.01	18634	4165	124	92
E01013670	Leicester 025C	21998	697	4008	732	5.62	25488	2216	0.95	17740	4090	124	98
E01013671	Leicester 025D	21748	598	3896	613	5.64	26393	2211	0.98	17974	4101	121	95
E01013672	Leicester 025E	24325	514	4575	521	5.61	28411	2216	0.99	18290	4121	133	111
E01013673	Leicester 036A	15635	634	3647	632	5.20	18756	2174	1.00	15480	3611	101	101
E01013674	Leicester 036B	12974	797	3206	790	4.24	15489	2173	1.01	12720	3113	102	103
E01013675	Leicester 036C	14399	680	3588	700	4.97	18574	2174	0.97	14844	3588	97	100
E01013676	Leicester 036D	12725	808	3462	835	4.69	17037	2173	0.97	13984	3428	91	101
E01013677	Leicester 036E	12455	626	3283	674	4.45	17002	2173	0.93	13392	3384	93	97
E01013678	Leicester 035A	16498	656	3748	690	5.14	19747	2174	0.95	15419	3711	107	101
E01013679	Leicester 035B	17925	536	4041	533	5.21	15177	2174	1.01	14937	3545	120	114
E01013680	Leicester 008C	17320	714	3871	874	5.26	25636	2217	0.82	16816	4208	103	92
E01013681	Leicester 016A	15973	799	3378	788	5.03	22968	2196	1.01	15815	3632	101	93
E01013682	Leicester 016B	14561	781	3168	788	4.98	21033	2196	0.99	15327	3599	95	88
E01013683	Leicester 016C	14789	884	3463	977	4.95	23602	2196	0.90	15733	3805	94	91
E01013684	Leicester 016D	14777	810	2987	899	4.80	19845	2196	0.90	14777	3643	100	82
E01013685	Leicester 008D	16768	618	3554	627	5.19	25211	2217	0.99	16602	3822	101	93

E01013686	Leicester 008E	16542	766	3530	769	5.18	24025	2217	1.00	16378	3756	101	94
E01013687	Leicester 031C	16856	672	3917	808	4.88	24324	2175	0.83	15464	3956	109	99
E01013688	Leicester 031D	15389	655	3158	723	4.88	21056	2175	0.91	14941	3715	103	85
E01013689	Leicester 033A	16366	548	3232	521	5.22	17663	2175	1.05	15296	3514	107	92
E01013690	Leicester 033B	15812	649	3451	625	5.06	20142	2175	1.04	15351	3521	103	98
E01013691	Leicester 035C	14444	591	3619	614	4.70	15409	2175	0.96	13756	3383	105	107
E01013692	Leicester 035D	14105	511	3746	503	4.78	12784	2175	1.02	13562	3257	104	115
E01013693	Leicester 035E	13604	491	3715	505	4.82	14202	2175	0.97	13881	3377	98	110
E01013694	Leicester 013A	14775	662	3335	663	4.90	17193	2205	1.00	14629	3438	101	97
E01013695	Leicester 014A	14495	592	3480	601	4.96	15570	2205	0.99	14495	3480	100	100
E01013696	Leicester 009A	16789	681	3893	725	5.58	27911	2205	0.94	18053	4186	93	93
E01013697	Leicester 009B	18803	754	4415	765	5.40	30089	2205	0.99	17908	4050	105	109
E01013698	Leicester 014B	16340	569	3771	585	5.16	20056	2205	0.97	15712	3697	104	102
E01013699	Leicester 009C	21356	649	4079	670	5.60	29191	2205	0.97	18253	4162	117	98
E01013700	Leicester 013B	17956	583	3852	606	5.11	21884	2205	0.96	15890	3740	113	103
E01013701	Leicester 009D	15777	1247	3624	1719	5.32	31441	2205	0.73	17928	4587	88	79
E01013702	Leicester 030E	20569	624	3642	635	5.84	30580	2196	0.98	19045	4285	108	85
E01013703	Leicester 032A	24198	490	4713	497	6.19	41978	2196	0.99	22200	4809	109	98
E01013704	Leicester 032B	25355	522	4441	606	6.06	39803	2216	0.86	21487	4934	118	90
E01013705	Leicester 033C	17172	686	3403	699	5.32	24415	2196	0.98	16672	3867	103	88
E01013706	Leicester 032C	27396	646	4741	646	6.53	46491	2216	1.00	24244	5098	113	93
E01013707	Leicester 032D	20332	604	3772	605	5.81	29668	2196	1.00	18826	4239	108	89
E01013708	Leicester 033D	19745	580	3768	588	5.62	26218	2196	0.99	17788	4051	111	93
E01013709	Leicester 033E	21258	566	3667	574	5.61	24109	2175	0.99	17283	3986	123	92
E01013710	Leicester 030F	18886	553	4081	795	4.66	29159	2216	0.70	15870	4251	119	96
E01013711	Leicester 030G	22200	557	4356	863	4.77	32533	2196	0.65	16692	4491	133	97
E01013712	Leicester 032E	27394	403	5340	609	5.67	31917	2216	0.66	19023	4899	144	109
E01013713	Leicester 010A	18950	528	3186	506	5.06	19920	2217	1.04	15407	3501	123	91
E01013714	Leicester 010B	20371	537	3227	504	5.26	22652	2211	1.07	16297	3626	125	89
E01013715	Leicester 006C	19515	448	2717	440	5.03	21421	2217	1.02	15612	3575	125	76
E01013716	Leicester 006D	18561	623	2886	567	5.00	20983	2217	1.10	15468	3436	120	84
E01013717	Leicester 010C	15238	442	4068	607	4.87	23023	2211	0.73	15392	4109	99	99
E01013718	Leicester 010D	17391	557	2778	573	4.83	19865	2211	0.97	14864	3516	117	79
E01013719	Leicester 010E	18079	516	2818	503	5.01	21548	2217	1.03	15585	3566	116	79
E01013720	Leicester 010F	7449	564	2222	622	4.06	15748	2211	0.91	12415	3221	60	69
E01013721	Leicester 012A	15498	638	3482	684	5.06	20926	2217	0.93	15654	3744	99	93
E01013722	Leicester 015A	16479	603	4038	604	5.57	15629	2217	1.00	15999	3739	103	108
E01013723	Leicester 012B	15646	486	3801	483	5.59	14986	2217	1.01	15965	3690	98	103
E01013724	Leicester 015B	15959	604	3902	609	5.44	15027	2217	0.99	15647	3647	102	107
E01013725	Leicester 012C	14529	527	3120	607	4.80	12951	2217	0.87	13706	3546	106	88
E01013726	Leicester 012D	9900	596	2589	906	4.11	12376	2196	0.66	12073	3595	82	72
E01013727	Leicester 015C	14348	660	3267	675	4.90	17922	2233	0.98	14792	3513	97	93
E01013728	Leicester 012E	15650	543	4180	556	5.61	15454	2196	0.98	15969	3766	98	111
E01013729	Leicester 020A	15584	538	3946	548	5.09	24058	2220	0.98	16234	3758	96	105
E01013730	Leicester 015D	12405	754	3064	792	4.32	15440	2270	0.95	13197	3225	94	95
E01013731	Leicester 015E	11569	588	5188	650	4.79	19926	2270	0.90	15025	3654	77	142
E01013732	Leicester 005A	18638	770	3746	807	5.04	22199	2205	0.95	15662	3746	119	100
E01013733	Leicester 002A	16903	727	3936	713	4.79	26871	2205	1.02	15797	3611	107	109
E01013734	Leicester 002B	20084	494	4033	540	5.09	25931	2211	0.91	16462	3916	122	103

E01013735	Leicester 002C	17677	461	3856	474	4.93	25412	2205	0.97	15925	3744	111	103
E01013736	Leicester 002D	17238	628	4156	728	4.70	24356	2205	0.86	15255	3813	113	109
E01013737	Leicester 002E	16311	460	3697	469	5.04	29190	2205	0.98	16816	3851	97	96
E01013738	Leicester 006E	21311	487	3854	512	5.35	25692	2211	0.95	17049	3973	125	97
E01013739	Leicester 005B	15091	574	3114	595	4.44	17431	2205	0.96	13596	3312	111	94
E01013740	Leicester 005C	18822	508	3575	508	4.93	21650	2205	1.00	15302	3575	123	100
E01013741	Leicester 005D	18975	529	3712	540	5.01	23481	2205	0.98	15813	3712	120	100
E01013742	Leicester 018A	21704	486	3631	464	5.23	20757	2196	1.05	15959	3595	136	101
E01013743	Leicester 017F	20031	431	3626	422	5.06	19226	2216	1.02	15291	3555	131	102
E01013744	Leicester 018B	23864	475	3672	469	5.46	19145	2216	1.01	16345	3747	146	98
E01013745	Leicester 017G	24579	444	4083	430	5.49	21080	2216	1.03	16720	3781	147	108
E01013746	Leicester 018C	15853	253	2599	696	3.82	17091	2203	0.36	12102	4125	131	63
E01013747	Leicester 021C	21702	569	3529	533	5.22	23652	2216	1.07	16441	3638	132	97
E01013748	Leicester 018D	19443	227	3480	691	4.22	17049	2196	0.33	12962	4405	150	79
E01013749	Leicester 021D	22058	459	3729	443	5.23	22943	2216	1.04	16340	3692	135	101
E01013750	Leicester 021E	21663	444	3728	428	5.37	23570	2216	1.04	16793	3766	129	99
E01013751	Leicester 022A	20381	538	3347	527	5.24	20583	2196	1.02	15923	3678	128	91
E01013752	Leicester 022B	20535	474	3481	458	5.20	22221	2216	1.03	16169	3664	127	95
E01013753	Leicester 022C	18822	504	3391	515	4.94	18993	2196	0.98	14938	3569	126	95
E01013754	Leicester 018E	6827	574	2747	770	3.76	14897	2217	0.75	11771	3350	58	82
E01013755	Leicester 018F	3131	554	2550	797	3.86	15186	2196	0.70	12044	3493	26	73
E01013756	Leicester 027A	19934	643	3737	675	5.36	21025	2216	0.95	16339	3853	122	97
E01013757	Leicester 027B	24491	488	4708	492	5.84	28820	2216	0.99	18839	4242	130	111
E01013758	Leicester 021F	23467	462	4013	446	5.72	23385	2216	1.04	17644	3934	133	102
E01013759	Leicester 027C	26477	540	4350	544	6.00	25450	2216	0.99	18778	4224	141	103
E01013760	Leicester 022D	17300	625	3752	693	4.72	21430	2196	0.90	14786	3642	117	103
E01013761	Leicester 022E	17019	594	3166	626	4.74	18996	2196	0.95	14423	3518	118	90
E01013762	Leicester 022F	19855	555	3562	555	5.35	24324	2216	1.00	16826	3830	118	93
E01013763	Leicester 027D	15945	744	3725	841	4.38	20195	2196	0.88	13745	3515	116	106
E01013764	Leicester 027E	22974	456	4177	465	5.57	27445	2216	0.98	17948	4095	128	102
E01013765	Leicester 027F	17200	576	3004	583	5.00	19933	2216	0.99	15357	3576	112	84
E01013766	Leicester 027G	27996	480	4588	515	5.98	28298	2216	0.93	19175	4412	146	104
E01013767	Leicester 014C	19171	569	3823	579	5.49	24147	2211	0.98	17117	3941	112	97
E01013768	Leicester 014D	14728	708	3366	704	4.42	18034	2211	1.01	13637	3236	108	104
E01013769	Leicester 014E	13042	653	2965	661	4.42	14662	2211	0.99	13174	3189	99	93
E01013770	Leicester 013C	17868	538	3747	549	5.07	23515	2211	0.98	15954	3747	112	100
E01013771	Leicester 013D	21115	533	4079	534	5.68	27340	2211	1.00	18202	4079	116	100
E01013772	Leicester 014F	13782	607	3538	618	4.89	16678	2211	0.98	14507	3469	95	102
E01013773	Leicester 013E	17090	553	3540	576	5.20	19146	2211	0.96	15679	3727	109	95
E01013774	Leicester 023A	16038	740	3493	714	5.10	18605	2175	1.04	15130	3528	106	99
E01013775	Leicester 029C	15222	912	3165	946	5.04	22707	2175	0.96	15693	3724	97	85
E01013776	Leicester 023B	17275	588	3994	744	4.72	21662	2175	0.79	14765	3878	117	103
E01013777	Leicester 029D	15897	754	3245	771	5.08	24620	2175	0.98	16057	3774	99	86
E01013778	Leicester 023C	12913	640	3082	1087	4.19	15773	2175	0.59	12660	3852	102	80
E01013779	Leicester 023D	15713	745	3393	930	4.54	22747	2175	0.80	14415	3812	109	89
E01013780	Leicester 020B	21781	565	4213	657	5.74	30475	2175	0.86	18777	4482	116	94
E01013781	Leicester 023E	16271	577	3849	743	4.60	23085	2175	0.78	14659	3888	111	99
E01013782	Leicester 023F	16732	569	3579	692	4.87	22456	2175	0.82	15211	3890	110	92
E01013783	Leicester 020C	20513	603	3759	629	5.75	25314	2175	0.96	17837	4131	115	91

E01013784	Leicester 023G	19157	499	3747	545	5.49	25190	2175	0.92	17258	4118	111	91
E01013785	Leicester 020D	24414	546	4376	547	6.22	33569	2196	1.00	20690	4558	118	96
E01013786	Leicester 020E	16878	671	3353	674	4.98	23255	2175	1.00	15627	3645	108	92

2009

LSOA Code	LSOA Name	Per Meter Gas Consumption (kW h)	Number of Gas Meters	Per Meter Electricity Consumption (kW h)	Number of Electricity Meters	Average Number of Rooms	Median Household Income (£)	Heating Degree Days (k-days)	Ratio of Gas to Electricity Meters	Benchmark Gas Consumption (kW h)	Benchmark Electricity Consumption (kW h)	Gas Consumption Index	Electricity Consumption Index
E01013600	Leicester 003A	11643	763	3298	772	4.62	14861	2217	0.99	12128	3233	96	102
E01013601	Leicester 003B	13939	646	3820	659	5.34	17588	2217	0.98	13939	3604	100	106
E01013602	Leicester 003C	11416	813	3288	830	4.45	17831	2217	0.98	12275	3256	93	101
E01013603	Leicester 003D	10847	779	2924	849	4.40	16220	2217	0.92	11920	3286	91	89
E01013604	Leicester 003E	12621	636	3416	675	4.91	17880	2217	0.94	13147	3486	96	98
E01013605	Leicester 003F	14505	709	3307	713	5.06	24237	2217	0.99	14361	3634	101	91
E01013606	Leicester 008A	16014	685	3724	713	5.19	24331	2217	0.96	14692	3761	109	99
E01013607	Leicester 008B	15845	946	4599	1167	5.32	24809	2196	0.81	14948	4106	106	112
E01013608	Leicester 034A	15949	636	3876	626	5.31	27606	2175	1.02	15336	3800	104	102
E01013609	Leicester 034B	15923	743	3660	756	5.18	26960	2175	0.98	15022	3773	106	97
E01013610	Leicester 034C	13906	754	3339	773	5.00	20948	2175	0.98	13768	3552	101	94
E01013611	Leicester 034D	14634	654	3738	664	5.12	24215	2174	0.98	14489	3665	101	102
E01013612	Leicester 034E	17035	655	3822	671	5.37	27489	2175	0.98	15486	3900	110	98
E01013613	Leicester 031A	13603	746	3265	805	5.16	26266	2175	0.93	14786	3841	92	85
E01013614	Leicester 031B	14082	742	3339	729	5.04	25038	2175	1.02	14369	3629	98	92
E01013615	Leicester 001A	15206	546	4221	552	5.85	38517	2217	0.99	18320	4397	83	96
E01013616	Leicester 001B	10411	641	3445	689	4.53	25140	2217	0.93	13521	3551	77	97
E01013617	Leicester 004A	14123	896	4014	1051	4.73	25104	2217	0.85	13846	3787	102	106
E01013618	Leicester 001C	11118	656	3444	712	4.64	24012	2217	0.92	13559	3588	82	96
E01013619	Leicester 001D	12009	638	3396	685	4.77	17187	2217	0.93	12776	3465	94	98
E01013620	Leicester 004B	11444	611	3185	646	4.67	15796	2217	0.95	12439	3353	92	95
E01013621	Leicester 004C	11699	738	2964	787	4.47	13540	2217	0.94	11699	3221	100	92
E01013622	Leicester 004D	10847	630	3522	759	4.36	18554	2217	0.83	12188	3487	89	101
E01013623	Leicester 004E	15634	767	3892	791	5.24	30585	2217	0.97	15792	3932	99	99
E01013624	Leicester 007A	15208	515	3409	525	4.89	16509	2205	0.98	12888	3409	118	100
E01013625	Leicester 006A	15606	688	3076	662	4.62	22621	2217	1.04	13338	3344	117	92
E01013626	Leicester 007B	17221	581	3412	583	5.13	21284	2211	1.00	14116	3592	122	95
E01013627	Leicester 007C	19182	419	3510	421	5.08	23019	2211	1.00	14209	3618	135	97
E01013628	Leicester 006B	13575	678	2888	688	4.39	18953	2217	0.99	12341	3245	110	89
E01013629	Leicester 007D	17529	562	3358	548	5.16	20123	2211	1.03	14023	3535	125	95
E01013630	Leicester 007E	17160	554	3147	572	5.09	17067	2211	0.97	13406	3497	128	90
E01013631	Leicester 026A	15262	552	3664	554	5.28	19308	2175	1.00	14002	3592	109	102
E01013632	Leicester 026B	13511	732	3016	757	4.55	14197	2175	0.97	11852	3208	114	94
E01013633	Leicester 028A	13067	678	3367	700	4.81	17789	2175	0.97	12938	3401	101	99
E01013634	Leicester 028B	14072	624	3351	627	4.88	16700	2175	1.00	12910	3351	109	100
E01013635	Leicester 029A	18212	577	3872	569	5.51	27239	2175	1.01	15700	3872	116	100
E01013636	Leicester 029B	21226	492	4201	510	5.99	33020	2175	0.96	17688	4331	120	97
E01013637	Leicester 028C	13584	726	3171	820	4.80	15399	2175	0.89	12578	3485	108	91

E01013638	Leicester 026C	13837	631	3210	647	4.50	15017	2220	0.98	12032	3210	115	100
E01013639	Leicester 028D	14120	390	3697	535	5.21	19771	2175	0.73	13980	4063	101	91
E01013640	Leicester 026D	14407	647	3659	642	4.97	14911	2220	1.01	12863	3326	112	110
E01013641	Leicester 028E	16210	613	3831	619	5.32	25665	2175	0.99	15009	3793	108	101
E01013642	Leicester 030A	17248	677	3648	775	4.79	32429	2196	0.87	14998	3965	115	92
E01013643	Leicester 030B	14799	723	3444	723	5.37	25156	2175	1.00	15101	3785	98	91
E01013644	Leicester 024A	17848	703	4425	2694	3.63	18202	2196	0.26	10817	4214	165	105
E01013645	Leicester 024B	15411	277	4010	1209	4.44	8355	2175	0.23	10930	4358	141	92
E01013646	Leicester 024C	16949	861	4339	1141	4.16	17917	2175	0.75	11689	3527	145	123
E01013647	Leicester 024D	13359	219	3672	575	3.34	20556	2175	0.38	10519	3949	127	93
E01013648	Leicester 024E	15117	653	3541	638	5.05	15031	2175	1.02	12921	3340	117	106
E01013649	Leicester 030C	16077	556	4312	792	4.74	27426	2196	0.70	14227	4146	113	104
E01013650	Leicester 030D	14578	753	3110	753	5.41	28029	2175	1.00	15675	3888	93	80
E01013651	Leicester 011A	12518	680	3044	696	4.59	18179	2205	0.98	12518	3309	100	92
E01013652	Leicester 011B	13855	587	3447	609	4.97	17763	2205	0.96	13195	3482	105	99
E01013653	Leicester 011C	14889	753	3201	690	4.89	17230	2205	1.09	13061	3233	114	99
E01013654	Leicester 017A	12357	813	2459	855	4.20	17664	2203	0.95	11769	3193	105	77
E01013655	Leicester 011D	14583	734	3430	735	4.76	21450	2205	1.00	13379	3430	109	100
E01013656	Leicester 017B	16607	512	3305	512	5.01	21856	2211	1.00	13955	3554	119	93
E01013657	Leicester 017C	17367	558	3411	534	4.90	22239	2211	1.04	13783	3445	126	99
E01013658	Leicester 017D	16789	581	3032	566	5.00	22525	2211	1.03	13991	3526	120	86
E01013659	Leicester 017E	17085	574	3271	577	4.94	22311	2211	0.99	13890	3556	123	92
E01013660	Leicester 019A	15335	646	3246	669	4.93	21390	2211	0.97	13692	3567	112	91
E01013661	Leicester 019B	14821	454	4330	636	4.55	18051	2216	0.71	12560	3765	118	115
E01013662	Leicester 021A	20249	662	3578	547	5.31	24647	2216	1.21	14999	3376	135	106
E01013663	Leicester 021B	19523	518	3720	509	5.31	23347	2216	1.02	14790	3683	132	101
E01013664	Leicester 019C	11526	764	2730	817	4.20	15980	2216	0.94	11526	3174	100	86
E01013665	Leicester 019D	16704	619	3465	639	4.91	23114	2211	0.97	13920	3609	120	96
E01013666	Leicester 025A	21182	608	3682	609	5.58	28714	2216	1.00	16169	3959	131	93
E01013667	Leicester 019E	13004	673	2614	684	4.48	19346	2216	0.98	12504	3309	104	79
E01013668	Leicester 019F	18796	474	4028	594	4.77	24040	2216	0.80	13821	3873	136	104
E01013669	Leicester 025B	21216	485	3790	485	5.76	31286	2216	1.00	16973	4119	125	92
E01013670	Leicester 025C	20048	705	3833	732	5.62	27870	2216	0.96	16168	4035	124	95
E01013671	Leicester 025D	19934	601	3877	616	5.64	29436	2211	0.98	16474	4081	121	95
E01013672	Leicester 025E	22896	514	4599	523	5.61	31466	2216	0.98	16712	4106	137	112
E01013673	Leicester 036A	14094	634	3666	636	5.20	19255	2174	1.00	13818	3559	102	103
E01013674	Leicester 036B	12048	801	2855	796	4.24	16351	2173	1.01	11585	3103	104	92
E01013675	Leicester 036C	13271	680	3509	693	4.97	19590	2174	0.98	13405	3509	99	100
E01013676	Leicester 036D	11637	810	3489	832	4.69	18744	2173	0.97	12788	3387	91	103
E01013677	Leicester 036E	11298	628	3286	683	4.45	18043	2173	0.92	12280	3353	92	98
E01013678	Leicester 035A	15262	656	3762	691	5.14	21160	2174	0.95	14002	3688	109	102
E01013679	Leicester 035B	15862	536	4038	531	5.21	16281	2174	1.01	13442	3451	118	117
E01013680	Leicester 008C	16997	628	3936	839	5.26	27358	2217	0.75	15313	4279	111	92
E01013681	Leicester 016A	14651	798	3209	791	5.03	24557	2196	1.01	14364	3606	102	89
E01013682	Leicester 016B	13117	773	3048	809	4.98	22695	2196	0.96	13954	3629	94	84
E01013683	Leicester 016C	13426	892	3208	1018	4.95	24754	2196	0.88	14283	3819	94	84

E01013684	Leicester 016D	13039	813	2905	901	4.80	21505	2196	0.90	13442	3631	97	80
E01013685	Leicester 008D	15209	619	3630	627	5.19	27121	2217	0.99	15058	3781	101	96
E01013686	Leicester 008E	16073	586	3533	768	5.18	25863	2217	0.76	14882	4157	108	85
E01013687	Leicester 031C	15421	656	3632	804	4.88	26563	2175	0.82	14279	3948	108	92
E01013688	Leicester 031D	13933	667	3118	725	4.88	22688	2175	0.92	13660	3668	102	85
E01013689	Leicester 033A	14937	553	3196	536	5.22	18229	2175	1.03	13704	3474	109	92
E01013690	Leicester 033B	14430	662	3452	627	5.06	21504	2175	1.06	13875	3452	104	100
E01013691	Leicester 035C	12937	588	3796	617	4.70	15264	2175	0.95	12321	3329	105	114
E01013692	Leicester 035D	12607	512	3705	505	4.78	13595	2175	1.01	12240	3221	103	115
E01013693	Leicester 035E	12608	502	3768	506	4.82	16056	2175	0.99	12608	3335	100	113
E01013694	Leicester 013A	13328	663	3291	660	4.90	19857	2205	1.00	13463	3428	99	96
E01013695	Leicester 014A	13262	592	3076	605	4.96	18391	2205	0.98	13262	3457	100	89
E01013696	Leicester 009A	15220	826	3916	840	5.58	32067	2205	0.98	16725	4079	91	96
E01013697	Leicester 009B	18190	423	4481	808	5.40	35198	2205	0.52	16843	5035	108	89
E01013698	Leicester 014B	14861	568	3938	586	5.16	21141	2205	0.97	14153	3646	105	108
E01013699	Leicester 009C	19290	682	4037	673	5.60	30657	2205	1.01	16487	3997	117	101
E01013700	Leicester 013B	16441	585	3865	600	5.11	23994	2205	0.98	14422	3681	114	105
E01013701	Leicester 009D	14611	1452	3749	1887	5.32	34721	2205	0.77	16603	4463	88	84
E01013702	Leicester 030E	18839	626	3835	641	5.84	34041	2196	0.98	17607	4262	107	90
E01013703	Leicester 032A	22457	492	4757	500	6.19	44135	2196	0.98	20051	4709	112	101
E01013704	Leicester 032B	23335	534	4621	620	6.06	43938	2216	0.86	19775	4916	118	94
E01013705	Leicester 033C	15732	692	3395	709	5.32	26881	2196	0.98	15274	3857	103	88
E01013706	Leicester 032C	25170	653	4618	657	6.53	51944	2216	0.99	22473	5131	112	90
E01013707	Leicester 032D	18776	606	3756	610	5.81	33351	2196	0.99	17385	4220	108	89
E01013708	Leicester 033D	18377	581	3686	589	5.62	27728	2196	0.99	16120	3963	114	93
E01013709	Leicester 033E	18877	566	3766	573	5.61	26036	2175	0.99	15731	3923	120	96
E01013710	Leicester 030F	17103	556	3869	797	4.66	32721	2216	0.70	14872	4251	115	91
E01013711	Leicester 030G	21114	573	4370	870	4.77	34677	2196	0.66	15300	4414	138	99
E01013712	Leicester 032E	25207	405	5210	606	5.67	35151	2216	0.67	17384	4869	145	107
E01013713	Leicester 010A	17770	528	3218	513	5.06	21862	2217	1.03	14103	3497	126	92
E01013714	Leicester 010B	18820	536	3301	508	5.26	23655	2211	1.06	14703	3588	128	92
E01013715	Leicester 006C	17829	450	2810	443	5.03	22694	2217	1.02	14150	3558	126	79
E01013716	Leicester 006D	16774	619	2968	567	5.00	22681	2217	1.09	14096	3411	119	87
E01013717	Leicester 010C	13766	440	4016	607	4.87	23851	2211	0.72	13905	4057	99	99
E01013718	Leicester 010D	16072	557	2776	571	4.83	20416	2211	0.98	13393	3470	120	80
E01013719	Leicester 010E	16407	518	2972	502	5.01	23483	2217	1.03	14144	3539	116	84
E01013720	Leicester 010F	6340	562	2176	626	4.06	15417	2211	0.90	11321	3200	56	68
E01013721	Leicester 012A	14106	639	3398	685	5.06	22516	2217	0.93	14106	3693	100	92
E01013722	Leicester 015A	14904	607	3916	603	5.57	18139	2217	1.01	14470	3660	103	107
E01013723	Leicester 012B	13901	488	3930	487	5.59	16927	2217	1.00	14331	3639	97	108
E01013724	Leicester 015B	14465	603	3847	613	5.44	15886	2217	0.98	13909	3596	104	107
E01013725	Leicester 012C	12662	531	3192	610	4.80	14475	2217	0.87	12414	3508	102	91
E01013726	Leicester 012D	9262	604	2510	907	4.11	12972	2196	0.67	11026	3535	84	71
E01013727	Leicester 015C	12975	661	3230	677	4.90	18730	2233	0.98	13240	3473	98	93
E01013728	Leicester 012E	14351	544	3996	557	5.61	17116	2196	0.98	14351	3700	100	108
E01013729	Leicester 020A	14282	540	3738	550	5.09	26149	2220	0.98	14724	3738	97	100

E01013730	Leicester 015D	11218	753	3030	790	4.32	16767	2270	0.95	12062	3224	93	94
E01013731	Leicester 015E	10608	596	5098	649	4.79	22531	2270	0.92	13777	3615	77	141
E01013732	Leicester 005A	16876	775	3807	808	5.04	24300	2205	0.96	14302	3696	118	103
E01013733	Leicester 002A	15414	737	3940	696	4.79	28966	2205	1.06	14542	3550	106	111
E01013734	Leicester 002B	18393	496	4107	541	5.09	26920	2211	0.92	14833	3874	124	106
E01013735	Leicester 002C	16337	460	3758	475	4.93	27068	2205	0.97	14587	3720	112	101
E01013736	Leicester 002D	16068	631	4110	726	4.70	26925	2205	0.87	14095	3805	114	108
E01013737	Leicester 002E	15067	460	3506	469	5.04	29184	2205	0.98	15067	3770	100	93
E01013738	Leicester 006E	19413	488	3834	513	5.35	26746	2211	0.95	15407	3912	126	98
E01013739	Leicester 005B	13602	579	3130	600	4.44	18738	2205	0.97	12365	3295	110	95
E01013740	Leicester 005C	17343	511	3523	509	4.93	21193	2205	1.00	13656	3488	127	101
E01013741	Leicester 005D	17500	529	3530	540	5.01	23597	2205	0.98	14228	3640	123	97
E01013742	Leicester 018A	19426	484	3743	468	5.23	22321	2196	1.03	14390	3599	135	104
E01013743	Leicester 017F	18454	431	3820	423	5.06	20618	2216	1.02	13875	3505	133	109
E01013744	Leicester 018B	21936	476	3887	468	5.46	21619	2216	1.02	14822	3702	148	105
E01013745	Leicester 017G	22526	441	4087	434	5.49	22561	2216	1.02	15017	3749	150	109
E01013746	Leicester 018C	14947	258	2490	699	3.82	17681	2203	0.37	11072	4082	135	61
E01013747	Leicester 021C	19800	565	3652	534	5.22	23820	2216	1.06	14667	3581	135	102
E01013748	Leicester 018D	18150	227	3506	694	4.22	16853	2196	0.33	11710	4328	155	81
E01013749	Leicester 021D	19505	451	3703	444	5.23	24855	2216	1.02	14889	3703	131	100
E01013750	Leicester 021E	20261	444	3818	435	5.37	24556	2216	1.02	15120	3743	134	102
E01013751	Leicester 022A	18500	539	3263	531	5.24	22249	2196	1.02	14453	3626	128	90
E01013752	Leicester 022B	19052	478	3628	465	5.20	23425	2216	1.03	14544	3628	131	100
E01013753	Leicester 022C	17362	504	3419	516	4.94	19123	2196	0.98	13355	3488	130	98
E01013754	Leicester 018E	6478	574	2763	769	3.76	17315	2217	0.75	10980	3369	59	82
E01013755	Leicester 018F	2937	552	2427	798	3.86	17054	2196	0.69	10878	3518	27	69
E01013756	Leicester 027A	18325	653	3669	685	5.36	23776	2216	0.95	14898	3822	123	96
E01013757	Leicester 027B	22422	487	4501	495	5.84	33306	2216	0.98	17517	4247	128	106
E01013758	Leicester 021F	21796	463	4002	451	5.72	25126	2216	1.03	15909	3885	137	103
E01013759	Leicester 027C	23842	540	4319	548	6.00	31135	2216	0.99	17531	4234	136	102
E01013760	Leicester 022D	15623	626	3697	701	4.72	22378	2196	0.89	13353	3625	117	102
E01013761	Leicester 022E	15498	604	3404	627	4.74	20353	2196	0.96	13134	3474	118	98
E01013762	Leicester 022F	18398	554	3665	561	5.35	25523	2216	0.99	15205	3818	121	96
E01013763	Leicester 027D	14850	743	3661	844	4.38	21796	2196	0.88	12692	3486	117	105
E01013764	Leicester 027E	21382	457	4068	465	5.57	28227	2216	0.98	16077	3988	133	102
E01013765	Leicester 027F	15449	579	3229	587	5.00	21991	2216	0.99	13918	3588	111	90
E01013766	Leicester 027G	25860	476	4848	518	5.98	30419	2216	0.92	17356	4367	149	111
E01013767	Leicester 014C	17533	571	3867	580	5.49	25470	2211	0.98	15516	3867	113	100
E01013768	Leicester 014D	13851	684	3323	716	4.42	19157	2211	0.96	12367	3323	112	100
E01013769	Leicester 014E	12067	655	2977	667	4.42	16257	2211	0.98	11948	3201	101	93
E01013770	Leicester 013C	16454	539	3708	547	5.07	24196	2211	0.99	14433	3672	114	101
E01013771	Leicester 013D	19196	534	4049	535	5.68	29578	2211	1.00	16548	4049	116	100
E01013772	Leicester 014F	12906	610	3554	620	4.89	17928	2211	0.98	13169	3417	98	104
E01013773	Leicester 013E	15271	553	3603	579	5.20	20817	2211	0.96	14140	3677	108	98
E01013774	Leicester 023A	14499	742	3315	712	5.10	20555	2175	1.04	13809	3489	105	95
E01013775	Leicester 029C	14307	744	3439	951	5.04	23529	2175	0.78	14165	3999	101	86

E01013776	Leicester 023B	15900	591	3594	755	4.72	23901	2175	0.78	13590	3864	117	93
E01013777	Leicester 029D	14290	757	3200	777	5.08	26023	2175	0.97	14582	3721	98	86
E01013778	Leicester 023C	11553	642	3266	1103	4.19	18776	2175	0.58	11789	3888	98	84
E01013779	Leicester 023D	14229	745	3254	920	4.54	23980	2175	0.81	13298	3740	107	87
E01013780	Leicester 020B	20229	564	4319	704	5.74	33434	2175	0.80	17143	4546	118	95
E01013781	Leicester 023E	15055	583	3778	742	4.60	24317	2175	0.79	13442	3817	112	99
E01013782	Leicester 023F	15218	571	3373	698	4.87	24229	2175	0.82	13961	3877	109	87
E01013783	Leicester 020C	18532	603	3722	627	5.75	27138	2175	0.96	16256	4090	114	91
E01013784	Leicester 023G	17411	499	3682	553	5.49	27176	2175	0.90	15686	4091	111	90
E01013785	Leicester 020D	22378	544	4414	552	6.22	37408	2196	0.99	18964	4551	118	97
E01013786	Leicester 020E	15353	669	3312	696	4.98	25346	2175	0.96	14349	3680	107	90

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LSOA Code	LSOA Name	Per Meter Gas Consumption (kW h)	Number of Gas Meters	Per Meter Electricity Consumption (kW h)	Number of Electricity Meters	Average Number of Rooms	Median Household Income (£)	Heating Degree Days (k-days)	Ratio of Gas to Electricity Meters	Benchmark Gas Consumption (kW h)	Benchmark Electricity Consumption (kW h)	Gas Consumption Index	Electricity Consumption Index
E01013600	Leicester 003A	11766	765	3264	772	4.62	16681	2217	0.99	12130	3231	97	101
E01013601	Leicester 003B	13533	648	3874	660	5.34	17971	2217	0.98	13810	3620	98	107
E01013602	Leicester 003C	11154	810	3292	830	4.45	19050	2217	0.98	12124	3228	92	102
E01013603	Leicester 003D	10901	778	2822	846	4.40	16509	2217	0.92	11721	3243	93	87
E01013604	Leicester 003E	12586	638	3382	678	4.91	17258	2217	0.94	12843	3451	98	98
E01013605	Leicester 003F	14636	713	3364	728	5.06	22442	2217	0.98	13808	3578	106	94
E01013606	Leicester 008A	15939	685	3779	715	5.19	23691	2217	0.96	14359	3705	111	102
E01013607	Leicester 008B	16342	965	4274	1133	5.32	23436	2196	0.85	14462	3994	113	107
E01013608	Leicester 034A	16197	637	3965	625	5.31	27354	2175	1.02	14997	3740	108	106
E01013609	Leicester 034B	15742	741	3625	756	5.18	27688	2175	0.98	14713	3776	107	96
E01013610	Leicester 034C	13666	767	3452	779	5.00	21886	2175	0.98	13530	3523	101	98
E01013611	Leicester 034D	14539	654	3657	667	5.12	25240	2174	0.98	14254	3694	102	99
E01013612	Leicester 034E	16994	662	3754	681	5.37	28203	2175	0.97	15174	3870	112	97
E01013613	Leicester 031A	13380	746	3239	811	5.16	24566	2175	0.92	14234	3811	94	85
E01013614	Leicester 031B	14158	744	3415	733	5.04	25297	2175	1.02	14018	3595	101	95
E01013615	Leicester 001A	15129	546	4292	554	5.85	37019	2217	0.99	17799	4335	85	99
E01013616	Leicester 001B	10149	642	3443	690	4.53	24974	2217	0.93	13011	3478	78	99
E01013617	Leicester 004A	14767	897	4182	1041	4.73	25256	2217	0.86	13547	3734	109	112
E01013618	Leicester 001C	10850	656	3419	711	4.64	23415	2217	0.92	13073	3524	83	97
E01013619	Leicester 001D	12035	639	3024	685	4.77	17652	2217	0.93	12536	3437	96	88
E01013620	Leicester 004B	11264	611	3143	672	4.67	16102	2217	0.91	12112	3380	93	93
E01013621	Leicester 004C	11167	740	3029	797	4.47	15680	2217	0.93	11755	3257	95	93
E01013622	Leicester 004D	10757	630	3552	760	4.36	18545	2217	0.83	11821	3448	91	103
E01013623	Leicester 004E	15786	767	3764	799	5.24	29710	2217	0.96	15326	3880	103	97
E01013624	Leicester 007A	15315	516	3346	526	4.89	20065	2205	0.98	13090	3449	117	97
E01013625	Leicester 006A	15626	691	3205	664	4.62	20272	2217	1.04	12602	3237	124	99
E01013626	Leicester 007B	17260	584	3311	588	5.13	21528	2211	0.99	13808	3561	125	93
E01013627	Leicester 007C	18735	419	3445	421	5.08	24242	2211	1.00	14193	3627	132	95
E01013628	Leicester 006B	13406	674	2887	684	4.39	18236	2217	0.99	11864	3173	113	91
E01013629	Leicester 007D	17406	567	3407	548	5.16	21190	2211	1.03	13814	3513	126	97
E01013630	Leicester 007E	16472	552	3176	577	5.09	20538	2211	0.96	13613	3610	121	88
E01013631	Leicester 026A	15194	553	3812	554	5.28	19886	2175	1.00	13813	3596	110	106
E01013632	Leicester 026B	13046	734	3185	758	4.55	15097	2175	0.97	11648	3217	112	99
E01013633	Leicester 028A	13307	678	3413	699	4.81	18567	2175	0.97	12673	3413	105	100
E01013634	Leicester 028B	13656	623	3390	628	4.88	16935	2175	0.99	12528	3357	109	101
E01013635	Leicester 029A	17968	577	3811	573	5.51	25236	2175	1.01	15099	3811	119	100
E01013636	Leicester 029B	21251	495	4001	510	5.99	30913	2175	0.97	17138	4256	124	94
E01013637	Leicester 028C	13515	727	3151	820	4.80	17009	2175	0.89	12399	3501	109	90

E01013638	Leicester 026C	13786	630	3514	650	4.50	15613	2220	0.97	11783	3195	117	110
E01013639	Leicester 028D	14139	391	3620	533	5.21	20228	2175	0.73	13727	4068	103	89
E01013640	Leicester 026D	13940	646	3736	643	4.97	15469	2220	1.00	12672	3336	110	112
E01013641	Leicester 028E	15979	611	3701	621	5.32	22909	2175	0.98	14395	3701	111	100
E01013642	Leicester 030A	17308	675	3656	788	4.79	30712	2196	0.86	14423	3889	120	94
E01013643	Leicester 030B	15067	726	3426	726	5.37	25414	2175	1.00	14772	3765	102	91
E01013644	Leicester 024A	18066	733	4467	2656	3.63	19783	2196	0.28	10565	4175	171	107
E01013645	Leicester 024B	15618	282	3944	1196	4.44	7856	2175	0.24	10552	4334	148	91
E01013646	Leicester 024C	16592	858	4261	1145	4.16	20184	2175	0.75	11603	3551	143	120
E01013647	Leicester 024D	13327	219	3870	578	3.34	18762	2175	0.38	9872	3794	135	102
E01013648	Leicester 024E	14448	711	3457	765	5.05	16629	2175	0.93	12900	3527	112	98
E01013649	Leicester 030C	15747	559	4339	795	4.74	26998	2196	0.70	13693	4055	115	107
E01013650	Leicester 030D	14547	752	3102	753	5.41	28461	2175	1.00	15313	3877	95	80
E01013651	Leicester 011A	12518	664	3054	691	4.59	18478	2205	0.96	12272	3319	102	92
E01013652	Leicester 011B	13905	588	3578	610	4.97	16948	2205	0.96	12875	3440	108	104
E01013653	Leicester 011C	14675	728	3297	700	4.89	17282	2205	1.04	12761	3297	115	100
E01013654	Leicester 017A	12453	806	2606	850	4.20	17942	2203	0.95	11425	3139	109	83
E01013655	Leicester 011D	14759	755	3480	745	4.76	20964	2205	1.01	12946	3346	114	104
E01013656	Leicester 017B	16213	511	3502	513	5.01	20542	2211	1.00	13511	3502	120	100
E01013657	Leicester 017C	16341	557	3441	535	4.90	20188	2211	1.04	13178	3341	124	103
E01013658	Leicester 017D	16281	592	3225	586	5.00	21869	2211	1.01	13567	3468	120	93
E01013659	Leicester 017E	16618	572	3168	590	4.94	20087	2211	0.97	13189	3482	126	91
E01013660	Leicester 019A	15109	646	3216	672	4.93	21602	2211	0.96	13490	3534	112	91
E01013661	Leicester 019B	14460	475	4297	638	4.55	17849	2216	0.74	12151	3672	119	117
E01013662	Leicester 021A	19942	655	3752	548	5.31	23911	2216	1.20	14556	3350	137	112
E01013663	Leicester 021B	19682	521	3732	509	5.31	22676	2216	1.02	14472	3623	136	103
E01013664	Leicester 019C	11392	767	2684	819	4.20	17031	2216	0.94	11392	3158	100	85
E01013665	Leicester 019D	17349	612	3497	634	4.91	22750	2211	0.97	13554	3533	128	99
E01013666	Leicester 025A	21082	609	3784	610	5.58	29071	2216	1.00	15971	3984	132	95
E01013667	Leicester 019E	12564	672	2751	685	4.48	20378	2216	0.98	12317	3275	102	84
E01013668	Leicester 019F	18445	474	4060	595	4.77	22402	2216	0.80	13270	3794	139	107
E01013669	Leicester 025B	20850	485	3803	484	5.76	30969	2216	1.00	16680	4089	125	93
E01013670	Leicester 025C	19590	706	3827	732	5.62	28418	2216	0.96	15927	4028	123	95
E01013671	Leicester 025D	19782	598	3968	617	5.64	28556	2211	0.97	15953	4049	124	98
E01013672	Leicester 025E	22689	514	4413	527	5.61	31287	2216	0.98	16441	4086	138	108
E01013673	Leicester 036A	14076	636	3614	638	5.20	18373	2174	1.00	13406	3509	105	103
E01013674	Leicester 036B	11950	799	2890	796	4.24	15757	2173	1.00	11168	3010	107	96
E01013675	Leicester 036C	12966	679	3536	695	4.97	18033	2174	0.98	12966	3433	100	103
E01013676	Leicester 036D	11664	813	3515	832	4.69	19143	2173	0.98	12542	3348	93	105
E01013677	Leicester 036E	11369	629	3279	683	4.45	18396	2173	0.92	11843	3312	96	99
E01013678	Leicester 035A	15033	657	3564	693	5.14	20415	2174	0.95	13543	3637	111	98
E01013679	Leicester 035B	15682	536	3957	533	5.21	16753	2174	1.01	13178	3471	119	114
E01013680	Leicester 008C	16964	631	3767	846	5.26	25279	2217	0.75	14751	4186	115	90
E01013681	Leicester 016A	14267	801	3492	795	5.03	22852	2196	1.01	13851	3527	103	99
E01013682	Leicester 016B	13233	773	3020	806	4.98	22637	2196	0.96	13643	3595	97	84
E01013683	Leicester 016C	13038	909	3390	1026	4.95	23647	2196	0.89	13724	3725	95	91

E01013684	Leicester 016D	13091	811	2855	903	4.80	20946	2196	0.90	13091	3568	100	80
E01013685	Leicester 008D	15256	622	3573	628	5.19	25268	2217	0.99	14530	3683	105	97
E01013686	Leicester 008E	16149	586	3540	771	5.18	25549	2217	0.76	14549	4165	111	85
E01013687	Leicester 031C	15129	656	3643	810	4.88	24344	2175	0.81	13630	3875	111	94
E01013688	Leicester 031D	13676	669	3086	720	4.88	21412	2175	0.93	13150	3588	104	86
E01013689	Leicester 033A	14719	556	3601	539	5.22	17267	2175	1.03	13381	3429	110	105
E01013690	Leicester 033B	14615	663	3393	639	5.06	21327	2175	1.04	13533	3462	108	98
E01013691	Leicester 035C	12744	592	3603	616	4.70	16809	2175	0.96	12137	3336	105	108
E01013692	Leicester 035D	12516	512	3683	505	4.78	15335	2175	1.01	12151	3230	103	114
E01013693	Leicester 035E	12709	504	3615	507	4.82	16749	2175	0.99	12460	3317	102	109
E01013694	Leicester 013A	13307	665	3537	663	4.90	19184	2205	1.00	13047	3401	102	104
E01013695	Leicester 014A	13264	592	3546	604	4.96	16741	2205	0.98	12754	3409	104	104
E01013696	Leicester 009A	15335	827	3915	840	5.58	31101	2205	0.98	16314	4036	94	97
E01013697	Leicester 009B	18118	473	4363	894	5.40	30988	2205	0.53	15893	4902	114	89
E01013698	Leicester 014B	14872	569	3952	587	5.16	20421	2205	0.97	13770	3592	108	110
E01013699	Leicester 009C	19008	738	3894	725	5.60	28938	2205	1.02	15973	3934	119	99
E01013700	Leicester 013B	16101	586	3815	601	5.11	22979	2205	0.98	14001	3633	115	105
E01013701	Leicester 009D	14865	1594	3661	2062	5.32	33173	2205	0.77	15984	4359	93	84
E01013702	Leicester 030E	18613	642	3796	647	5.84	31885	2196	0.99	16921	4172	110	91
E01013703	Leicester 032A	22581	494	4651	502	6.19	42044	2196	0.98	19466	4651	116	100
E01013704	Leicester 032B	22935	540	4286	624	6.06	41464	2216	0.87	19112	4815	120	89
E01013705	Leicester 033C	15644	689	3428	703	5.32	26353	2196	0.98	14899	3809	105	90
E01013706	Leicester 032C	25354	650	4616	661	6.53	50491	2216	0.98	21857	5073	116	91
E01013707	Leicester 032D	18834	606	3820	611	5.81	34257	2196	0.99	17279	4198	109	91
E01013708	Leicester 033D	18135	581	3642	590	5.62	28568	2196	0.98	15908	4002	114	91
E01013709	Leicester 033E	19037	567	3715	571	5.61	25815	2175	0.99	15477	3911	123	95
E01013710	Leicester 030F	16853	559	3843	793	4.66	33484	2216	0.70	14529	4177	116	92
E01013711	Leicester 030G	20823	577	4311	871	4.77	32768	2196	0.66	14664	4311	142	100
E01013712	Leicester 032E	25648	407	5191	614	5.67	33642	2216	0.66	16874	4807	152	108
E01013713	Leicester 010A	17379	524	3173	514	5.06	20328	2217	1.02	13577	3449	128	92
E01013714	Leicester 010B	18391	536	3286	508	5.26	21941	2211	1.06	14147	3533	130	93
E01013715	Leicester 006C	17849	451	2678	449	5.03	20326	2217	1.00	13522	3479	132	77
E01013716	Leicester 006D	16836	623	2925	602	5.00	20274	2217	1.03	13468	3401	125	86
E01013717	Leicester 010C	13886	441	3953	604	4.87	22217	2211	0.73	13352	3953	104	100
E01013718	Leicester 010D	15970	557	2870	573	4.83	19484	2211	0.97	12879	3417	124	84
E01013719	Leicester 010E	16493	523	2973	500	5.01	20671	2217	1.05	13519	3417	122	87
E01013720	Leicester 010F	6457	566	2125	625	4.06	14877	2211	0.91	10762	3079	60	69
E01013721	Leicester 012A	13808	650	3583	688	5.06	21238	2217	0.94	13672	3619	101	99
E01013722	Leicester 015A	14865	624	4133	626	5.57	17813	2217	1.00	14293	3690	104	112
E01013723	Leicester 012B	13989	490	3912	488	5.59	16966	2217	1.00	14274	3656	98	107
E01013724	Leicester 015B	14321	603	3976	614	5.44	17863	2217	0.98	14040	3648	102	109
E01013725	Leicester 012C	12700	527	3054	615	4.80	14827	2217	0.86	12211	3510	104	87
E01013726	Leicester 012D	9054	605	2696	907	4.11	14521	2196	0.67	10778	3547	84	76
E01013727	Leicester 015C	12821	662	3295	680	4.90	18486	2233	0.97	12950	3432	99	96
E01013728	Leicester 012E	13877	544	4106	557	5.61	18189	2196	0.98	14306	3733	97	110
E01013729	Leicester 020A	14014	541	3679	551	5.09	25986	2220	0.98	14448	3679	97	100

E01013730	Leicester 015D	10908	754	3169	793	4.32	17689	2270	0.95	11856	3201	92	99
E01013731	Leicester 015E	10584	595	4971	655	4.79	22016	2270	0.91	13397	3576	79	139
E01013732	Leicester 005A	16918	776	4037	811	5.04	23067	2205	0.96	13867	3637	122	111
E01013733	Leicester 002A	15587	742	3830	689	4.79	28862	2205	1.08	14170	3450	110	111
E01013734	Leicester 002B	18662	496	4215	544	5.09	25156	2211	0.91	14246	3797	131	111
E01013735	Leicester 002C	16219	460	3820	476	4.93	26159	2205	0.97	14104	3638	115	105
E01013736	Leicester 002D	15922	632	4074	763	4.70	23983	2205	0.83	13269	3738	120	109
E01013737	Leicester 002E	14650	460	3539	470	5.04	27197	2205	0.98	14505	3686	101	96
E01013738	Leicester 006E	19347	489	3822	512	5.35	26012	2211	0.96	14997	3860	129	99
E01013739	Leicester 005B	13411	579	3085	600	4.44	22453	2205	0.97	12534	3317	107	93
E01013740	Leicester 005C	17126	510	3553	509	4.93	24391	2205	1.00	13811	3518	124	101
E01013741	Leicester 005D	17314	531	3572	544	5.01	22421	2205	0.98	13741	3572	126	100
E01013742	Leicester 018A	19299	483	3851	465	5.23	20407	2196	1.04	13884	3501	139	110
E01013743	Leicester 017F	18437	432	3727	425	5.06	18584	2216	1.02	13264	3419	139	109
E01013744	Leicester 018B	21559	479	3923	468	5.46	20529	2216	1.02	14469	3632	149	108
E01013745	Leicester 017G	21927	451	4034	434	5.49	21739	2216	1.04	14716	3667	149	110
E01013746	Leicester 018C	15983	259	2540	699	3.82	16775	2203	0.37	10585	4032	151	63
E01013747	Leicester 021C	19637	563	3677	537	5.22	22152	2216	1.05	14128	3536	139	104
E01013748	Leicester 018D	17656	227	3468	696	4.22	16788	2196	0.33	11318	4281	156	81
E01013749	Leicester 021D	19327	453	3747	444	5.23	22985	2216	1.02	14316	3603	135	104
E01013750	Leicester 021E	20236	443	3652	437	5.37	22553	2216	1.01	14558	3652	139	100
E01013751	Leicester 022A	18231	539	3454	533	5.24	20547	2196	1.01	13917	3560	131	97
E01013752	Leicester 022B	19510	477	3731	464	5.20	21110	2216	1.03	13936	3520	140	106
E01013753	Leicester 022C	17235	505	3470	514	4.94	19212	2196	0.98	13057	3436	132	101
E01013754	Leicester 018E	6552	578	2759	769	3.76	17564	2217	0.75	10568	3285	62	84
E01013755	Leicester 018F	2485	554	2502	798	3.86	16833	2196	0.69	10802	3427	23	73
E01013756	Leicester 027A	18124	653	3687	693	5.36	24334	2216	0.94	14735	3841	123	96
E01013757	Leicester 027B	22581	488	4456	497	5.84	32795	2216	0.98	17107	4204	132	106
E01013758	Leicester 021F	21829	462	4085	452	5.72	23307	2216	1.02	15373	3854	142	106
E01013759	Leicester 027C	23999	541	4392	548	6.00	31230	2216	0.99	17266	4264	139	103
E01013760	Leicester 022D	15327	628	3809	702	4.72	22253	2196	0.89	12989	3593	118	106
E01013761	Leicester 022E	15270	603	3309	628	4.74	19133	2196	0.96	12620	3411	121	97
E01013762	Leicester 022F	18286	556	3773	561	5.35	21875	2216	0.99	14398	3699	127	102
E01013763	Leicester 027D	14535	742	3795	851	4.38	20669	2196	0.87	12113	3419	120	111
E01013764	Leicester 027E	21052	457	4086	465	5.57	26180	2216	0.98	15480	3929	136	104
E01013765	Leicester 027F	15171	582	3220	588	5.00	20968	2216	0.99	13546	3500	112	92
E01013766	Leicester 027G	25765	477	4994	518	5.98	31868	2216	0.92	17409	4380	148	114
E01013767	Leicester 014C	17173	572	3928	583	5.49	24875	2211	0.98	15064	3851	114	102
E01013768	Leicester 014D	13896	687	3276	712	4.42	18067	2211	0.96	11877	3212	117	102
E01013769	Leicester 014E	11758	654	3100	674	4.42	16471	2211	0.97	11758	3163	100	98
E01013770	Leicester 013C	16155	539	3699	549	5.07	24134	2211	0.98	14048	3627	115	102
E01013771	Leicester 013D	18806	534	3956	536	5.68	28658	2211	1.00	16073	3996	117	99
E01013772	Leicester 014F	12850	610	3413	621	4.89	18261	2211	0.98	12850	3413	100	100
E01013773	Leicester 013E	15206	554	3674	579	5.20	20492	2211	0.96	13824	3637	110	101
E01013774	Leicester 023A	14887	782	3411	754	5.10	21470	2175	1.04	13658	3481	109	98
E01013775	Leicester 029C	14449	778	3285	992	5.04	23646	2175	0.78	13893	3957	104	83

E01013776	Leicester 023B	15564	552	3786	709	4.72	21540	2175	0.78	12862	3786	121	100
E01013777	Leicester 029D	14098	758	3240	776	5.08	25200	2175	0.98	14098	3682	100	88
E01013778	Leicester 023C	11001	644	3206	1185	4.19	19214	2175	0.54	11460	3909	96	82
E01013779	Leicester 023D	14481	747	3420	911	4.54	25084	2175	0.82	12929	3717	112	92
E01013780	Leicester 020B	20086	564	4209	703	5.74	35213	2175	0.80	17168	4575	117	92
E01013781	Leicester 023E	14862	582	3693	746	4.60	24818	2175	0.78	13037	3808	114	97
E01013782	Leicester 023F	15460	570	3363	698	4.87	23580	2175	0.82	13443	3821	115	88
E01013783	Leicester 020C	18380	605	3610	631	5.75	28023	2175	0.96	16123	4102	114	88
E01013784	Leicester 023G	17449	499	3666	555	5.49	26905	2175	0.90	15306	4073	114	90
E01013785	Leicester 020D	21775	543	4308	555	6.22	36865	2196	0.98	18611	4535	117	95
E01013786	Leicester 020E	15200	671	3309	726	4.98	24452	2175	0.92	13818	3718	110	89

APPENDIX 8: LOCAL AUTHORITY FEEDBACK SCHEDULE

SECTION A – Data and Method

- Are the results easily understood?
- What other data would you like to see incorporated into the analysis?
- Is the method used understood?
- Are the variables used in the model sensible to a policy officer?

SECTION B – Results

- Are these preliminary results consistent with what you would expect given the schemes currently in operation at improving domestic energy
- Are these results an improvement on simply using raw scores?
- Does the council have local data this could be compared with for accuracy checking?
- Is there a concern if some areas are missing? (i.e. gas grid, disclosure?)
  n/a

SECTION C – Application

- Do you see practical applications for these results?

- How might this information be best presented for Local Authority understanding?

- Are these results in a format that is suitable for interpretation?

- Would these results be used for evaluation or targeting areas for policy intervention?

OTHER NOTES