Reducing residential sector dependence on fossil fuels: a study of motivating factors

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Reducing residential sector dependence on fossil fuels: a study of motivating factors

by

Sven Hallin

School of Civil and Building Engineering

A Doctoral Thesis
Submitted in partial fulfilment of the requirements for the award of
Doctor of Philosophy of Loughborough University

( 3 June 2015)

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Abstract

This research considers the motivating factors behind energy use in the residential sector, which in 2011 accounted for more than 26% of overall energy use in the UK. The study took a mixed method approach and considered case studies in both the UK and Australia, two countries with very different energy regimes. UK case studies were analysed using predictive energy modelling, quantitative assessment of actual energy use and thermal comfort, and qualitative interview and focus group assessment of individual motivation around energy use. The Australian case studies were assessed qualitatively and their attitudes compared to the UK core group. Additional perspectives were gained through interviews with UK landlords, a large environmental group, a senior politician, and two senior policymakers from a large energy company. The investigation assesses the implied importance of the key strands developed from previous research in instigating changes in behaviour amongst occupants. These include psychological, social, financial, educational and regulatory factors. In particular, it looks at the ineffectiveness of the Green Deal on energy behaviour in the residential sector. The research offers a reasoned explanation as to why it is important to record predictive, actual, and intended behaviour with regard to energy use. The study concludes that a variety of incentives are necessary to encourage behaviour change, and that the complexity of occupant behaviour makes it difficult to develop a single policy to encourage more sustainable energy use. There is sometimes a disconnect between intention and behaviour. However, there seems to be a certain commonality among the occupants, in that their behaviour around energy is often other than predicted by conventional economics and more likely to incorporate predictions from behavioural economics. This is recognised by the case study participants in both the UK and Australia, and they largely agree on the beneficial role of government in regulating them and "nudging" them in the right direction with regard to influencing their motivations around energy use. Financial incentives are also a key driver in motivating residents to use energy more sustainably, but they need to be carefully aligned to suit a wide range of individuals. Another issue that became clear in the research is that policy focusing purely on energy efficiency can be ineffective, if the policy goal is to mitigate the effects of climate change. The rebound effect is likely to result in a lower demand for residential energy transferring to increased demand for energy elsewhere in the economy. The study recommends that policy should focus on sustainable energy use, using financial and other mechanisms to discourage the use of fossil fuels.
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CHAPTER 1: Introduction

This thesis is about the motivation residential energy users have to use energy both efficiently and sustainably. It evaluates energy use historically, from a theoretical perspective and through empirical research. The results seek to improve clarity in an area where the research to date tends to be diverse, with a number of different perspectives on how occupant behaviour is determined. This work is comprised of seven chapters. Chapter 1 outlines the factors determining energy use in the residential sector, assesses energy requirements in the UK, and considers the cost of a transition to a sustainable energy system. Chapter 2 formalises the aim and objectives of this research. Chapter 3 outlines the literature in this research area, which include the UK government's residential energy policy "The Green Deal", behavioural theories including Nudge Theory, and measuring externalities caused by energy use. Chapter 4 discusses the research philosophy and methodology adopted in this study. Chapter 5 considers the actual research methods undertaken in this study, both in the UK and Australia. Chapter 6 reports and analyses the results obtained from the research. Chapter 7 looks at the analytical and policy conclusions that can be drawn from the research results.

1.1 Factors determining Energy Use

Energy use in buildings depends on the interaction between the occupants (Monahan & Gemmell, 2011), the building fabric (Lomas, 2010), the way energy is delivered (Lowe, R., 2007) and the local climate (Reinders et al, 2003).

The energy requirements of the occupants need to be considered. Are these energy needs typical in some way and are these needs being met by the supplied energy to the building? Questions such as property tenure, number, income and age of occupants, the time the occupants spend in the property, their behaviour patterns/ preferences and level of satisfaction while there, need to be addressed along with the implications for energy use.
The building fabric needs to be assessed in terms of type of construction, size, layout, design and energy efficiency.

Does the way energy is used in the building make economic sense, or would changes to the way energy is used, conserved or supplied provide better value for money? How efficiently spread is heating, lighting and ventilation throughout the building?

The location of the building is a key factor as the local climate could have a major impact on the energy requirements of the structure.

1.2 UK domestic energy requirements:
It is of significance to see how energy is consumed between sectors in the UK, so that the relevance of the residential sector can be determined. Final energy consumption in 2010 was:

<table>
<thead>
<tr>
<th>Sector</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>transport</td>
<td>35%</td>
</tr>
<tr>
<td>domestic</td>
<td>30.5%</td>
</tr>
<tr>
<td>industrial</td>
<td>17.3%</td>
</tr>
<tr>
<td>commercial</td>
<td>6.2%</td>
</tr>
<tr>
<td>other-energy use</td>
<td>5.7%</td>
</tr>
</tbody>
</table>

Table 1 Final energy consumption in 2010 (adapted from DUKES 2011)

The UK remained a net importer of primary energy importing 28% of its usage requirements, with energy consumption overall increasing by 4.4%. Only 3.3% of supplied energy came from renewables, thus limiting the choice of the residential sector to use energy sustainably, although this grew to 5.2% in 2013. (DECC, 2014aa). Interestingly, MacKay (2008) allows an approximate analysis of the economic costs of a transition to a sustainable energy system (over all sectors) choosing a range of sustainable energy sources augmented by nuclear power. There are many pathways one could choose to achieve this aim,
and one option can be seen by visiting the link on the Department of Energy and Climate Change website:¹

If we had the aspiration to entirely avoid using fossil fuels, and reduce our fossil fuel consumption by nearly 100%, (replacing about 68 kilowatt-hours per day per person, kWh/d /p, of fossil fuel energy with 68 kWh/d/p of sustainable energy) the commissioning cost could be around £14,000 per person. Averaged over 19 years this is around £737 per person per year, less than 3% of the average annual income of £26,000 (Great Britain. Office for National Statistics.2010). However, this calculation is per capita, which means the actual cost per person as a proportion of income per year would be unevenly spread across the population.

Considering this theoretical scenario, it can be seen that household energy use needs a significant shift to replace fossil fuels with renewable energy in the UK. However, the UK government is committed to reducing carbon emissions to 80% of 1990 levels by 2050, so the relevance of renewables in this study is not limited to energy saving, solar panels and heat pumps. Renewable power sources, diversified and potentially intermittent though they are, are needed to supply the residential sector. The problem of intermittence can be mitigated if, for example, wind farms are spread geographically. It is likely that sufficient wind will be blowing in some parts of the country at any one time, but there is then an additional transmission cost.

In addition, MacKay (2008) points out that demand reduction can be relatively inexpensive and very effective. For example loft and cavity insulation reduces heat loss in a typical house by about a quarter (Eden and Bending,1985). Thanks to incidental heat gains, this 25% reduction in heat loss translates into roughly a 40% reduction in heating consumption.

¹ http://2050-calculator-tool.decc.gov.uk/pathways/4011134133111101221340024412023430220130343202232/prima ry_energy_chart
Yet, because progress in improving existing energy efficiency has been considered too slow to help meet the UK carbon emissions targets (Davis, 2012), the Green Deal, which started at the end of January 2013, is designed to encourage residential property owners to increase the level of energy efficiency measures installed in their property (see appendix 1). Along with a new Energy Company Obligation (ECO) provided for in the Energy Act (2011), it is an initiative replacing the previous Carbon Emissions Reduction Target (CERT) and the Community Energy Saving Programme (CESP), which expired in 2012.

In the meantime there is a need to understand what financial and non-financial formats will motivate householders to make improvements in their energy efficiency, especially with regard to space and water heating, which is around 80% of residential energy use (James, 2012). What framework will motivate people to choose heat pumps over gas boilers, for example? Will debt linked to energy efficiency measures have a negative psychological impact? For example, the effect of the Green Deal may be to depress house prices as new buyers resist paying for energy efficiency debt linked to a property over time.

Green Deal projects alone (under the Green Deal Golden Rule which specifies that the charge attached to an energy saving measure must be less than the expected savings from it) may be limited to only basic cavity and loft insulation and draught proofing, so limiting the possible energy savings that can be achieved (Bowen and Rydge, 2011).

For companies planning to become turnkey providers of energy efficient solutions under the auspices of the Green Deal, retrofits may also turn out to be limited in terms of financial profitability. Whether the relationship benefits (personal information and personal contact) from supplying a large number of residential customers provides the basis of a good business model is far from proven. If consumers dislike the core product offering, in this case improved energy efficiency secured by a long term property charge, then extra discretionary spending on other related household products that these companies supply may not be forthcoming.
This research seeks by its fruition to establish why people respond to energy incentives in a variety of ways, some of which can be construed as irrational or suboptimal in traditional economic terms. An understanding of these responses could inform energy efficiency policies in the future.
CHAPTER 2. Aim and Objectives

This chapter presents a plain statement that outlines the aim and objectives of this study.

2.1 Aim

To assess how financial and non-financial incentives influence energy demand in residential property.

2.2 Objectives

1. a) To do a survey of the available literature with regard to energy demand behaviour and the complex nature of why energy using decisions are made.

b) To review historical energy efficiency schemes.

c) To assess the existing Green Deal, the current providers and the offerings they make.

2. To assess key energy suppliers’ motivation to influence energy demand behaviour (this could be to profit maximise, sales maximise, satisfy regulation, etc.)

3. To assess how suppliers and environmental groups interact on the issue of energy demand reduction.

4. To assess how politicians could influence energy use behaviour and their motivation for so doing.

5. To select 6 case study residential properties in Loughborough, UK and use quantitative methods to characterise the household energy use and qualitative methods to determine energy efficiency behaviour with regard to price and other incentives.
6. To subdivide the properties by private and rented, so that behavioural responses to energy demand can be assessed in Owner Occupied, Tenant and Landlord sub-groups.

7. To select 6 participants in Victoria State, Australia and use qualitative methods to determine energy efficiency behaviour with regard to price and other incentives.

8. To hypothesise a number of incentive mechanisms that could encourage efficient energy use behaviour.

Rather than expanding the discussion of these issues at this point, each of these objectives is explored at length in subsequent chapters.
CHAPTER 3. Literature Review

This chapter reviews published academic literature relating to this research. After an introduction, Section 3.2 presents an overview of energy use, including determinants of thermal comfort, temperature & physiology, economic theory, production and consumption, energy demand, and demand elasticity. Section 3.3 examines the development of energy use by humans historically. Section 3.4 examines the cost of energy, including the social costs and marginal abatement costs of carbon dioxide emissions which together determine the actual price of emissions. Section 3.5 discusses legislated energy policy in the UK, including historical energy efficiency schemes and the current Green Deal. Section 3.6 focuses on residential energy demand behaviour and the barriers to energy efficiency. Section 3.7 discusses the findings of the literature review. Section 3.8 summarises the literature review and identifies the research gap, which is to contribute to the body of knowledge relating to motivating factors determining residential energy behaviour.

3.1 Introduction

The Climate Change Act 2008 established a legally binding target to reduce the UK’s greenhouse gas emissions to at least 80% below 1990 base levels by 2050, and to achieve a 50% reduction in emissions over the 2023 - 27 period. With domestic emissions around 30% of the total, this implies a necessary reduction in the final budget period of 585 million tonnes of carbon dioxide equivalent in the residential sector (see table 2).
### Table 2 Carbon Budgets: 2008 to 2027 (DECC 2011aa)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon budget level (Million tonnes of carbon dioxide equivalent)</td>
<td>3,018</td>
<td>2,782</td>
<td>2,544</td>
<td>1,950</td>
</tr>
<tr>
<td>Percentage reduction below base year levels</td>
<td>23%</td>
<td>29%</td>
<td>35%</td>
<td>50%</td>
</tr>
</tbody>
</table>

James,( 2012) in his review of emissions reductions in the UK residential sector concludes that reductions of under 2% per annum are likely to be delivered by 2020, when in fact overall reductions of approximately 6% per annum are needed. Interestingly, this research concludes the key barrier to achieving satisfactory residential carbon emission reduction is psychological.

![Figure 1 CO2 emissions from the residential sector in the period 1990–2010 (James, 2012)](image)

In 2009, 15% of direct UK CO₂ emissions were from the residential sector and this increased to 27% if indirect emissions are included, such as aviation and shipping.
Figure 1 shows the trend in CO₂ emissions (in Million metric tons of carbon dioxide) in the UK residential sector from 1990 to 2010 by final user and by source (DECC, 2011a & DECC, 2011b). "By source" does not include shipping and aviation.

It is interesting to note that the absolute value of CO₂ emissions has remained largely unchanged, and James (2012) contends that this is because improvements in energy efficiency over the last 20 years have largely been absorbed by increases in demand. This increased demand can be partly attributed to the rebound effect (Saunders, 1992), where energy savings from the improved energy efficiency measures result in a less than proportionate reduction in energy use.

The switch from coal to gas-fired electricity generation in the 1990s resulted in a small decline in indirect emissions, and this helped to outweigh the increasing use of electricity for household appliances. The Committee on Climate Change (CCC, 2008) conclude that improved insulation and heating system efficiency has been broadly offset by higher average internal temperatures in homes resulting in a fairly flat profile for direct residential emissions.

It can be seen from figure 2 (DECC & AMECO, June 2013) which outlines the trend in UK CO₂ emissions from the residential sector in the period 1985–2013 that the contribution of the residential sector to a reduction in carbon emissions has so far been fairly negligible. However, it is clear that emissions in relation to GDP have declined.
Energy use and carbon emissions in the residential sector by end use in 2008 are shown in table 3. Overall energy use declined by 8% between 2008 and 2013 (DECC,2014aa)

Table 3 Residential energy use & emissions (DECC,2011c;DEFRA, 2011)

<table>
<thead>
<tr>
<th>Energy using source</th>
<th>kWh</th>
<th>Energy Percentage</th>
<th>Tonnes CO₂</th>
<th>CO₂ Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space heating</td>
<td>12,631</td>
<td>65%</td>
<td>2.9</td>
<td>52%</td>
</tr>
<tr>
<td>Water heating</td>
<td>3,207</td>
<td>16%</td>
<td>0.8</td>
<td>15%</td>
</tr>
<tr>
<td>Cooking</td>
<td>554</td>
<td>3%</td>
<td>0.2</td>
<td>4%</td>
</tr>
<tr>
<td>Lighting and appliances</td>
<td>3,054</td>
<td>16%</td>
<td>5.5</td>
<td>29%</td>
</tr>
<tr>
<td>Total</td>
<td>19,448</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The most recent budget, the 3rd Carbon Budget 2018 - 2022 (CCC, 2008) to reduce carbon emissions up to 2022 from the Committee on Climate Change, states that measures are required to ensure the insulation of 90% of all lofts and cavity walls, as well as 2 million solid wall dwellings (around 20% of the stock of solid wall dwellings). In addition, the budget requires a replacement of 13 million boilers with the newer more efficient condensing boiler, along with a significant increase in appliance efficiency. It is predicted that these measures could result in a reduction in annual CO\textsubscript{2} emissions in the residential sector of 17 MtCO\textsubscript{2} from 2008 levels.

Nevertheless, this 3rd carbon budget only requires average annual reductions in emissions of 1.7% (proportion of direct emissions from the residential sector in table 1), leaving average annual reductions of around 4.5% required to meet the fourth carbon budget (2023 - 2027) which is designed to achieve progress sufficient to meet the 2030 target of 60% reduction in greenhouse gas emissions from 1990 levels (CCC, undated). The Committee on Climate Change propose greater reductions with each carbon budget to reflect the cumulative effect of energy-saving measures.

Before looking at the factors, both positive and negative, which will allow the latest Carbon Budget to be achieved we need to have an understanding of the theoretical underpinnings behind our energy use. This is considered in the next section.

### 3.2 Energy Use

#### 3.2.1 Parameters of Thermal Comfort

ASHRAE (2004) defines thermal comfort as “that condition of mind which expresses satisfaction with the thermal environment”. Although this definition allows for some ambiguity, it is worth exploring the key drivers of thermal comfort as proposed by Fanger (1970). It reveals the boundaries within which energy efficiency measures must sit.
The principal environmental factors affecting the thermal comfort of an individual are air temperature, mean radiant temperature (MRT), humidity and air movement. In addition their personal metabolic rate (depending on their level of activity) and the amount and type of clothing worn affect their thermal comfort. Metabolic rate is also influenced by contributing factors such as food and drink, body shape, subcutaneous fat, acclimatization, age, gender and state of health (Auliciems and Szokolay, 2007).

These six elements define the human thermal environment, and are summarised in table 4 below:

**Table 4 Human Thermal Elements**

<table>
<thead>
<tr>
<th>environmental:</th>
<th>personal:</th>
<th>contributing factors:</th>
</tr>
</thead>
<tbody>
<tr>
<td>air temperature</td>
<td>metabolic rate (activity)</td>
<td>food and drink</td>
</tr>
<tr>
<td>air movement</td>
<td>clothing</td>
<td>acclimatization</td>
</tr>
<tr>
<td>humidity</td>
<td></td>
<td>body shape</td>
</tr>
<tr>
<td>radiation</td>
<td></td>
<td>subcutaneous fat</td>
</tr>
<tr>
<td></td>
<td></td>
<td>age and gender</td>
</tr>
<tr>
<td></td>
<td></td>
<td>state of health</td>
</tr>
</tbody>
</table>

Air temperature determines convective heat dissipation from the body and is measured by dry bulb temperature. The evaporation rate from the skin is affected by relative humidity and air movement. Relative humidity is the ratio of the prevailing partial pressure of water vapour to the saturated water vapour pressure.

Parsons (2003) defines mean radiant temperature (MRT) as “the temperature of a uniform enclosure with which a small black sphere at the test point would have the same radiation exchange as it does with the real environment”. Gan
(2001) characterises the human skin as very absorptive with also high emissivity. This makes it very reactive to changes in MRT, making it an important parameter controlling human energy balance.

The metabolic heat production of the body is expressed by a unit called a met. 1 met = 58.2 W/m². However the heat transfer from the body is complicated by the insulation effect of clothes covering the skin. Fanger (1970) devised a unit called the Clo to standardise this energy transfer for the purposes of thermal comfort studies. The Clo (see figure 3) corresponds to an insulating cover over the whole body of a transmittance (U-value) of 6.45 W/m²K

3.2.2 Temperature & Physiology
The body produces heat in two ways (see figure 4).
1. Through basal metabolism which constantly generates heat due to unconscious biological processes
2. Through muscular metabolism whilst doing conscious controllable mechanical work.

The produced heat is transferred through the body to the surface of the skin where it is dissipated to the environment by convection, radiation, (possibly) conduction and evaporation in order to maintain a constant internal body temperature (Auliciems and Szokolay, 2007). An average sized man at rest loses heat at the rate of approximately 100 W.
The body’s heat balance can be expressed as an equation:

\[ M \pm R \pm Cv \pm Cd - E = \Delta S \text{ (W)} \]

where $M$ = metabolic rate  
$Cv$ = convection  
$R$ = net radiation  
$Cd$ = conduction  
$E$ = evaporation heat loss  
$\Delta S$ = change in heat stored

Figure 4 How the body exchanges heat (from Auliciems and Szokolay, 2007)

If $\Delta S$ is positive, the body temperature increases, if $\Delta S$ is negative, it decreases. The heat dissipation rate depends on environmental factors, but the body is not purely passive, it is homeothermic, keeping a stable body temperature that is generally independent of the temperature of its surrounding environment.
In warm conditions (or where there is increased metabolic heat production after, for example, exercise) the body responds by vasodilation: subcutaneous blood vessels expand and increase the blood supply in the skin, which increases the skin temperature. This in turn increases heat dissipation to the atmosphere. If this is not sufficient to restore thermal equilibrium the sweat glands are activated and evaporative cooling takes place. Sweat can be produced for short periods at a rate of 4 L/h (litres per hour), but this mechanism is fatigable with the sustainable rate about 1 L/h.

If these mechanisms cannot restore heat balance in the body, hyperthermia will occur. Heat stroke can develop when the internal body temperature reaches about 40°C. At this point venous blood returning to the heart muscle is reduced leading to fainting. Prior to this there are usually early symptoms such as fatigue, headache, loss of appetite, nausea, vomiting, dizziness, shortness of breath, flushing of the face and neck, rapid pulse rate, glazed eyes, as well as mental effects, such as poor judgement, apathy or irritability.

In cold conditions the body responds with vasoconstriction which reduces circulation to the skin, lowers the skin temperature, thus reducing the heat dissipation rate. If this is inadequate to conserve heat, the body will seek to produce heat through muscular tension or shivering (thermogenesis). The internal body tissues stay at the required 37°C, while body extremities such as fingers and toes are allowed to be starved of blood and may reach temperatures below 20°C before deep body temperature would be affected.

If these physiological adjustments fail to restore thermal equilibrium, hypothermia will occur. If the internal body temperature drops below 25°C, it can be fatal.

There should always be a temperature gradation between the deep body temperature, the skin temperature and the external air temperature in order to allow adequate, but not excessive heat dissipation. The ecological conditions which allow this, ensure a sense of physical well-being and may be judged as comfortable. Therefore thermal comfort, while specific to the individual, is
A summary of the effect of increasing and decreasing temperatures on the human body is outlined in table 5 below.

Table 5 Critical body temperatures (from Auliciems and Szokolay, 2007)

<table>
<thead>
<tr>
<th>Skin temperature</th>
<th>Deep body temperature</th>
<th>Regulatory zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>pain: 45°C</td>
<td>42°C</td>
<td>Death</td>
</tr>
<tr>
<td>40°C</td>
<td></td>
<td>Hyperthermia</td>
</tr>
<tr>
<td>31-34°C</td>
<td>37°C</td>
<td>Comfort</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vasoconstriction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thermogenesis</td>
</tr>
<tr>
<td></td>
<td>35°C</td>
<td>Hypothermia</td>
</tr>
<tr>
<td>pain: 10°C</td>
<td>25°C</td>
<td>Death</td>
</tr>
</tbody>
</table>
3.2.3 Economic Theory on Energy

Energy economics is the study of different sources of energy, that is the fuels which we use in the economy to produce heat and power (Weyman-Jones, 2009). These individual fuels comprise of primary and secondary electricity, natural gas, oil and coal or marketable commodities. It is worth noting that renewable sources of energy and nuclear power are generally used to produce electricity. Fuels are widely traded both nationally and internationally.

The distribution of some fuels lends itself to the development of a natural monopoly. For example, electricity and natural gas need to be distributed through some form of grid pattern, either through wires in the case of electricity or pipes in the case of gas, in order to reach their purchasers. It would be clearly inefficient if a number of energy companies had their own distribution networks delivering the same forms of energy to the same consumers. Because of the nature of fuel as a critical element in human survival and economic activity, through its function in the derived demand for energy, there is a natural political interest in fuel regulation. Thus economic regulation forms an intrinsic part of energy economics. Nevertheless, Newbery (1999) argues that there should be competition where possible, and regulation only when it is unavoidable, and that the quality of this regulation is key in determining the efficiency of the energy network. He also suggests (Newbery, 1997) that liberalisation of the energy market (provided it is implemented successfully) is more important than privatisation, as there may be little difference between how private and publicly owned energy companies are regulated.

Economic regulation is commonly based on value judgements (normative economics) which are intended to allocate resources optimally according to some standard of human welfare. However a competitive market theoretically produces an outcome in resource allocation which is similar to that of a welfare maximising model. So a cost benefit analysis can conveniently describe the route to optimal resource allocation.
In cost benefit analysis, the individual demand curve is a function of quantity and price, where these two variables have a negative correlation. Thus, as price increases a lower quantity is demanded, and vice versa. A competitive market produces an equilibrium price which leaves a consumer surplus to the left of the downward sloping demand curve but above the equilibrium price, and a producer surplus to the left of the upward sloping supply curve below the equilibrium price, as in figure 5.

![Figure 5 Competitive Market Demand & Supply](https://martinmorning.wordpress.com/2013)

This equilibrium price is in fact a Pareto optimum as no further adjustment can be made without either a consumer or supplier being worse off. However a Pareto optimal solution does not imply an equitable distribution of resources, whereas a cost benefit analysis looks at whether the benefits obtained are large enough to outweigh the costs.
So in a welfare maximising model, the Pareto criterion can be said to apply. At this point price equals marginal cost. The cost of producing one extra unit (of energy) would be the same as the price a consumer would be willing to pay for it, and thus be of no benefit to the supplier.

However, setting up an energy company can involve very large fixed costs, which are never entirely absent. For example, an electricity company may need to develop an entire grid network in order to supply its potential customers. In this case a supplier could lose money if they price their output on a marginal cost basis. An optimum price will be derived on the basis of an average cost curve. However, in reality, this grid network is generally owned by a separate company (Newbery, 1999).

In a cost benefit analysis, the social discount rate needs to be considered. This is the appropriate discount rate to be used in social investments. It has to include the concept of social marginal cost and social marginal benefit.

In choosing a discount rate for a cost benefit welfare analysis it has to reflect society's preference for consumption today (assuming consumption raises utility, and aggregate utility equals welfare) over consumption tomorrow, if "tomorrow" is the next time period. In the case of energy, consumption is some function of the energy producing capital stock. In practice, this capital stock will depreciate over time, but even if this wasn't the case the consumption of energy today is likely to have more value than the consumption of energy tomorrow, all other things being equal. This is because energy today can be put to use in a variety of ways, whereas energy tomorrow cannot be used immediately. Of course one has to consider whether energy use in each time period is the same. If it is not, this could have an impact on the chosen discount rate. For example, if energy consumed in the future is predicted to be a far greater quantity, it could have an effect on energy value. However, given equal energy consumption in each period, a cost benefit analysis should have a positive discount rate. Economists determine the social discount rate (SDR) is equal to the rate of social time preference (STP) which should be equal to
the social opportunity cost of capital (SOC). This applies when the economy is in an efficient equilibrium, which is not always the case. If for example society is under-investing in future energy producing capital, this will likely result in higher energy costs in the future (all other things, such as changes in technology being equal). If energy is more valuable in the future it should increase the SOC. Theoretically, this should mean that more investment funds are attracted to invest in energy producing capital.

Setting a discount rate for an energy model is therefore in practice very difficult. Another consideration is the complexity of the energy market. Because of its sheer scale it will always be characterised as an oligopoly, or sometimes a monopoly (for example, owners of the electric power grid or the gas pipelines). Different primary suppliers of energy sources will have a whole range of different costs, and barriers to entry to these businesses will also vary. An optimal energy market cannot be solely left to competitive forces, but to maximise social welfare will also need careful regulation and possible subsidy.

3.2.4 Energy Supply and Demand

3.2.4.1 Energy Supply Theory

The way in which energy resources are allocated spatially and temporally forms the basis of energy supply economics. Fossil fuels are considered to be depletable resources as they cannot be replaced within a reasonable timeframe. This contrasts with renewable energy sources which include for example, wind and solar power. Medlock (2009a) contends that until fairly recently energy economists were concerned with the efficient allocation of depletable resources, as most energy was provided through the use of fossil fuels. Clearly, economists are now considering the energy provided from renewable sources, (Poudineh & Jamasb, 2014) and the different demands this places on the distribution of energy. The cost of renewable energy distribution is a highly relevant factor in influencing the use of sustainable energy in the residential sector.

In a model of the mechanics of energy supply, the marginal user cost (MUC) continues to rise in each time period by the risk adjusted rate of interest. If the
marginal extraction cost (MEC) also continues to rise in each time period, which may be quite likely as depleted resources become increasingly more costly to extract, then the total marginal cost of resource extraction, which equals the resource price, will increase until the resource is no longer competitive. This may be because it is faced with competition from another energy source, such as non-depletable renewable energy. At this point there will be a transition to the new form of energy.

Increasing the risk adjusted interest rate lowers the resource price and raises the extraction rate in the current period. Lowering the price of an alternative resource (at which point there would be a transition) will result in lowering the resource price and increasing the extraction rate in all periods.

This model of energy supply is interesting, because it implies that innovation which lowers the cost of an alternative energy supply will lead to the depletion of the original resource more rapidly. This follows because firms that wish to maximise the resource value will want to use as much of it as possible before the transition takes place to another energy resource. A resource that is left in the ground has no value. However, this is a theoretical proposition and assumes perfect knowledge of when the transition to the alternative energy resource will take place. It also assumes the means are available to extract supplies of the original resource to the point of exhaustion in the time period before the transition.

3.2.4.2 Energy Demand Theory
Medlock, (2009b) outlines a basic model of a firm’s energy requirements.

**Equation 2  A Firm’s Energy Requirements**

\[ E = \frac{\mu}{\xi} K \]

where \( E \) is energy use, \( \mu \) is the capacity utilisation of capital, \( \xi \) as the energy efficiency of capital, and \( K \) is the capital stock or output capacity. In this equation, \( K \), the capital stock, is the volume of the firm’s physical energy-using capital equipment, such as blast furnaces, assembly lines, manufacturing plant,
transport facilities and buildings. K may be measured in constant price £, aggregated physical units, or most often units of potential output when fully utilised. E is the volume of energy used by the firm, usually measured in heat equivalent units or oil equivalent units, and this is determined by two parameters: \( u \) is the percentage of the capacity that is actually utilised in any period – e.g. blast furnaces may never be shut down, but assembly lines may not operate at night; \( \varepsilon \) is the amount of the output capacity, K, that can operate with one unit of energy. The higher is \( \varepsilon \) the less energy is required to operate the plant to a given degree of capacity utilisation.

\[
C (\text{cost}) = rK + wL + p_e E + p_m M
\]

where \( r \) is the rent on capital K, \( w \) is a wage paid to Labour L, \( p_e \) is the price of energy E, and \( p_m \) is the price of material inputs M. This equation which is in fact a definition or identity simply states that the cost is the sum of all the expenditures on inputs. For each input category: capital, K, labour, L, energy, E, and materials, M measured in volume units, the amount used must be multiplied by the corresponding market price per unit of input for that input category, \( r \) for K, \( w \) for L, \( p_e \) for E and \( p_m \) for M. These prices and the input volumes can often be calculated in index number form, i.e. as a multiplicative proportion of the numerical value of each variable at the start of the period.

In a condition where a firm wishes to minimise costs, the problem is expressed as follows: this means that the firms’ costs are to be minimised by choosing the values of the variables, K, L, E, M

\[
\min C_{K,L,E,M}
\]

Equation 3 Cost Minimisation

Trivially, the firm can obviously minimize cost by doing nothing, i.e. not paying for any inputs. However the firm will be constrained by its continued existence in the market to satisfy the demands of its customers. This is expressed by stating that its cost minimisation condition is subject to:
\( \mathcal{Q} = f(K, L, E, M) \) for a given level of output, \( \mathcal{Q} \)

Equation 4 Maximised Output

\[
\min_{K, L, E, M} \frac{C}{K, L, E, M} (r + p_e \frac{u}{e}) K + wL + pmM + \phi E + \lambda [\mathcal{Q} = f(K, L, \frac{u}{e} K, M)]
\]

where \( \phi \) is the cost of efficiency improvement. \( \lambda \) is the impact on cost of a small increment in the output required, known in economics as marginal cost. Note here that energy usage by the firm is related to its capital stock as expressed in equation 2 above. Solving equation 4 in order to minimise cost, the first order condition means that the firm will choose inputs of K, L, M and E (expressed in terms of K), and a utilisation rate of capital, \( u \), so that the marginal values of output production from each input are equal to that input's market price; (cost is minimised at this point, subject to a minimum output, and output is maximised subject to a maximum cost). The extra output production in this solution is valued at \( \lambda \), marginal cost, which in a competitive market will just equal the market price. This last result must hold since if a firm's marginal cost was above the market price it would be driven out of business by its losses, and if its marginal cost was below the market price its profits would attract competition from other producers. As a consequence of the analysis related to equation 4, the general function for the firm's energy demand is then:

Equation 5 A Firm's Energy Demand

\[ E^* = E(\mathcal{Q}, r, w, p_e, p_m) \]

Equation 5 states that the optimal, i.e. cost minimising demand for energy depends on the firm's output target and the prices of the inputs including the price of energy. One can envisage a similar statement of the decisions of a household minimising its expenditure on energy and other commodities and appliances that use energy. The above equation models how a change in variables alters the overall demand for energy.

While domestic energy demand will form part of the function of a firm's energy demand, residential energy demand studies also relate levels of demand to
periods of occupancy (Richardson, Thomson, & Infield. 2008) to predict the
timing and level of energy use.

3.2.5 Energy Demand
Medlock (2009b) suggests the principal cause of low levels of economic and
social development in developing countries is the absence of modern energy
sources. This implies there will be higher levels of economic and social
development in more developed countries which have the capacity to generate
energy from a greater number of sources (such as solar phone chargers). Old
technologies when they were first developed, such as the internal combustion
engine powered by fossil fuel, facilitated far more productive transport of goods
and services. While fossil fuels, in this case, provide the energy to power a
vehicle, it can be seen that there is no direct demand for fossil fuel per se. The
demand is for the vehicle and for the service it can provide. But without the
fossil fuel the vehicle will not work. This is an example of how energy is a
derived demand. In modern society it is used to provide functionality to all kinds
of capital equipment. Large amounts of productive machinery rely on electricity
as their source of power, but the electricity itself can be produced from a
number of primary energy sources.

So Medlock maintains that the demand for energy at the individual and firm
level results from a set of decisions around purchasing both the type and
quantity of various items of capital equipment. This capital equipment is
differentiated by factors such as its type of fuel input, rate of capital utilisation
and efficiency. Energy demand is further complicated by the structure of the
economy in a particular area and the way that structure changes over time
relative to income. Additionally, technical change, government policy and the
energy input costs of capital items will all have some effect on the demand for
capital goods, and thus for the energy supply that powers them.

One of the factors to be considered in the case of energy demand is the need
to convert primary energy sources into more usable forms of fuel. For example,
crude oil has to be refined into products such as petrol and heating oil. During
the process of refinement a proportion of energy is lost. All fuel types can be converted into electricity, with various levels of efficiency.

So energy, along with capital, are inputs which provide a set of energy services such as producing steam energy (which can be used to drive a turbine) to provide transport. A simple energy/capital consumption model can be proposed where energy consumption depends on the variables of energy efficiency, the capital utilisation rate and the operational scale (see section 3.2.4.2).

Importantly, the relationship between energy and capital is equipment specific. Energy intensity can be defined as the quantity of energy consumed per unit of economic output. Energy intensity is influenced at the macro level by the economic structure and the available technology. More developed economies tend to be more service orientated and as such the preponderance of service businesses will tend to make the economy less energy intensive. Also, more developed economies will tend to be more technologically advanced with regard to efficiency, thus reducing energy intensity. Medlock contends that there is empirical evidence that energy intensity declines as economies develop. This is supported by a Department of Energy and Climate Change (DECC 2013) special feature, which considers international energy efficiency in a number of European countries.

The more sophisticated an economy becomes, the more diverse economic activity will tend to become, reducing the importance of heavy industry as an overall share of the economic activity. However, this does not mean that energy intensity cannot vary significantly between equally developed countries. The structure of the economy also has an important influence on energy demand. With economic development economies tend to move from dependence on agriculture to a greater reliance on industrial output followed by a growth in service industry. Medlock also makes the point that the later an economy develops, the lower its energy requirements will be. This is because it benefits from the diffusion of new technologies from other areas. So developing economies can learn from the technical developments of the developed world (they may not, however, always be able to adopt these technologies easily,
due to limited technical capacity and infrastructure). Another interesting point is that energy demand is sector specific. This leads to an asymmetry in the relationship between energy and income. For example, a recession will lead to a lowering of GDP in an economy but not necessarily a commensurate lowering of energy intensity. Highly energy intensive industries might not necessarily synchronise with the normal business cycle. Long term infrastructure projects might fit into this category.

So the decision to consume energy can be said to involve three simultaneous choices; the choice to invest in capital stock, the choice of a particular type of capital stock and the choice of a rate of capital utilisation. Combined, these three choices lead to a demanded amount of energy service. The production of capital stock requires investment which implies a degree of long run decision-making. Where the production of energy is intended to meet the needs of an entire population, the role of a regulator taking a strategic overview could be paramount.

3.2.6 Demand Elasticity

The price elasticity of demand (PED) is a measure used in economics to show the responsiveness, or elasticity, of the quantity demanded of a good or service to a change in its price. More precisely, it describes the percentage change in quantity demanded in response to a one percent change in price (holding constant all the other determinants of demand, such as income). The demand for a good is said to be elastic (or relatively elastic) when its PED is greater than one (in absolute value): that is, changes in price have a relatively large effect on the quantity of a good demanded.

With respect to energy the short run PED is small (inelastic). In the domestic sector, the majority of space heating is supplied by gas boilers. People have little option but to buy gas for this energy using capital at the prevailing price. Eventually, however, they can change the type of heating system they use and/or improve their energy efficiency, so the long run PED is more elastic. A study by Sentenac-Chemin (2012) found that the price effect on fuel is
symmetric, with the short run PED remaining the same whether the price increases or decreases.

In reality price elasticity will often vary at different points along the demand curve. Medlock highlights the importance of empirical studies which estimate income elasticity and price elasticity of energy demand. He contends that these elasticities are vital when forecasting energy demand.

Income elasticity of energy demand is defined as the percentage change in energy demand resulting from a 1% change in income, with all other factors being held constant. This ratio of percentage changes is an approximation to the concept of a ratio of infinitesimal proportional changes as expressed by differential calculus.

\[
\varepsilon_y = \frac{\% \Delta E}{\% \Delta Y} = \frac{dE/E}{dY/Y} = \frac{dE}{dY} \frac{Y}{E}
\]

where \(\varepsilon_y\) is the income elasticity of energy demand, \(E\) denotes energy demand by the residential household, and \(Y\) denotes income.

Medlock asserts that much of the empirical literature assesses the income elasticity of energy demand to be close to 1, but this may be overstated with respect to industrialised countries. There is evidence that energy intensity is inversely related to economic development (Galli 1998; Medlock and Soligo 2001).

So in developed countries the percentage change in income leads to a lower percentage change in energy demand, i.e. income elasticity of energy demand is less than one. As incomes rise, there is less expenditure on energy. Fouquet and Pearson (2006) provide a good example of this with their analysis of the development of light as an energy source. However, it is important to point out that this evidence is contested in other studies, e.g. Ozturk, Aslan, & Kalyoncuc, (2010).
(Own) price elasticity of energy demand is defined as the percentage change in energy demand given a 1% change in the price of energy, all other factors being constant.

**Equation 7  Price Elasticity of Energy Demand**

\[
\varepsilon_P = \frac{\% \Delta E}{\% \Delta P} = \frac{\delta E}{\delta P} \cdot \frac{P}{E}
\]

where \(\varepsilon_P\) denotes price elasticity of energy demand, \(P\) denotes the price of energy and \(E\) denotes energy demand.

Medlock states that in general, income and price elasticities of energy demand are useful in directing energy policy. For example (own) price elasticity if measured accurately, can be used to measure the approximate reduction in carbon emissions if a tax or a subsidy is put in place. So in terms of policy, a known price elasticity can, for example, help determine the level of tax required to result in a desired reduction of emissions. However, in practice, there is little consensus regarding the appropriate value of income and/or price elasticity. These elasticities are not static, and vary from region to region, with changes in technology, capital stock utilisation and composition, and economic structures. An equation to determine income or price elasticity can be formulated using a long run estimate of optimal energy demanded which equates to a number of variables, such as income, energy price, and other variables that may influence demand and coefficients of these variables. A partial adjustment mechanism can be included in these equations to take account of delays in demand adjustment to changes in income and price, etc.

It can be seen that developing a satisfactory dynamic energy demand function is extremely complicated, and often will be specific to a particular set of circumstances.

Also Medlock points out that the long and short run effects of energy price changes on overall energy demand can be difficult to separate. As energy is a derived demand it is predicated on the choice of ownership of energy using
capital, linked to a particular level of energy efficiency and a planned rate of capital utilisation. So expectations concerning future energy prices are very important on the decision-making process when purchasing energy using capital. Hassett and Metcalf (1993) support this view, and contend that consumers use a high discount rate, which implies a quick return to cover the risk of their investment in the face of future uncertainty in energy prices. There can be quite a large fixed cost to replacing energy using capital, so an increase in energy price might result in a short term change in capital utilisation. In the longer run however, the capital might be replaced for a more efficient alternative, leading to a greater price elasticity effect. Also the demand response is likely to be asymmetric. This can happen because, for example, an increase in energy cost can give rise to an incentive to increase energy efficiency in the capital stock. If energy costs then fall, the newly efficient capital stock remains unchanged, and thus does not lead to a reversible response to the price change.

3.3 Energy Historically

The development of human energy use began historically from the early human period around 12,000 years ago (Fouquet, 2009). With life on Earth ultimately depending on solar energy, he provides an estimate of the energy contribution of the Sun. Taken from Ruddiman (2001), it is estimated that the Sun provides an average of 1366 W per square metre per second, which equates to approximately 128 million million tonnes of oil equivalent (mtoe). Plant life convert some of this energy through photosynthesis, and this provides the initial base for the food chain. Early on humans tended to live nomadic existences following seasonal variations in plant growth. As hunter-gatherers a large area of land was needed to support the food requirements of approximately 2000 kcal per day that the average human needed. Organised growth of plants was the beginnings of our agriculture but it is uncertain as to the drivers of its permanent adoption.

It is estimated that the human population around 12,000 years ago was approximately 4 million. Land was used by human settlements while it was
temporarily fertile, but once soil nutrition became depleted communities moved on to fresh areas for cultivation. Around 7000 years ago it is estimated that the population had increased on earth to around 5 million. It is likely that there would have been an intensification of more permanent agriculture to support this population growth. And over the following 2000 years agricultural yields were improved by the development of irrigation, the use of animals, the invention of the plough, the wheel and the production of metals. This progression help support the growth of the human population on earth to approximately 15 million around 5000 years ago (Melanima, 2003, p.80).

The structure of human habitation on earth around that time (3000 years BC), was related to their ability to provide food for their survival, but also related to their requirements for heat. Human populations at this time, tended to live sufficiently close to the equator to ensure winters were mild enough to survive without the necessity of additional heat. Although there is evidence (Melanima, 2003) that humans discovered fire 500,000 years ago, its use was primarily for cooking food. The heat improved the calorific and nutritional value of the food. However, slowly from this period onwards, the ability to use fire for warmth allowed the spread of human settlements into more temperate climates. Populations would use large quantities of crop residue and wood from forests to provide their domestic heating needs. So gradually, with human infiltration into colder regions, three quarters of energy requirements were related to the need to provide warmth with the remaining quarter being used for animal fodder and human food.

As well as providing cooked food and human warmth, fire also created light which meant greater protection and safety, but also the ability to carry out more tasks after dark. The heat generated from fire was also beneficial in producing better tools thus improving the efficiency of human existence. It is estimated that by the 16th century, around 1/8 of the Earth’s land area was under continuous agricultural cultivation. Still, at this point, most of the energy requirements of the population was generated either directly or indirectly from solar radiation.
One important point that Fouquet raises is the fact the population density had a big impact on technological development. In 16th century Asia it is thought that 500 to 850 people could live in one square kilometre, due to the ability to have a relatively more intensive agricultural environment. In contrast, in Europe it is estimated that agriculture at that time only supported about 60 people per square kilometre. So with less intensive farming, there was more incentive for technical innovation as lower yielding land was more suited for the use of animals either for use in animal husbandry or to perform agricultural tasks to improve the land efficiency. Oxen and later horses began to be used to plough the land, increasing crop yields through the use of natural fertiliser and also freeing up human time to develop other activities in commercial and industrial areas.

The development of horseshoes and harnesses for horses in the Middle Ages massively improved those animals’ productivity. The expansion of water mills which had been invented around 500 years before the birth of Christ, provided an established source of power for crushing grain, fulling cloth and tanning leather, as well as smelting and shaping iron and sawing wood. Water mills and then windmills in the 12th century drove down the cost of making flour and bread, but Fouquet (2008) claims that animals in this era provided by far the most dominant source of power.

As the population grew in this time, there was increased pressure on land use and tension between its use for forestry or agriculture. These pressures were abated by the onset of the Black Death during the 14th century, but they started to re-occur by the beginning of the 16th century. Wind power provided a means of moving goods between countries, as in economies such as Holland’s. The ability to develop trade meant more of the population could be involved in industrial activities such as textiles, metalworking and brewing. This marked the beginning of the transition to an industrial economy. Urban centres grew as populations migrated from the land, but development was limited by the sources of power. Much energy use was limited to the rate at which it could be converted from solar power either directly or indirectly into goods and services. Peat was exploited at this time as a more concentrated form of energy to
create heat. It was effectively an intermediate product between an organic or a mineral source of energy. The active development of coal as a source of energy (to mitigate the pressure on land from using wood as a source of heating fuel) occurred in Britain during the 16th century. Production increased from about 27,000 toe (tonnes of oil equivalent) to about 1.5 million toe in the 18th century.

The development of the steam engine along with the refinement of water pumps allowed coalmining to be carried out at greater depths, thus improving mine productivity. However Fouquet explains that the transformation from an agricultural to an industrialised economy did not happen overnight. It was a slow process which evolved over 200 years. However coal eventually became the dominant source of energy in 18th century Britain for both heat and power. Coal provided the source of power for both steam railways and steamships, which were the main means of transport for over 80% of goods.

New energy sources were introduced in the 19th century. Coal gas, petroleum and electricity were first used in the emerging market for light sources. As the price of these energy sources declined, they started to be used in other industrial areas. After the invention of the internal combustion engine at the beginning of the 20th century, the transport market became a source of much larger demand for petroleum products. As cars became cheaper, this demand increased.

While initially electricity was used to provide light, its flexibility as a source of power in comparison with the steam engine led to the electrification of much of the world's economies. Electrical power meant that each worker had much more control over his or her equipment. As the demand for electricity grew more of it was generated from oil as well as coal.

Fouquet contends that from a worldwide perspective the transition from wood fuel to coal only took place in the second half of the 19th century. Even in 1900, the beginning of the 20th century, nearly 40% of global energy needs were still being provided by wood. However the 20th century saw rapid transition to the
use of fossil fuels, and by the year 2000 they provided an estimated 78% of energy needs.

Energy consumption per capita increased in two phases. The first was from 1850 to 1913 and the second from 1939 to 1979. The cost of this consumption, both socially and economically, is reviewed in the next section.

3.4 The Costs of Energy

3.4.1 The Social Cost of Carbon dioxide emissions
Pigou (1920) developed the idea of taxing a market that generates negative externalities in order to improve its efficiency. This sort of tax affects the market outcome and takes account of the social cost of market activity where this cost is not taken account of by private costs. This tax then influences the private sector to reduce the negative externalities, such as polluting carbon emissions. Tol (2011) argues that the social cost of carbon (SCC) is equivalent to an estimated Pigou tax that should be placed on carbon emissions. In previous work (Tol, 2007) he looks at 211 estimates of the social cost of carbon. He does this by way of a statistical meta analysis.

In this meta analysis he tests three hypotheses.
1. that the Stern review (Stern, 2006) discount rate is an outlier in the literature.
2. That the estimated economic costs of the impact of climate change increase over time.
3. The uncertainty over the social costs of carbon lead to a statistical distribution with a fat right tail.

This research highlights some caveats to his analysis. The over 200 estimates of SCC look at the marginal costs of climate change, and these marginal costs are based on a dozen estimates of the total costs of climate change. Tol asserts that the total cost estimates ignore interactions between different impacts of climate change, they neglect higher-order effects on the economy and population, extrapolation is done from just a few case studies, a changing climate is imposed on a static society, the models of adaptation to climate
change are too simplistic, adaptation methods and benefit transfers assumed are controversial, and the level of uncertainty is ignored (see table 6).

Table 6 Caveats to Social Cost of Carbon Estimates (Tol, 2011)

<table>
<thead>
<tr>
<th>Caveat</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interactions between consequences of climate change</td>
<td>Different geographical areas could be affected positively or negatively</td>
</tr>
<tr>
<td>Higher order effects</td>
<td>Change in balance of upper atmosphere temperature, changes in biodiversity, population movements, technology adaptations, changes in agricultural yields, plus many other affects</td>
</tr>
<tr>
<td>Assumption of climate change on a static society</td>
<td>How society adapts dynamically to change is unknown</td>
</tr>
<tr>
<td>Climate change modelling is too simplistic</td>
<td>The sheer complexity of how climate change affects economic, population, health and tensions over resources is unresolved</td>
</tr>
<tr>
<td>Adaptation methods and benefit transfers assumed are controversial</td>
<td>Uncertainty over political, economic, social and technological resolution of responding to climate change</td>
</tr>
<tr>
<td>The effects of climate change are highly uncertain</td>
<td>This allows almost any point of view to be accepted, and makes political action difficult</td>
</tr>
</tbody>
</table>

These caveats have not been resolved in further research, partly because of the complexity of this area. Tol contends that he presents the best available knowledge in his research but admits that does not necessarily mean that it is "good".

The 211 estimates of SCC were derived from 47 studies. These estimates represent marginal damage costs discounted to 1995 dollars. The assumptions behind the studies vary. For example, in some the total cost of climate change
is based on original calculation, while in others total cost estimates are borrowed from other studies. Most of the studies use marginal costs to estimate the SCC but some use an average cost for an unspecified method. Some studies assumed the climate changes but that society is static, while others assume that society changes dynamically in the face of climate change. The studies are weighted by quality with more recent studies receiving a higher weighting. A probability density function is assigned to each data point, and the study produces a probability density function of the SCC with a right fat tail, reflecting the uncertainty in the sample, which suggests the possibility of catastrophic effects from climate change must at least be considered.

The research results show that a higher discount rate implies a lower estimate of the SCC and thinner tail. This is because the economic modelling uses money as a common metric to apply to the social cost of carbon emissions. The value of money in the future is usually less than its value in the present, hence the use of a discount rate to determine its present value. A fatter statistical probability tail would imply that there is a higher risk of a greater future cost of the SCC, which in modelling terms would require a lower discount rate. A higher discount rate means the future cost of carbon emissions is projected to reduce more rapidly. Future social costs can only be lower if carbon emission effects in the future are less harmful. The only way they can be less harmful is if they are reduced in scale.

Tol concludes that the discount rate and equity (quality) weighting are drivers to a large extent of the social cost of carbon as derived from the available studies. He also suggests four new results. Number one, there is a downward trend in the estimates of the social cost of carbon. Number two, the Stern review is an outlier in terms of its discount rate even when compared to other studies that use a low discount rate. Number three, the uncertainty about the social cost of carbon is so great that a statistical analysis of studies on the effect of climate change could be dominated by the large tail on the distribution curve. Number four, if everyone were to pay a tax equivalent to the social cost of carbon (SCC) it is likely that the annual taxes associated with this would exceed most people's annual income.
The implications of this research are that even the most conservative assumptions imply that the social cost of carbon is positive (the research estimates a median $20/tC and a mean of $23/tC for the whole world), and that therefore greenhouse gas emission reduction is justified. Secondly, the level of uncertainty is so great that a considerable risk premium is justified (there is a 1% probability that the social cost of carbon is greater than $78/tC). Thirdly, because of the uncertainty, more research is needed into the economic impacts of climate change. Pizer et al (2014) support this view, and there is active ongoing research in this area, albeit with different Integrated Assessment Models (IAM's) which do not share standard parameters.

3.4.2 The Marginal Abatement Costs of carbon dioxide emissions

The cost of abatement of carbon dioxide emissions has to be set off against the damage caused by these emissions. As long as abatement is cheaper than the negative effects of these emissions, it is worth paying. It is therefore worth calculating the abatement costs of reducing carbon dioxide emissions. As is pointed out by Kesicki & Strachan (2011) and further discussed in this section, marginal abatement costs are frequently modelled using methodologies that do not fully encapsulate the complexity of actual abatement.

Kuik et al.(2008) look at the marginal abatement costs of carbon dioxide, by reviewing 26 different estimates of MAC from computer-based economic models developed in a variety of studies. The models can be viewed as interpreting marginal abatement costs in an idealised manner, where the cost is spread evenly across all carbon emissions sources, the costs change over time according to some optimisation rule, and where different greenhouse gases are considered the marginal abatement cost is equalised between them. In order to do a meta-analysis, which analyses multiple studies in a statistical manner, Kuik et al's research considers a linear regression analysis of the marginal abatement cost (MAC) estimated from the different models as the dependent variable expressed as a function of a range of model-related explanatory variables (EVi) and random error(ε). $\Sigma_i$ is the sum of independent variables. This gives the equation:
Equation 8 Marginal Abatement Cost (MAC)

\[ \text{MAC} = \sum \beta_i \text{E} V_i + \epsilon \]

which can also be expressed as

\[ \text{MAC} = \beta_0 + \beta_1 \text{explanatory variable}_1 + \cdots + \beta_K \text{explanatory variable}_K + \text{error}(\epsilon) \]

where \( \beta \) is a coefficient showing if and how the explanatory variables affect the estimated value for the dependent (MAC) variable. The level and direction (positive or negative) of any statistical significance is of particular interest. However, it is important to emphasise that Kuik et al's analysis is not a method for estimating MAC, but a study of the characteristics in different models which produce different estimated values.

While the 26 models considered in this research predicted 62 different marginal abatement costs of carbon dioxide emissions over time, between the periods 2025 and 2050, the research normalised these costs into 2005 € per tonne. Molecular weights were used to convert other greenhouse gases to one common gas (CO\(_2\)) and market exchange rates were used to convert multiple currencies to a single standard, the euro.

The Explanatory Variables used in the regression function were stabilisation target, emissions baseline, model and policy assumptions, and also the particular forum in which the model was developed. Enough information on these variables was only available for 47 (2025) MAC estimates in the models considered (49 for 2050).

Table 7 shows the statistical values for both the full and restricted MAC estimates (Kuik et al., 2008). As can be seen from the figures, predicted maximum and minimum MAC costs are spread widely. Mean averages for abatement to 2025 are significantly lower than those to 2050. This indicates that early abatement of carbon dioxide emissions is likely to save significant costs in the future.
Table 7 Statistical values of MAC estimates (Kuik et al, 2008)

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Full database</th>
<th>Restricted database</th>
<th>2025</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>23.8</td>
<td>23.8</td>
<td>63.0</td>
<td>55.8</td>
</tr>
<tr>
<td>Median</td>
<td>16.2</td>
<td>16.2</td>
<td>34.6</td>
<td>32.2</td>
</tr>
<tr>
<td>Maximum</td>
<td>119.9</td>
<td>119.9</td>
<td>449.3</td>
<td>209.4</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.0</td>
<td>0.4</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>St.dev.</td>
<td>26.7</td>
<td>27.9</td>
<td>72.5</td>
<td>52.9</td>
</tr>
<tr>
<td>N</td>
<td>62</td>
<td>47</td>
<td>62</td>
<td>49</td>
</tr>
</tbody>
</table>

The restricted set of 47 models with full data is used for the actual meta analysis. The stabilisation targets in all models (equilibrium concentration level of carbon dioxide emissions) were converted to ppmv CO2 concentration measures (parts per million by volume in the atmosphere). The average stabilisation target in the 47 restricted studies was 506 ppmv CO2. 400 ppm is the current average in the UK (Solomon et al, 2009). Across the studies the average increase in baseline emissions between 2000 and 2100 was 174%. The median increase was 179%.

The baseline emissions in the studies examined were based on a variety of different assumptions regarding economic growth, industry structure and technological developments. The baseline in conjunction with the stabilisation target determines the effectiveness of the emissions reduction effort, and thus the MAC. Some studies have shown (Weyant et al., 2006) that a multi-gas policy towards managing greenhouse gas emissions yields greater cost savings, than can be achieved with a single gas (carbon dioxide) policy. Kuik et al incorporate a binary explanatory variable to reflect gas policy, with a multigas policy taking the value of one and a single gas policy taking the value zero.

Another issue Kuik et al consider is "induced" technical change. This assumes that the rate of technical change is dependent on the overall greenhouse gas reduction policy (and subsequent carbon price). The models under study found
that induced technical change results in a lower marginal abatement cost than would otherwise be the case, if for example a steady rate of technical change was assumed. The authors claim that technological change that is induced by the emissions reduction policy can become self reinforcing leading to carbon free energy technologies being the lowest cost option available. This remains unproven however. Popp, Hascic. & Medhi (2011) find that induced technical change leads to greater investment in renewable technologies, but that the effect is minor. Greenhouse gas reduction policy, can equally result in investments in other existing carbon-free energy sources, such as hydropower and nuclear power, which serve as substitutes for renewable energy.

Another variable of significance was found to be the level of aggregation of the model under study. The number of energy sources in the model was also significant. Both of these variables had a positive effect on the MAC.

Another explanatory variable which was given a value in this study, related to whether the individual studies were top-down or bottom-up. "Bottom-up models" are supposedly rich in technical detail but less accurate in explaining microeconomic behaviour and macroeconomic feedbacks. "Top-down" models were given a value of one, and bottom-up models a value of zero in the SPSS regression representation. It is not clear how these values affected the fit in the regression models.

Some of the models under study assumed intertemporal optimisation where consumption, investment and abatement were optimised over the entire planning period. Other models only optimised periods recursively.

Models which included Carbon Capture and Storage (CCS) were given a value of 1 associated with this variable. Models without CCS were given a value of zero. In the context of this research CCS was considered a backstop technology, which could produce unlimited quantities of low carbon energy at a (high) constant cost.
A final variable was included to account for the difference in modelling fora. This was incorporated as it was assumed that each energy modelling forum would have different levels of optimism with regard to technical progress and the cost of energy emission abatement. This seems to be an entirely subjective added variable.

Two meta regression models were developed from this research. The first included all the variables described above, and the second was developed from stepwise regression and only included variables that were significant at the 10% level.

Kuik et al claim that their first meta regression model explains more than 50% of the variance discovered in the marginal abatement costs under consideration in their research. In summary, their meta analysis suggests the differences between marginal abatement cost models can to some degree be explained by differences in stabilisation target and emissions baseline, the degree of assumed intertemporal optimisation, whether or not a multigas policy variable is included, and whether there is the assumption of Carbon Capture and Storage (CCS) as a backstop technology. This implies some consideration of the cost of producing renewable energy weighted against the costs of reducing carbon dioxide emissions through CCS. As a developing technology, the costs of CCS are uncertain and changing with developing technology and whether the extracted CO₂ can be resold to reduce costs.

Table 8 shows the MAC (in euros, 2005) for 2025 and 2050 (across the target range 550-350 ppmv).

Table 8  Range of Marginal Abatement Cost in €2005/tCO₂ over time (Kuik et al, 2008)

<table>
<thead>
<tr>
<th>€2005/tCO₂</th>
<th>2025</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAC</td>
<td>13 – 119</td>
<td>34 – 212</td>
</tr>
</tbody>
</table>
3.4.3 The Price of carbon dioxide emissions

The price of carbon dioxide emissions is determined at the point where the social cost of carbon dioxide emissions intersects with the marginal abatement cost of carbon dioxide emissions. However, this is a theoretical construct, which in practice is impossible to assess accurately. Tol (2005) argues that the abatement of carbon dioxide emissions is costly and should be offset against the benefit to society (i.e. avoiding climate change). In order to assess the impact of climate change, and thus the impact of excessive carbon dioxide emissions, he contends a set of indicators should be developed which reflect a tractable set of impacts which can be summarised and compared in a meaningful way. Physical measures can be used to assess the impact on the natural environment, but these do not necessary link adequately to an assessment of human welfare λ.

In order to explicitly compare the impact of excessive carbon dioxide emissions with the cost of their mitigation (and determine the price of carbon dioxide emissions), a common metric needs to be used. Money is argued to be a reasonable common denominator with which to express mitigation costs, and although environmental impacts are not always easy to express in monetary terms it is possible to do so according to Tol.

However, according to Pearce et al.,(1996) valuations in economic terms can be controversial, requiring sophisticated analysis that is generally lacking in a climate change context. Externalities not borne by the producers of greenhouse gases can have an enormous impact on the environment and society. Different people will be impacted by different externalities in different ways. Some might suffer health problems from pollution, others might have their homes flooded more frequently due to rising sea levels, and others might suffer from hunger due to reduced agricultural yields. Some people's personal preferences will be affected by carbon dioxide emission mitigation through regulation.

27 studies of marginal damage costs are reviewed in Tol's paper, and the 94 estimates those studies produced are combined to form a joint probability
density function. However, one of the limitations of this research is the fact that climate change impacts cannot be measured as a homogenous intertemporal or interspatial function. In reality, impacts are local and related to extreme weather variability. Comparing case studies in different countries for example is extremely difficult. This limits the ability to extrapolate costs and consequences across regions. Adaptation to climate change is hard to measure in different countries or areas, as the aims of successful adaptation might vary according to social and economic priorities. The aim of adaptation might be to maintain current income levels, to maintain current levels of food production and other aims might involve maintaining satisfactory thermal comfort for the population in general. Adaptation is not a linear function as it interacts with other variables such as technological change and improved levels of education, and so on.

Another uncertainty in calculating the cost of climate change, and thus the marginal cost of carbon dioxide emissions, is the likelihood of a catastrophic event. With the current state of knowledge, this seems to be a value judgement rather than a carefully constructed statistical probability. The view of Tol's paper is that aggregation of the marginal damage costs of CO₂ emissions may underestimate the true costs as they do not take account of extreme weather events. Despite this, it is asserted that there is an improving understanding of the aggregate impacts of climate change, particularly with respect to the impact on agriculture and coastal areas. There is an increased understanding of the relevance of other nonmarket impacts, such as the effect on people's health, an externality which is hard to measure in financial terms.

Tol's mean average Social Cost of Carbon (SCC) emissions in his 2007 research in 1995 US dollars is approximately $23 per tonne of carbon dioxide emitted. The study of MAC by Kuik et al reveal a 2005 cost in euros of anything between €13 and €212. The key point is that marginal abatement costs can be argued to roughly double between 2025 and 2050.

Adjusting these estimates to 2015 prices and using market exchange rates, would result in a marginal abatement cost of between $14 and $127 per tonne of carbon dioxide emitted (in 2025). However if we carried out the abatement
today, we could discount the estimates by around a quarter (discounting using the Bank of England's long term average interest rate of 5%).

This would give MAC's in April 2015 money of between $10 and $95. The mean average SCC would be approximately $36 in April 2015 money.

The price of carbon emissions is theoretically determined by the marginal abatement cost of reducing an extra tonne of carbon dioxide being equal to the marginal social cost of emitting an extra tonne of carbon dioxide.

In figure 6 below, \( \lambda^* \) on the Y axis, is the price of carbon emissions and \( E^* \) on the X axis is the efficient level of emissions. If emission levels were higher, the cost of the damage caused by the emissions would be higher than the cost of abatement.

![Figure 6 Price of Carbon Emissions](http://hsalbert.blogspot.se/2011)
This highlights the clear dilemma we have in determining the price of carbon emissions. We have to weigh the effects of these emissions in terms of their cost to society (and possibly on a world scale) against the costs of reducing these emissions. As has been demonstrated by the above research this is a very difficult thing to do. However, Pigou’s idea of taxing a market that generates negative externalities is clearly a good idea. Weitzman (2014) also recommends abatement as an insurance against catastrophic events, lessening the probability of their occurrence.

Despite these difficulties, energy efficiency schemes to address the problem of carbon emissions have been incorporated into policy, and these are outlined in the next section.

3.5 Energy Policy

3.5.1 Historical energy efficiency schemes
Since the late 1980s that have been a number of energy efficiency schemes created by the UK government. These are outlined below, with a summary table provided at the end of the section (Table 6).

The Non Fossil Fuel Obligation was established in 1989 (NFFO) under the Electricity Act of that year. This Act also established The Scottish Renewables Obligation (SNO). Originally only intended to support nuclear electricity generation, the scheme was expanded in 1990 to include renewables. Funding for the scheme was supplied by a levy from fossil fuel energy producers.

In 2000 the climate change programme was established (Climate Change Programme, 2000). This has since been updated, but was intended to reduce greenhouse gas emissions to mitigate climate change. Its stated objectives were to:

- Improve business’ use of energy, stimulate investment and cut costs;
- Stimulate new, more efficient sources of power generation;
- Cut emissions from the transport sector;
• Promote better energy efficiency in the domestic sector, saving householders money;
• Improve the energy efficiency requirements of the building regulations;
• Continue cutting emissions from agriculture;
• Ensure the public sector took a leading role.

In 2001 The Climate Change Levy (The Climate Change Levy, 2001) was introduced (CCL) and effectively replaced the Fossil Fuel Levy. The CCL was a tax on nondomestic intensive energy users in industry and public sector. Renewable energy suppliers were exempt from this tax. Also intensive energy companies who accepted the Climate Change Agreement, could get a discount on the tax of 80%.

In 2002 the Renewables Obligation (The Renewables Obligation Order, 2002) became the primary policy instrument to promote renewable energy, and required electricity end suppliers to purchase a proportion of their electricity energy supply from producers whose energy mix included specific renewable technologies. In return, they received tradable renewable obligation certificates (ROC’s).

In 2002 the energy efficiency commitment (EEC) was introduced (Ofgem, 2002). This required energy suppliers to achieve the target level of savings over the time period to 2005. The way suppliers would achieve their target would be by helping the implementation of domestic energy efficiency improvements. A second phase of EEC was implemented between 2005 and 2008, with a savings target of 130 TWh.

The European Union Emissions Trading System (EU ETS, 2005) started in 2005, replacing the UK emissions trading scheme in 2006. The ETS was intended to aid compliance with the Kyoto obligations. Member States allocated a proportion of their total 2008 to 2012 emissions budget to sectors covered by the scheme, and tradable quotas were then divided among firms.
In 2007 The Code for Sustainable Homes (DCLG..2005) established minimum energy performance standards for the construction of new houses. These standards covered the use of energy, water, materials and waste. After 2008 all new homes were rated against this code and had to meet its level 3, which stipulated an energy improvement of 25% in comparison with 2006 building regulations. The latest revision to the code was in 2010. In conjunction with this code, Building Regulations Part L also stipulate energy efficiency requirements for new houses in England and Wales.

2008 saw the introduction of the Climate Change Act (2008), which set a legally binding target of an 80% reduction in carbon emissions from 1990 to 2050. In addition an intermediate target of 34% was set for 2020. The Act sets out the principal of five yearly carbon budgets to meet the reduction targets. The fourth budget covering the period 2023 to 2027, was agreed in 2011 by the Committee on Climate Change. Policies to meet the climate change act budgets have to be submitted to parliament, and the Low Carbon Transition Plan was proposed in 2009. This plan set out emission reduction policies across the power and heavy industry sector, the transport sector, homes and communities, workplaces and jobs, agriculture, and land use and waste management. A policy to reduce aviation and shipping emissions was included by the end of 2012.

In 2008 The Carbon Emissions Reduction Target (CERT), which was a development on the Climate Change and Sustainable Energy Act (2006), replaced the Energy Efficiency Commitment. There was a greater focus on increased domestic energy saving measures such as loft and cavity wall insulation. Also there was an increased commitment to target people who are most vulnerable to fuel poverty. The scheme imposed a saving requirement of 293,000,000 t of CO₂ from energy suppliers until the scheme's end in 2012.

Also in 2008 the Renewable Transport Fuel Obligation (2007) was introduced (RTFO). This requires a specific percentage of UK road fuel to be from renewables. The obligation can be bought out for 30p per litre.
Energy performance certificates (EPC’s) were also introduced in 2008 (EPC, 2008). These are required whenever a building is constructed, sold or rented. The certificates show performance ratings between A and G, much like energy performance certificates on white goods.

In 2009 the Community Energy Saving Programme (Electricity and Gas (Community Energy Saving Programme) Order 2009) was established (CESP, 2009). This scheme addressed fuel poverty in the UK by requiring energy suppliers to achieve a 19.25mt reduction in carbon emissions in the most deprived areas of the UK during the lifetime of the scheme.

Firms and public bodies whose emissions were not covered by the EU system or other UK agreements were included in the Carbon Reduction Commitment Energy Efficiency Scheme (CRC, 2010) in 2010. The scheme was set up as a mandatory scheme aimed at improving energy efficiency and cutting emissions in large public and private sector organisations.

Feed in Tariffs (Feed-in Tariffs, 2010) were also introduced in 2010. These were for small-scale low carbon electricity generated by the domestic and commercial sectors. A subsidy is provided for electricity which is fed into the grid. The feed in tariffs vary according to the producing technology.

Also in 2010, funding for a Carbon Capture and Storage (CCS) demonstration project was announced with the Energy Act (2010). This amounted to £1 billion for a full-scale pilot project.

The government introduced its own Carbon Plan in 2011 (The Carbon Plan: Delivering our low carbon future, 2011) which set out the proposed mechanism for reducing carbon emissions in the government sector, department by department, up to 2020. An update on measures delivered was included in a report by Ofgem in December of that year (Ofgem, 2011).

£3 billion in funding was allocated in 2012 for a Green Investment Bank (GIB, 2012), which could provide capital funding to projects that will assist the
transition to low carbon growth. Despite the name, the Green Investment Bank is not strictly speaking a bank since it has assets (the loans) but no debts. It is simply a conduit for one-off subsidised loans from the Treasury approved by a technical committee.

Also in 2012 the Renewable Heat Incentive (in the Energy Act, 2008) was made available for a long term tariff support of renewable heat installations for the non-domestic sector. The second phase of this in early 2013, coincides with the introduction of the Green Deal, to provide support for renewable energy installations in the domestic sector.

The 2012 Energy Bill, now the Energy Act 2013 (Energy Bill, 2012) formally introduced the Green Deal onto the statute books. Smart meter rollout has already begun, and is intended to be complete in the UK domestic sector by the end of 2019. Smart meters are intended to allow consumers to become more aware of their energy usage, and thus encourage them to adopt more efficient energy use.

Table 9 shows a summary of UK energy efficiency schemes.
<table>
<thead>
<tr>
<th>Year</th>
<th>Energy Efficiency Scheme</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>Non Fossil Fuel Obligation (NFFO)</td>
<td>To support nuclear power</td>
</tr>
<tr>
<td>1990</td>
<td>Non Fossil Fuel Obligation (NFFO)</td>
<td>To additionally support renewable energy</td>
</tr>
<tr>
<td>2000</td>
<td>Climate Change Programme</td>
<td>To reduce greenhouse gas emissions to mitigate climate change (including promoting better energy efficiency in the domestic sector and improving the energy efficiency requirements of the building regulations)</td>
</tr>
<tr>
<td>2001</td>
<td>Climate Change Levy (CCL)</td>
<td>To tax nondomestic intensive energy users in industry and the public sector. (Renewable energy suppliers were exempt)</td>
</tr>
<tr>
<td>2001</td>
<td>Climate Change Agreement</td>
<td>Intensive energy companies who accepted the Climate Change Agreement, could get a discount on the CCL tax of 80%.</td>
</tr>
<tr>
<td>2002</td>
<td>The Renewables Obligation Order</td>
<td>Required electricity end suppliers to purchase a proportion of their electricity energy supply from renewable technologies, receiving tradable renewable obligation certificates in return (ROC's).</td>
</tr>
<tr>
<td>2002</td>
<td>Energy Efficiency Commitment (EEC)</td>
<td>Required energy suppliers to achieve a target level of energy savings over the time period to 2005, via facilitating implementation of domestic energy efficiency improvements.</td>
</tr>
<tr>
<td>Year</td>
<td>Energy Efficiency Scheme</td>
<td>Rationale</td>
</tr>
<tr>
<td>------</td>
<td>---------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>2005</td>
<td>European Union Emissions Trading System (EU ETS)</td>
<td>To comply with the Kyoto Protocol. Tradable permits introduced and divided amongst firms in sectors covered by the agreement.</td>
</tr>
<tr>
<td>2007</td>
<td>Code for Sustainable Homes</td>
<td>To establish minimum energy performance standards for the construction of new houses. 25% energy improvement required over 2006 building regulations.</td>
</tr>
<tr>
<td>2008</td>
<td>Climate Change Act</td>
<td>To set a legally binding target of an 80% reduction in carbon emissions from 1990 levels by 2050. Carbon budgets set for five year periods by appointed Committee on Climate Change.</td>
</tr>
<tr>
<td>2009</td>
<td>Low Carbon Transition Plan</td>
<td>Set out policies to reduce emissions across key sectors.</td>
</tr>
<tr>
<td>2008</td>
<td>Carbon Emissions Reduction Target (CERT)</td>
<td>Replaced the Energy Efficiency Commitment. Greater focus on increased domestic energy saving measures and increased commitment to target fuel poverty.</td>
</tr>
<tr>
<td>2008</td>
<td>Renewable Transport Fuel Obligation</td>
<td>Requires a specific percentage of UK road fuel to be from renewables.</td>
</tr>
<tr>
<td>2008</td>
<td>Energy performance certificates (EPC's)</td>
<td>EPC's give an energy performance rating</td>
</tr>
<tr>
<td>2009</td>
<td>Community Energy Saving Programme</td>
<td>To address fuel poverty in the UK via energy suppliers facilitating domestic energy efficiency improvements.</td>
</tr>
<tr>
<td>2010</td>
<td>Code for Sustainable Homes</td>
<td>Code revised to improve energy efficiency</td>
</tr>
<tr>
<td>2010</td>
<td>Carbon Reduction Commitment Energy Efficiency Scheme</td>
<td>A mandatory scheme to improve energy efficiency and cut emissions in large public and private sector organisations</td>
</tr>
<tr>
<td>Year</td>
<td>Energy Efficiency Scheme</td>
<td>Rationale</td>
</tr>
<tr>
<td>-------</td>
<td>------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>2010</td>
<td>Feed in Tariffs</td>
<td>A subsidy provided for electricity which is fed into the grid by small-scale low carbon generation.</td>
</tr>
<tr>
<td>2010</td>
<td>Energy Act (2010)</td>
<td>To provide funding for Carbon Capture and Storage (CCS)</td>
</tr>
<tr>
<td>2011</td>
<td>The Carbon Plan: Delivering our low carbon future</td>
<td>Proposed a mechanism for reducing carbon emissions in the government sector up to 2020</td>
</tr>
<tr>
<td>2012</td>
<td>Green Investment Bank</td>
<td>Capital funding for projects that will assist the transition to low carbon growth.</td>
</tr>
<tr>
<td>2012</td>
<td>Renewable Heat Incentive</td>
<td>Support for renewable heat installations for the non-domestic sector</td>
</tr>
<tr>
<td>2012</td>
<td>Energy Bill, 2012</td>
<td>Formally introduced the Green Deal</td>
</tr>
<tr>
<td>2013</td>
<td>Renewable Heat Incentive</td>
<td>Support for renewable heat installations for the domestic sector</td>
</tr>
<tr>
<td>2013</td>
<td>Smart Meter Rollout</td>
<td>To install smart electricity and gas meters to every household.</td>
</tr>
</tbody>
</table>
3.5.2 The Green Deal
This section states the objective of the Green Deal, provides a theoretical perspective and outlines the mechanism and structure of the policy. It then discusses complications with the Green Deal configuration.

3.5.2.1 Objective
The Green Deal, along with a new Energy Company Obligation (ECO) provided for in the Energy Act (2011), is a long term initiative designed to upgrade the energy efficiency of Britain’s homes. Householders can arrange for government regulated assessors to survey their homes and recommend a range of energy-saving measures. Finance can be provided for these measures provided the energy saving over time is greater than the cost of installation of the energy saving measure.

The Green Deal replaces the previous Carbon Emissions Reduction Target (CERT) and the Community Energy Saving Programme (CESP), which expired in 2012. The ECO obliges energy companies to provide a subsidy to improve energy efficiency in low income households and designated low income and rural areas.

3.5.2.2 Theoretical analysis
Some prescient thoughts on the Green Deal by Weyman-Jones (2013) are set down in formal algebraic statements. He regards the Green Deal essentially an alternative form of financing for energy efficiency improvements in the home. He postulates that with an average dual fuel bill of £1500 per annum, an average UK household might aim to save £300 a year of this (20% of energy costs) by installing upfront energy-saving improvements.

An initial consideration is how much the energy savings are worth in general? The annual value of savings is $P^E \Delta E$, where $P^E$ is the energy price paid by households and $\Delta E$ is the typical energy consumption saved. If the £300 per year savings were projected to last indefinitely, then the annual saving in present value terms is $V = P^E \Delta E / i$ where $i$ is the household’s discount rate. Although $V$ is the present value to the householder, it may not equate to the present value for the
policymaker. This is because the social value $P^s \Delta E$ of energy saved may be different than the market value $P^E \Delta E$ of energy saved. The price of energy to the policymaker may include externalities, such as pollution, security of supply and the effects of climate change. Additionally, the social discount rate $\rho$ is likely to be different from the private household discount rate $i$.

Assuming initially the householder accesses the competitive capital market to finance a loan for $T$ years to install energy improvement measures, the loan repayment $k$ has a present value over the life of the loan equal to the cost of installing the energy efficiency improvements.

So the net present value to the householder accessing the capital market is:

$$\frac{P^s \Delta E}{i} - \frac{k}{i} \left[ 1 - \left( 1 + i \right)^{-T} \right]$$

The first expression is the present value of the cost of energy saved (i.e. not used) assuming that these cost savings last for many years. Energy saved is the change in energy demand, $\Delta E$, and $P$ is the price of energy paid by households. The present value is arrived at by discounting by the current interest rate $i$. The second expression is the loan repayments for a finite number of years required to finance the very long-lived energy cost savings calculated at the same rate of interest. Their difference is the net present value of the installation to the householder.

The net present value for the householder remains positive, irrespective of the discount rate, provided the annual market value of the energy saved exceeds the annual loan repayment $\left[ 1 - \left( 1 + i \right)^{-T} \right] < 1$.

---

2 The formula is the sum of an infinite geometric series where each succeeding term is the term before divided by $(1 + i)$.

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If the current price of energy in the market is always lower than the discounted future savings, then whatever rate these future savings are discounted at is unimportant as the householder always makes a profit, compared to the price he/she would have had to pay if they had not made energy improvements.

In this scenario, the householder can simply extend their energy efficiency property loan secured on the property value. In fact, even in the case where the householder is in negative equity, the loan is secured through energy savings which are greater than the cost of energy use. Loan payments are automatically deducted from the household electricity bill, regardless of which energy supplier is used.

So theoretically a householder should always be able to obtain an energy efficiency loan on this basis. If they cannot do so, for example, because they are regarded as a poor finance risk, then this represents a capital market failure. The policy maker could overcome this capital market failure by providing additional information and research findings, or through providing additional forms of loan finance which focus on energy-saving potential and ignore household creditworthiness. This second strategy for providing finance to address capital market failure seems to be the one adopted by the Green Deal.

Weyman - Jones (2013) therefore suggests:

**Conclusion 1.** The Green Deal is designed to address a particular example of capital market failure, it is not an exclusively environmental policy instrument.

The policymakers calculation should be:

\[
\frac{P_s \Delta E}{\rho} \cdot \frac{k}{i} \left[ 1 - (1 + i)^{-T} \right]
\]
Comparing this with equation 9, two terms have changed. The price at which energy savings are valued is now $P_s$ and the discount rate for computing the present value of the long-lived energy savings, i.e. the first expression in the equation, is now the policy-maker’s social discount rate, $\rho$ instead of the householder’s cost of capital, $i$, the rate of interest payable on the Green Deal loan. The difference is critical because policy-makers in the years preceding the Green Deal argued that the social discount rate for energy savings was lower than the rate at which households borrowed capital for housing related loans. In the Stern Review (Stern, 2006), for example, it was argued that the value for $\rho$ should be 1% per annum at a time when $i$ was about 5-7% per annum. The effect is to make energy saving investments much more attractive from a socially responsible viewpoint than most households believed from their private interest viewpoint.

The total benefits may be greater than competitive loan repayments because:

a) the policymaker values units of energy saved at a higher level than the market price of energy because they incorporate a premium, which reflects the real price of carbon (including externalities);

b) the policymaker has a lower social discount rate than the competitive capital market interest rate.

The Green Deal currently offers the following:

1. an energy efficiency assessment at a fixed price $F$
2. if energy savings are assessed to fulfil the condition $P_E - k > 0$ in the first year of the project, then these savings are eligible for a loan finance that is repaid through the household energy bills at a Green Deal interest rate of $i_G$.

Currently $i_G \approx 0.07$, which is greater than the private capital market rate, but may be fixed into the future. So the householder, after paying any assessment charge, can carry out recommended energy savings and expect reduced energy bills, equal in expected present value terms to:
Equation 11  Recommended Energy Saving Calculation

\[
\frac{P}{i} \frac{\Delta E}{k} \left[ 1 - (1 + i)^{-T} \right] - F
\]

There could be some obstacles to participation in the scheme from the householder's point of view:

- the fixed assessment charge may eliminate the present value of the net benefits
- qualified assessors may be difficult to find, although there are now 2,900 advisors registered to carry out Green Deal assessments (DECC, 2014a)
- the assessor may identify fewer energy saving measures than the householder wishes to install
- the householder may have a higher discount rate than both the Green Deal and the competitive market rate (Hassett & Metcalf, 1993)
- There is an expected value condition that depending on the assessor’s assumptions, and random variables involved, may in some cases result in negative present values.

Solutions to these problems can include lower assessment charges, more accurate assessments, and the assumption of more realistic discount rates by the public.

Another potential problem could arise when the householder sells their property to a third party. Potential buyers could be put off by being locked into long-term Green Deal loan finance for energy improvements which could have been installed at a more competitive market rate.

Take-up of Green Deal finance could be disappointing because:

- The policy-maker’s social discount rate is lower than the Green Deal rate, the competitive market loan rate and the typical household discount rate. This results in an inefficiently low number of projects undertaken from the policy-makers’ point of view.
The social valuation of energy by the policymaker exceeds the market price of energy: $P^S > P^E$. This is often cited as the motivation behind environmental policy initiatives of all kinds, e.g. air pollution is not costed into fossil fuel generation.

The solution to these problems requires replacing the Green Deal interest rate with the policymaker social discount rate, and assessing energy savings at the higher social cost of energy.

**Conclusion 2:** The Green Deal will disappoint policy-makers in the take-up rate so long as the energy savings are valued at a market price below the social cost of energy – but this will eventually require the incorporation of the social cost of energy into the market price and the public determination of a price of carbon for policy evaluation.

This view is supported by Tol (2007) and Stern (2009) even though both of these innovations have been resisted by UK policy-makers for the last decade, possibly for political reasons.

Finally, Weyman-Jones' analysis clarifies the policymaker's social valuation of the energy saved, $P^S$.

The objective is to capture both the benefit of saving energy costs and the benefit of reducing carbon emissions in the economy. The first benefit is measured at the margin by the social value of saved energy, $P^E \Delta E$, while the second is measured by the social value of reduced emissions, $P^C \Delta C$. The first term can be estimated by the market value of the energy saved. The second term is an external non-financial benefit unlikely to be generally taken into account in a typical individual’s decision-making process, despite the benefit resulting in a more healthy and secure (sustainable) long term quality of life.

The total benefit is:
Equation 12  Energy Saving Net Benefit

\[ P^E \Delta E + P^c \Delta C = (P^E + (\frac{\Delta C}{\Delta E}) P^c) \Delta E \]

where \((\frac{\Delta C}{\Delta E})\) is the marginal reduction in emissions per unit of household energy saved.

Consequently, the social cost of energy is:

Equation 13  Social Cost of Energy

\[ P^s = (P^E + (\frac{\Delta C}{\Delta E}) P^c) \]

The policymakers need to determine two critical numbers, \((\frac{\Delta C}{\Delta E})\) the marginal carbon saving per unit of energy saving in tonnes of CO\(_2\) equivalent per kWh of energy saved, and \(P^c\) the price of carbon emissions in £ per tonne of CO\(_2\) equivalent. The market price of energy \(P^E\) is already available in £ per kWh per unit of energy.

The component \((P^E + (\frac{\Delta C}{\Delta E}) P^c)\) is already well-known in environmental economic literature, as for example in the widely cited classic paper by Fullerton (2001). The long run equilibrium price of carbon \(P^c\) is given by the value of the equality of the marginal abatement cost (mac) and the social cost of carbon (scc), see section 3.4.3, Figure 6. In the short run, if carbon emissions exceed desirable levels, it will be the case that scc > mac. Consequently a lower bound for \(P^s\) is

Equation 14  Price of Carbon Emissions

\[ P^c = (P^E + (\frac{\Delta C}{\Delta E}) \text{mac}^0) \]

Fullerton’s key diagram below (figure 7) depicts the long-run welfare optimum at the intersection of the marginal abatement cost curve and the marginal social cost of carbon curve.
Marginal abatement cost (mac): Fullerton views emissions as an input with the downward sloping marginal product curve, regarding emissions as co-produced with each unit of production. This assumes that additional units of emissions are successively less crucial to reduction. Multiplying this marginal product curve by the price of the energy output produces a value of emissions' marginal product of input curve:

\[ P^E \left( \frac{\Delta Y_E}{\Delta C} \right) \]

The term \( \frac{\Delta Y_E}{\Delta C} \) is the marginal product of energy supply with respect to the input of emissions associated with the use of fossil fuels. It differs from the term \( \frac{\Delta C}{\Delta E} \) in the household investment decision. As Weyman Jones explains, in emissions abatement the marginal cost of abatement will be equated to the marginal value of emissions so that this value of emissions marginal product curve is also the marginal abatement cost curve. As such, the marginal abatement cost can also be equated to the marginal price of buying offsetting tradable permits, so this curve also serves as the demand for permits curve.

Social cost of carbon (scc): this represents the damage to the environment from carbon emissions and is measured by the curve of additional environmental damage cost arising from every addition to the stock of emissions, which accumulates forever. The damage is an increasing function of the stock of emissions, and the marginal social cost of carbon is the discounted present value of this damage to the environment arising from the marginal addition to the accumulated stock of emissions. This curve is upward sloping with respect to the flow of emissions that is added to the stock.

As an initial level of emissions: \( C^0, \text{mac}^0 < \text{scc}^0 \), reflects the fact that the world's annual flow of emissions is too high. The net welfare gain from reduction of the annual flow to \( C^* \) is:
Equation 16  Net Welfare Gain of CO₂ Reduction

$$\Delta W = \frac{1}{2} (scc^0 - mac^0) (C^0 - C^*)$$

$\Delta W$ is the change in welfare for society.

$scc^0$ is the current social cost of carbon emissions

$mac^0$ is the current marginal abatement cost

$C^0$ represents current carbon emissions

$C^*$ represents equilibrium carbon emissions (where $scc = mac$)

Without explicitly addressing market failure, the government's aim of the Green Deal scheme is to increase the level of energy efficiency measures installed in UK domestic and commercial property, although this dissertation only considers the scheme in relation to the domestic sector.

3.5.2.3 The Green Deal mechanism

Approximately 125 accredited providers are available to offer a choice of energy efficiency packages to customers at no advance cost. As has been outlined in the analysis above, this is the key element of the Green Deal. The energy efficiency
investments are recouped through energy bill repayments. The charge is added to the property energy/electricity bill, and remains a charge connected to the house regardless of who occupies it. This is why the Green Deal "Golden Rule", which is a legal requirement, specifies that any charge attached to an energy saving measure must be less than the expected savings from it. In this way the householder should always benefit from having the energy efficiency measure installed in their property. However an important point already considered is that the Green Deal's Golden Rule does not take into account the social cost of carbon emissions. In this sense it misses the point that the policy is trying to address.

In addition, the Green Deal also has no explicit discount rate with which to evaluate the savings benefits on a net present value basis. The government's own advice merely says that "the expected financial savings must be equal to or greater than the costs attached to the energy bill". The energy bill repayment includes the proportionate capital and interest costs quoted by the energy saving provider based on predicted use. The charges don't change regardless of actual energy costs.

The main components of the Green Deal scheme are on-site assessment, the installation of the efficiency measures, the provision of finance and the facility to attach a charge to a property's energy bill, and the delivery of continuing advice and support to consumers (DECC, 2011).

The Green Deal Plan is a new type of unsecured loan, on which interest will be charged. Householders will be liable for the loan so long as they are the electricity bill payers at the property. Energy efficiency measures installed under the Green Deal should mean there are some energy cost savings, which according to the Department of Energy and Climate Change website, will be mainly on space heating. There is a Green Deal quality Mark, which only approved Green Deal assessors, providers and installers can use. The Green Deal provider provides the key terms of the green deal contract, such as interest rate (which is fixed) and repayment amounts. The Green Deal repayments are collected by the electricity supplier via the electricity bill passed onto the Green Deal Provider. The Energy Performance Certificate (EPC) will reveal if there is a Green Deal on the property.
Green Deal plans are regulated under the Consumer Credit Act 1974. Separately to money owed to the Green Deal Provider, there may have been a charge for the Green Deal assessment, made by the initial Green Deal Assessor.

3.5.2.4 Structure of the Green Deal

A basic structure of the Green Deal is represented in figure 8 below.

**Flowchart of Green Deal Structure**

- **Green Deal Providers (GDP)** are responsible for arranging Green Deal Plans, provide the finance, and arrange for the installation of the agreed energy efficiency improvements through an authorised Installer.
- **Green Deal Oversight and Registration Body (GD ORB)** maintains a register of all authorised Green Deal Providers, Certification Bodies, Advisors and Installers. Responsible for Green Deal code of practice and authorises use of the Green Deal quality Mark.
- **Green Deal Assessor Certification Body (GDACB)** This body certifies Green Deal assessor organisations or individual Green Deal assessors. The GDACB is itself certified by the GD ORB.
- **Green Deal Assessor Organisation (GDAO)** Assesses households for Green Deal approved, energy efficiency measures. Provides Green Deal advice report to be used by GDP.
- **Household interested in energy efficiency (initially contacts GDAO)**

Figure 8 Flow Chart of the Green Deal  (Author's interpretation)

There is a Green Deal Oversight and Registration Body (GD ORB, 2013) which manages authorisation for participants in the Green Deal. GD ORB's role includes
maintaining a register of all authorised Green Deal Providers, Certification Bodies, Advisors and Installers. The body also maintains and monitors the Green Deal code of practice and authorises use of the Green Deal quality Mark.

Green Deal Providers (GDP) are responsible for arranging Green Deal Plans, provide the finance, and arrange for the installation of the agreed energy efficiency improvements through an authorised Installer. GDP’s offer a Green Deal plan to customers, and this plan is based on recommendations from an accredited Green Deal Assessor Organisation (GDAO). GDP’s also deal with customer complaints and are responsible for providing information to a new owner moving into a property with a Green Deal. The new owner will need details of the Green Deal Plan as it sets out the financial arrangements and warranties which cover the energy efficiency measures which have been installed.

The GDP is required to use a Green Deal advice report which can only be produced by an authorised Green Deal Assessor (GDA). This report identifies any potential energy efficiency improvements that can be carried out at a particular property. GDA’s are expected to produce these reports on an impartial basis, so that customers can use any GDP to quote for the potential energy efficiency improvements. This would seem to exclude GDP’s and GDA’s being too closely related, for example being part of the same company. This is part of the Code of Practice.

Green Deal Assessors can be a company or an individual, but they must be accredited by an authorised Green Deal Assessor Certification Body. This body will in turn be regulated and authorised by GD ORB. A GDA can carry out an assessment itself or employ or sub contract to suitably qualified individuals who are referred to as Green Deal Advisers. However the legal obligation with respect to any work done remains between the GDA and the customer.

The Green Deal adviser who visits the property carries out an assessment which involves a visual inspection of the property and the production of a Energy Performance Certificate (EPC). The visual inspection includes the recording of type of dwelling, habitation area, property age, extensions to the property, any
adjustments for window and roof areas, the type of heating system, the building construction and u-values of the building fabric.

Using the information from this inspection together with climate data for the area, and standard assumptions about the property (i.e. whether the property has high, low or standard energy use) and energy savings, the adviser produces an EPC which outlines the current and potential energy efficiency of the property, and the recommended range of measures needed to achieve the potential energy efficiency stated. An indication of whether these measures are suitable for the Green Deal (i.e. whether they meet the green deal requirements) should also be included on the energy performance certificate.

However, the EPC assessment represents an "average household" which does not take account of the actual household size, the frequency with which appliances are used and such things as the usage pattern (for example, usage during peak hours might cost more than usage at night).

So the GDA also has to do an Occupancy Assessment. This determines whether the household is a high or low energy user. This information can be obtained from actual energy bills. The degree of actual energy use can impact on the suitability of taking part in the green deal, and also determine whether it is worth obtaining a subsidy under the Energy Company Obligation (Energy Act, 2011) for eligible households. On the basis of the occupancy assessment the Green Deal adviser can propose a package of measures to improve efficiency in a property, and a calculation of the household's estimated annual savings once these measures are put in place. In addition the adviser will set out the maximum repayments that can be charged on the basis of the typical savings outlined.

The EPC assessment and the Occupancy Assessment are the two elements used to compile the draft Green Deal Advice Report. This report, which is made up of an Energy Performance Certificate (EPC) and Occupancy Assessment (OA), will be used to advise the customer on any energy efficiency recommendations made in the report, and their suitability or otherwise for the Green Deal. An example EPC and OA is available on the Energy Saving Trust website (EST, 2015). Where
the customer is deemed to be a high user of energy, they should be advised of further ways to reduce their energy consumption through behavioural changes. This could be for example, altering thermostatic settings to lower levels or changing the automatic times on which the heating is activated, etc. Once the draft Green Deal Advice Report has been completed for the client by the assessment company or the adviser, it must be lodged on the appropriate Energy Performance Certificate Register. Until this is done, no Green Deal plan can be put in place. The idea behind the Green Deal Advice Report is that the customer can take it to any Green Deal provider to obtain competitive quotes for the energy efficiency improvements he or she would like to make.

It is the Green Deal Provider's responsibility to notify customers of estimated energy savings for each proposed energy efficiency improvement, and also of the time period over which these savings will take place. One of the problems with regard to estimating future energy savings is the uncertainty around future energy prices. Green Deal Providers are expected to use commercial sources of energy price indices in order to project future energy prices, or alternatively refer to the Department of Energy and Climate Change for their statistical estimates of long-term energy price projections.

The Green Deal Provider has the responsibility to liaise with the energy supply company over any financial arrangements relating to the energy efficiency improvements proposed at a customer's property. There may be some upfront payments with the balance of the cost of improvement work being recovered through the property's future electricity bill. Some of the improvements under a Green Deal Plan could be funded by an energy supply company under the Energy Company Obligation. However, it is a decision between the energy supply company and the Green Deal Provider as to whether or not to reveal this to the customer.
3.5.2.5 The Green Deal Configuration

It can be seen that the Green Deal is somewhat complicated. Between the GD ORB and the providers, assessors, advisers and installers there are certification bodies who Davis (2012) refers to as Green Deal Advice Organisations. Prior to the development of the Green Deal, energy companies were required through the Energy Company Obligation (ECO) to help improve residential energy efficiency by offering subsidised cavity wall and loft insulation. Davis asserts that not enough progress was being made in order to achieve the government's energy reduction targets, and that the Green Deal is the latest policy attempt to redress this.

However, one can be excused for wondering whether the change from the structure where a single energy company offering energy efficiency measures to the retail sector, to a set up where there are approximately 5 tiers of individuals or companies involved in offering these measures, is more efficient. It would seem reasonable to assume that costs in the new, more complicated structure will be higher. While the costs of installation may be the same in both approaches, the Green Deal deliberately separates the assessment procedure from the plan provider. The intention behind this is to ensure the assessor is independent, and will not be influenced to recommend any particular provider of efficiency measures. As this assessment procedure has formal legal requirements and will take a reasonable amount of time and expertise, the assessment charge is likely to be significant. It was an average of £120 in 2013. This will have to be paid regardless of whether any energy efficiency measures recommended are actually implemented by the potential customer. So there will be some barrier to a potential residential customer getting his property assessed, if he is not already minded to improve his energy efficiency.

However, Davis contends that the Green Deal, as the umbrella under which other energy saving measures will operate, for example energy company obligation measures which are subsidised, is set to become a brand. The government hopes that this will raise awareness amongst consumers with regard to energy saving behaviour.

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3 www.moneysavingexpert.com/utilities/green-deal
A point that both Davis (2012) and Benfield (2012) make is that there is a great deal of flux around the green deal. Rapid changes in the renewable energy sector along with energy price uncertainties (UK legislation only requires that first year repayments under the green deal do not exceed the estimated first-year savings) make the rollout of the Green Deal a challenge. Davis indicated that some funding for the Green Deal could be sourced from the national lottery, and Benfield made the point that the government was discussing whether to formally include the energy company obligation (ECO) as part of the Green Deal.

At present according to the Energy Saving Trust (EST, 2013) the latest energy company obligation applies to the six big energy suppliers from 2013 and is divided into three parts:

**Affordable Warmth Obligation:**
This applies to low income and vulnerable households, but not social housing tenants. With complex, means tested eligibility criteria this obligation is to provide space and water heating measures, along with insulation, glazing and microgeneration technology.

**Carbon Saving Obligation:**
This measure can be included with the Green Deal, and provides funding to insulate hard to treat cavity walls and solid wall insulation, both internally and externally. A reasonably large proportion (around 8 million properties, DECC 2014a) of the UK housing stock has solid wall construction, so this measure is designed to aid the installation of this relatively expensive means of improving energy efficiency.

**Carbon Saving Communities Obligation:**
This is to provide insulation and glazing improvements to the population living in the bottom 15% of the U.K.’s most deprived areas. It will mainly apply to the social housing sector, and aims to help 230,000 people in low-income areas or in low-income households.

The Department for Energy and Climate Change (DECC, 2012) have included flexibility into the Green Deal to allow for rapid technological change. The list of
qualifying measures allowed under the Green Deal banner will be reviewed annually. Potentially, any energy saving measure can be included in the scheme provided the potential energy savings can be quantified, verified and modelled in the government's assessment tool (Standard Assessment Procedure).

3.5.2.3 **Renewable Heat Incentive (RHI)**

Alongside the Green Deal and the ECO the UK government has also set up the Renewable Heat Incentive (RHI, 2008). Like the FIT subsidy for small scale electricity generation, it provides financial incentives to encourage the uptake of renewable heat technologies for businesses, communities and the residential sector. It is intended to make a significant contribution towards the government's target of achieving 12% of heating from renewable sources by the year 2020. Generators of renewable heat can be paid for hot water and heat which they generate and use themselves. The annual subsidy will last for 20 years for non-domestic buildings, and seven years for domestic buildings (effective for the domestic sector from the summer of 2013).

While the RHI is separate from the Green Deal, it is subject to minimum energy efficiency standards being met, such as appropriate insulation recommended in a Green Deal assessment. Payments under the scheme are made for each kilowatt hour (kWh) of heat produced from renewable technologies such as air source heat pumps, ground source heat pumps, biomass boilers and solar thermal panels. As stated, domestic customers receive payments under the RHI for seven years. It is worth bearing in mind that even if the Green Deal has the intended effect of improving residential energy efficiency, previous social research such as that of Sorrell (2007) has identified a “rebound effect” where energy savings from improved energy efficiency are thought to have encouraged greater use of the services of, for example heat or transport, which that energy provides. Thus predicted savings from improved insulation or retrofitting may not occur.

In addition, Bowen and Rydge (2011) support the analysis that the economics of providing energy efficiency measures under the Green Deal, where savings should exceed costs, could limit retrofits of efficiency measures to possibly only basic cavity and loft insulation and draught proofing. It is therefore worth
considering an example of how the Green Deal might add up in economic terms, for a capital replacement item such as a new condensing gas boiler. The financial rationale will depend on the energy cost saving of the qualifying energy improvement relative to its capital cost in Net Present Value terms.

Appendix 2 shows an actual price paid by a householder known to the researcher in 2011 (their details are not revealed as they wish to remain anonymous), which minus some repair work, came to a round figure of £3,800.00. As an example of typical energy savings in a house of this type (three bedroom, semi detached, solid brick wall, slate roof) adopting the SAP energy assessment model (BRE, 2011) and assuming a boiler replacement was installed in the property increasing the efficiency of the main heating system from 60% to 84%, total annual energy costs would be reduced by 23% from £991.28 per annum to £767.61 per annum according to the model. This is a saving of approximately £224 per annum, which is significantly higher than the average saving of a boiler replacement of £90 per annum indicated in the previous Governments energy strategy (Great Britain, National Strategy for Climate and Energy, 2009).

A discounted cash flow analysis on Excel (see Appendix 3) with the above capital investment cost and predicted savings and using a modest (See Fig 9) discount rate of 5% gives a Net Present Value (NPV) after 15 years of -£1,359, with an Internal Rate of Return (IRR) of -1.7% (which stays the same regardless of the discount rate, as it is an indication of the necessary discount rate to break even).

![United Kingdom Interest Rate](source: www.tradingeconomics.com, 2013)

**Figure 9  UK Interest Rates 2002-2012 (Tradingeconomics.com 2013)**
So even without a fourfold difference in the discount rate from the norm as postulated by Bowen and Rydge (2011) as an average discount rate necessary in their research findings for people to be incentivised to invest in energy saving measures, some energy efficiency investments are unlikely to have returns that are comparable to those achieved on stocks, bonds, money market funds or real estate.

Of course this analysis is based on the assumption that any positive NPV makes for a good investment as the capital cost (which is a sunk cost, and irrecoverable in the case of most energy efficiency investments) is replenished by the discounted savings. In practice some energy efficiency investments are also energy consumption decisions. That is, they are not purely economic transactions. We need energy to survive, just as we need food (which also provides energy). The utility we receive from an energy investment cannot be easily measured in money terms, and a complete cost/benefit analysis has to try to account for the fact that we would probably invest in some form of heating regardless of the economic return. We need to keep warm enough to survive so we can safely assume that a positive rate of financial return on a boiler is not necessary for us to want to acquire one (or other substitute heating). The extra saving on a new boiler can then, in part, be regarded as a useful financial bonus rather than a key investment criterion. Investment criteria become more important where a new boiler is replacing one that still has some years of serviceable life left in it.

If we had no form of heating and decided to purchase a gas boiler, the capital fixed cost plus the variable cost of the gas and maintenance supplied over the life of the boiler characterise the overall cost of consumption for the consumer. When the boiler is at the end of its working life, it is rational for the consumer to replace it with a more energy efficient model, if available.

However to replace the boiler with a more efficient model while the original is still functional involves losing the remaining capital value. It also involves the opportunity cost of purchasing a new boiler earlier than absolutely necessary. So a rational economic consumer might look at these costs and compare them to the present value of the predicted savings.
An example might be replacing a boiler 7 years earlier than necessary. The irrecoverable remaining sunk cost in our previous example would then be approximately half the original cost, a figure of £1,900 plus the compound interest on borrowing £3,800 at 5% for a new boiler for 7 years, which is £1,547 (PV approx. £1,099), giving a total in today’s money of £2,999. Using this figure as the cost of capital to replace the boiler early, and setting it off against predicted energy savings over the life of the new boiler in our example, we still get a negative NPV of -£558 and an IRR of 1.67%.

However, if we are adding an energy efficiency investment to our house that we did not have previously, such as solar panels, it is reasonable to set off the entire cost against predicted energy savings to gauge the economic merit of the investment.

Figure 10 below shows the marginal abatement costs involved in applying various efficiency measures. The technical potential in 2020 includes hidden and missing costs and private discount rates and fuel prices (CCC, 2008). However, as has been discussed in this research, the degree to which these costs can be considered to be accurate is open to challenge. It has been shown that the net present value of replacing a boiler can be negative.
It is thus far from a foregone conclusion that UK carbon budget targets can be met. The lack of progress of the residential sector in the UK over the last 20 years could be regarded as a testament to the difficulties in reducing carbon emissions in practice. Jaffe & Stavins (1994) list many reasons why diffusion of energy conservation technology is gradual. These include those associated with market failure, such as information problems and unobserved costs. They also embrace reasons not related to market failure, such as information costs, discount rates and potential adapter heterogeneity. Their paper models the energy technology diffusion curve for newly built houses over a ten year period, and suggests policy prescriptions for slow uptake related to market failure (particularly government regulation and subsidy). They emphasise the importance of internalising externalities in the cost of energy, a sensible, but politically difficult remedy.

Table 10 summarises some of the difficulties in achieving required residential energy efficiency targets (James, 2012).
Table 10 Barriers in achieving efficiency targets (James, 2012)

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic financial barriers</td>
<td>These include the potentially higher upfront costs of energy efficiency products e.g. cavity wall insulation, and the interest rates available to households</td>
</tr>
<tr>
<td>Hidden costs</td>
<td>These include &quot;transaction costs&quot; associated with finding reputable providers, time costs of disruption, and the costs of differences in quality of product or service. Many of these hidden costs are related to the cost of acquiring information about, for example, suppliers</td>
</tr>
<tr>
<td>Lack of information</td>
<td>From a rational choice model of human behaviour if households do not know their level of energy expenditure, how energy can be reduced, by how much, or at what cost, they are unlikely to consider investment in energy efficiency. However, although information provision is often necessary, it is rarely sufficient in itself to encourage behaviour change.</td>
</tr>
<tr>
<td>Risk and uncertainty</td>
<td>Uncertainty about future energy prices can deter households from investing since they cannot be assured of further savings. Households may also be wary of the risk associated with unfamiliar products</td>
</tr>
<tr>
<td>Poorly aligned incentives</td>
<td>The most commonly cited barrier of this kind is the &quot;landlord-tenant&quot; split whereby landlords may under invest in energy efficiency measures because their tenants pay the energy bills are conversely tenants have no incentive to reduce their energy use as their landlord pays the bill</td>
</tr>
<tr>
<td>Psychological/sociological barriers</td>
<td>These include a range of less tangible barriers that do not conform to a &quot;rational consumer&quot; model of human behaviour. This may include inertia in decision-making or basing decisions on habit or a wish not to be perceived as the only one adopting a new technology</td>
</tr>
<tr>
<td>Regulatory barriers</td>
<td>There are also regulatory barriers that have been identified which relate specifically to the regulatory framework within the UK, which can make it more difficult for certain households to benefit from or consider energy-efficient measures</td>
</tr>
</tbody>
</table>

Of course, lowering indirect emissions from the residential sector can be achieved by reducing the carbon intensity of electricity. Decarbonising power stations through the increased use of renewable generation (wind turbines, biomass and solar), a greater output from nuclear power and the application of carbon capture and storage (CCS) can help make a significant contribution. Direct emission reduction from the residential sector requires regulation and behavioural change around energy use.

A more detailed consideration of residential energy demand behaviour is considered in the next section.
3.6 Residential Energy Demand Behaviour
A number of studies have been done which explore the influences behind residential energy demand behaviour. Consumer psychology and its complexity are investigated, and the interrelationships between emotional, financial, cultural and educational factors are examined.

3.6.1 Incentivising households’ energy behaviour
Gyberg & Palm, (2009) in research from Sweden, suggest that household energy behaviour is influenced by energy costs and the influence energy use has on the environment. They reject the notion that consumption is just a measure of welfare, or a means of satisfying a consumer’s utility. They assert that it is also a crucial factor in managing sustainable development. This is because responsibility for the environment has to a large extent been transferred from an aggregate national political level to a local level. At this local level consumption decisions collectively influence energy use and thus the effect on the environment. As a precondition for making these decisions, information and education are paramount.

However, a conclusion by Guy & Shove, (2000) is that a lack of knowledge and information are barriers to the adoption of energy efficiency measures. Consumers often want higher rates of return from their energy efficiency investments than are practical or realistic. The work done by Hassett & Metcalf (1993) supports this view. Market distortions, where energy prices do not reflect environmental costs, are also a problem. Of course if energy prices really did reflect their environmental costs, consumers might well choose more sustainable forms of energy. Uncertainty in terms of what these environmental costs are, or might be, means in practice that energy is unlikely to be priced in this manner.

In the Swedish approach to influencing consumers’ energy behaviour there are a number of factors which are considered important:

1. Individual Responsibility: a strong idea is to try to influence behaviour by emphasising the individual responsibility for the choice in energy use. Choosing a sustainable energy path could be cost-effective and would also be a valuable contribution to a better environment.
2. Creating Incentives: Gyberg & Palm (2009) assert there is no direct link between behavioural change and knowledge. Knowledge needs to be made effective, and in the case of motivating people to change their energy use the knowledge needs to appeal to ideological, health or materialistic consumer needs. Certainly it is easy to make the link between better health and more environmentally friendly behaviour.

3. Creating a Measurable World: if a consumer has more information on their energy consumption, they are more likely to take measures to adjust it. The work by Isacsson et al., (2006) supports this notion. As such, consumer access to better technology such as smart meters which provide real-time information on energy use, can encourage greater energy efficiency. This research states a common method to stimulate energy efficient behaviour amongst consumers is to measure their energy use in all energy related activity. Without this knowledge it is impossible for consumers to make the necessary adjustments in their behaviour. Smart meters could provide some of this knowledge, but their roll out has only just begun in the UK, so there is not enough empirical evidence to gauge their effectiveness. It is also possible that increased knowledge of consumer energy use leads to the desire to save more energy without it translating to the actuality, due to the low elasticity of demand associated with energy use.

4. Better Technology: this research found that a consumer's attitude was commonly that technology which consumed less electricity or heat was better no matter what. Of course better technology could be one factor that will encourage the rebound effect, as people use more energy than they otherwise would have because it is cheaper or more efficient.

3.6.2 The value in delaying improving energy efficiency
In considering the complex motivations behind why consumers decide to upgrade to more energy efficient products, it is interesting to look at the work of Hassett & Metcalf (1993). They contend that consumers effectively have an option value framework. In other words consumers have the option to delay making a decision
on whether to upgrade energy using capital, or retrofit energy saving measures. The reason the option has some value is due to the uncertainty of future energy prices combined with the fact that the decision to replace energy using capital is usually irreversible. For example, installing a new condensing gas boiler into a domestic premises is a relatively expensive purchase, and this piece of energy using capital would usually be expected to last for around 15 years or more. While this kind of purchase will usually be made when there is effectively no choice i.e. the old boiler is at the end of its useful life, the decision to upgrade before a consumer needs to will depend on the expected benefits. While there will be annual projected savings due to the greater efficiency, these will be highly dependent on future relative gas prices.

Another factor which will affect the value of the option to delay switching to more energy efficient products is the uncertainty over future technology. There are likely to be substantial technical developments in low carbon energy systems in the coming years. The speed of progression of these in terms of efficiency, cost and new technologies will no doubt have a large influence on an individual’s willingness to engage in a retrofit or purchase new lower energy using capital. As new technological development is uncertain and variable, better information, education, and clearly defined, government policy on energy use can improve consumer decision-making.

As an example of how quickly energy efficiency technology has improved we can consider the impact of new domestic buildings. Already total CO₂ emissions from new dwellings in the UK are 40–50% lower than the housing stock average as a whole (Lowe, 2007).

The argument in the Hassett & Metcalf (1993) paper is that this option value framework leads to slower diffusion of energy efficient products than would otherwise be the case. However, work done by Baker (2012) disputes this. His work shows that applying an option value framework to the question of what motivates consumers with regard to becoming more energy efficient is as likely to lead to a conclusion that there is as much slow diffusion of inefficient products as slow diffusion of efficient products. If this conclusion is correct, it casts some doubt
on an option value framework being an important driver behind the slow diffusion of energy efficient products.

So while clearly there is an option to delay purchasing energy efficient products, it is likely the value of this option will be dependent on a number of variables. If we consider the work of Gyberg & Palm, (2009) then we could value this option on ideological, health or materialistic grounds. Materialistic grounds would include the type of net present value analysis commonly done to determine the viability of investing for financial reasons.

While ideological reasons will have a psychological aspect, depending on an individual's view of the world, materialistic grounds could reasonably be argued to also have some psychological underpinning. People make purchasing decisions for all kinds of complex psychological reasons which can contribute to the overall product utility from an individual consumer's point of view. A branded product can be desirable because of the status of the brand. This point is not addressed by either Hassett & Metcalf (1993) or Baker (2012) in their research. However, this complexity is addressed by Waddams Price, Webster & Zhu (2013), where they conclude that policies tailored to specific markets and target groups achieve maximum effect.

3.6.3 The role of energy policy in influencing residential energy demand behaviour

James (2012) argues that far more needs to be done if the UK hopes to meet its emission targets. However, current policy has some limiting factors. Table 11 below summarises these.

There is an inherent limitation in the supplier obligation (carbon emission savings required) and electricity decarbonisation (percentage of supply that must come from renewables) policies as these are government imposed targets. As such there is no incentive to exceed them.
Ironically, if a higher level of emissions is achieved than targeted, the structure of the EU Emission Trading Scheme (EU ETS, 2005) could allow greater emissions from other energy suppliers in the EU, as emissions permits can be traded between countries. Thus these policies can in themselves become a barrier to greater and more rapid carbon emission reductions.

Another weakness of the supplier obligation in the UK is that it requires energy suppliers to undertake efficiency measures that are predicted to achieve the required level of energy saving, but they are not required to show that these savings are actually achieved. Even if the savings were made more transparent, perhaps through revised legislation, it would be difficult to measure whether the savings manifested themselves as increased levels of demand in other sectors of the economy.

As has been discussed in section 3.5.2, many energy saving measures do not meet the Green Deal "golden rule" of energy savings exceeding the cost of implementing the energy saving measure. James (2012) emphasises that residents should be allowed to make up the difference between the cost of a measure and the amount of finance available for it under the Green Deal. This will allow greater take-up of the Green Deal by people with greater financial means and others who are keen to adopt new technology. Increased uptake of new technologies is already driving down costs over time (IRENA, 2015) which benefit later adopters and the less well off. Suppliers of energy efficiency measures, most of which do not currently meet Green Deal finance requirements, could under this system become more incentivised to target what would be a much bigger market for their products. Increased competition in this market structure should over time lower the capital cost of energy efficiency measures thus leading to greater uptake.

The problem with the current feed in tariff (FIT) and renewable heat incentive policies (RHI) is that they don't incentivise cheaper technology development as the subsidy is based on current technology costs. However, cost reductions in renewable technology tend to be inversely proportionate to cumulative installed capacity (Poudineh & Jamasb, 2014), so policy adjustment to maintain the installation of small scale renewable technology is important.
<table>
<thead>
<tr>
<th>Policy</th>
<th>Details</th>
<th>Barriers overcome</th>
<th>Barriers remaining</th>
<th>Limited by…</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier obligation</td>
<td>Requirement to achieve a set tonnage of emission reductions from customers homes</td>
<td>Basic financial barriers</td>
<td>Poorly aligned incentives</td>
<td>Size of the supplier obligation imposed by government</td>
</tr>
<tr>
<td>Green Deal</td>
<td>Loans for energy efficiency with repayment charge it to the property's energy bill</td>
<td>Basic financial barriers</td>
<td>Lack of information. Risks and uncertainty. Psychological/Sociological barriers</td>
<td>&quot;Golden Rule&quot; that savings must exceed a loan repayment</td>
</tr>
<tr>
<td>Feed In Tariff</td>
<td>Pence per kWh subsidy for certified microgeneration</td>
<td>Basic financial barriers. Risks and uncertainty</td>
<td>Poorly aligned incentives Psychological/Sociological barriers</td>
<td>Willingness to subsidise.</td>
</tr>
<tr>
<td>Renewable Heat Incentive</td>
<td>Pence per kWh subsidy for certified renewable heat</td>
<td>Basic financial barriers</td>
<td>Poorly aligned incentives Psychological/Sociological barriers Risks and uncertainty</td>
<td>Willingness to subsidise. Biomass supply and cost</td>
</tr>
<tr>
<td>Electricity decarbonisation</td>
<td>Achieved through renewables obligation and EU ETS</td>
<td>Basic financial barriers</td>
<td>Regulatory barriers. Risks and uncertainty</td>
<td>EU ETS Planning and lead times</td>
</tr>
<tr>
<td>Building regulations</td>
<td>Carbon emission standards for new dwellings. Mandatory levels of energy efficiency for rented property are when making major refurbishments</td>
<td>Basic financial barriers. Risks and uncertainty. Psychological/Sociological barriers</td>
<td>Poorly aligned incentives</td>
<td>Willingness to impose a mandatory standards</td>
</tr>
</tbody>
</table>
The research by James (2012) suggests that addressing financial barriers, hidden costs, lack of information, risks and uncertainty, and poorly aligned incentives will be insufficient to achieve the required rapid emission reductions unless the psychological/sociological obstacles to improving energy efficiency are overcome (see table 11). The psychological obstacles arise, the research contends, because consumers are not "rational" and many policies are designed for a supposed "rational" purchaser (in an economic sense). In practice consumers are a disparate group who need to be appealed to on a number of different levels, as advertisers of fair trade coffee or luxury cars understand.

While this point is very well made in this paper, James (2012) does not offer much detail on how to achieve the rapid psychological paradigm shift required in carbon emission reduction. As section 3.6.8 Utility Theory in Economics discusses, imperfect theory on the basis of assuming rational human behaviour can be argued to be better than having no basis on which to judge people's responses.

3.6.4 Living systems as opposed to efficiency based approaches

Vale & Vale (2010) investigate the paradox of increased energy efficiency in residential properties going hand in hand with an increased use of energy resources. This research suggests that increasingly efficient energy use provide consumers with the scope to increase utility, for example by demanding increased floor area and property utility. This is an example of the rebound effect. The researchers postulate that post-occupancy evaluation (POE) could play a significant role in determining how to reduce energy demand. A key part of this evaluation would be to provide indicators that include an analysis of user behaviour as well as technical performance and usability within a building.

The premise behind the research is that it is not enough to increase technical efficiency, but that changes in behaviour are essential as well. An example is provided by the autonomous house in Southwell, Nottinghamshire (Vale and Vale, 2000) where the garden and conservatory are used for growing food, rain water is collected, and used water and sewage is treated on-site. Sewage is then used as a fertiliser for the food production. The authors contend that behaviour can change
when people come into direct contact with technologies that imply there are system limits, such as the use of microgeneration for the production of energy or the growing of food at home. While their analysis may be logical, it is hard to perceive how it could be implemented in a free society. Post-occupancy evaluations could well indicate how people could live a much lower energy consuming lifestyle, but implementing a systemic approach where the system encourages the development of energy-saving behaviour (perhaps through selective taxation and the quantification of resource using activities per household), as is advocated in this research, is easier said than done.

Reed's (2007) research also has a living systems based approach, much like Vale & Vale (2010), instead of the efficiency based approach to energy demand reduction. This view asserts that current practice looks at energy use in terms of efficiency on a case-by-case basis, which doesn't take account of the whole system within which energy is used. The argument put forward is that we should learn how to participate with the environment by using the health of an ecological system as a basis for designing energy reduction strategies. A whole systems model, despite the implication of totality in the name, actually requires looking at energy use with a place based approach. The ecology and each unique place will likely work differently, and we need to try to understand this in order to design how energy is used. The argument is put forward that this approach moves beyond sustainability and will succeed in regenerating the health of an environment. Effective engagement is achieved by understanding the entirety of what makes a place healthy. Part of this might be engaging with our own community, corporate campus, a small lot or a particular building.

However one weakness within this proposed approach to containing energy use is that suggesting that we engage with the particular ecology is a very vague statement. It's a bit like saying we need to understand ourselves better in order to know who we really are. This is axiomatic but not necessarily helpful.

Nevertheless, the point that we can adopt a more holistic viewpoint when we seek to make energy use more sustainable is a reasonable one (see figure 11 below from Reed, 2007). Reed considers that humans who take this approach will
experience a high level of satisfaction, and feel a sense of belonging to a larger whole which will encourage an adjustment to our needs, aspirations and values.

3.6.5 The Rebound Effect
Saunders (1992) and Sorrell (2007) consider the situation where energy savings from improved energy efficiency measures results in a less than proportionate reduction in energy consumption resulting from improved efficiency gains.

Saunders (1992) postulates two mechanisms for increased energy consumption in response to increased energy efficiency measures. Firstly, there is a direct rebound effect as increased energy efficiency makes its use relatively cheaper (the income effect) and other energy using capital potentially more attractive (the
substitution effect), highlighting finance as a driver of energy use. Secondly, on an aggregate scale an increase in energy efficiency is postulated to lead to increased economic growth, which increases the energy use of the whole economy (other things being equal, such as the energy intensity of the areas of growth).

At the microeconomic level, Saunders considers that even with the rebound effect, improvements in energy efficiency usually result in reduced energy consumption. However, at the macroeconomic level more efficient, and thus cheaper energy, tends to result in faster economic growth which in turn increases energy use.

The argument is that multiple energy improvements will tend to lower energy demand sufficiently to reduce energy prices and thereby stimulate a corresponding increase in energy demand throughout the economy. Overall, Saunders concludes that the net effect is an overall increase in energy use. Sorrell's research (2007) supports this view theoretically, with the qualification that it is practically impossible to estimate the macroeconomic consequences of individual improvements in energy efficiency.

3.6.6 Integrating analysis of residential efficiency behaviour
Wilson & Dowlatabadi (2007) review models of individual decision-making in this paper. From very diverse perspectives they try to develop a more integrated approach to the analysis of behaviour and its relationship to design in a residential energy context. From this collective viewpoint they assert that there is a gap between economic/technological potential and actual market behaviour. In other words people don't make full use of the potential to reduce energy use.

Table 12 outlines various decision-making approaches they have highlighted.
<table>
<thead>
<tr>
<th>Main Features</th>
<th>Conventional Economics</th>
<th>Behavioural Economics</th>
<th>Technology Diffusion</th>
<th>Social Psychology</th>
<th>Sociology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision model</td>
<td>Utility maximisation based on fixed and consistent preferences</td>
<td>Widely varying decision heuristics and context-dependent preferences</td>
<td>Attitude-based evaluation of technologies and the consequences of adoption</td>
<td>Interacting psychological and contextual variables</td>
<td>Sociotechnical construction of demand</td>
</tr>
<tr>
<td>Decision scale</td>
<td>Individual</td>
<td>Individual</td>
<td>Individual/social</td>
<td>Individual/social</td>
<td>Social</td>
</tr>
<tr>
<td>Main research methods</td>
<td>Quantitative (observed behaviour)</td>
<td>Quantitative (controlled experiments)</td>
<td>Quantitative and qualitative (surveys, interviews, observed behaviour)</td>
<td>Quantitative and qualitative (surveys, interviews, observed behaviour)</td>
<td>Qualitative (interviews, observation)</td>
</tr>
<tr>
<td>Main dependent variables</td>
<td>Preferences between decision outcomes</td>
<td>Preferences between decision outcomes</td>
<td>Rate of diffusion</td>
<td>Self-reports of behaviour and/or energy use</td>
<td>Observed are self-reported behaviour</td>
</tr>
<tr>
<td>Main independent variables</td>
<td>Costs and benefits of outcomes and their respective weightings</td>
<td>Aspects of the decision frame, context, and elicitation method, as well as outcomes</td>
<td>Adopt a role in social networks, communication channels, technology attributes, and leadership of adopter</td>
<td>Values, attitudes, norms, sociodemographics, economic incentives, skills, capabilities, and resources</td>
<td>Social, cultural and technical determinants of energy demand embedded in routine behaviour</td>
</tr>
<tr>
<td>Empirical basis in energy use</td>
<td>Extensive</td>
<td>Very little</td>
<td>Some</td>
<td>Extensive</td>
<td>Some</td>
</tr>
<tr>
<td>Implications for interventions to reduce residential energy use</td>
<td>Provide information about benefits and incentives to improve cost benefit ratio and improve cognitive capacity to assess net benefits/utility</td>
<td>Pay attention to framing and reference points for decisions, influence, heuristic selection by emphasising associations or emotive attributes, controlled choice sets and default options</td>
<td>Segments target population, exploit communications channels through social networks and use change agents, identify stage of decision process and target groups and use appropriate change mechanisms, ensure desired technology, Our behaviour has key attributes</td>
<td>Influence attitudes only if external conditions are weak, use multiple interventions with due attention to interaction effects, identify and target barriers, design salient and personally relevant information, values provided disposition for a long term change</td>
<td>Work towards long-term sociotechnical regime change, exploit opportunities of transition, recognise the social role of routine are habitual behaviour, manage expectations</td>
</tr>
<tr>
<td>Timescales for interventions</td>
<td>Short-term</td>
<td>Short-term</td>
<td>Short to medium term</td>
<td>Short to medium term</td>
<td>Long-term</td>
</tr>
</tbody>
</table>
It can be seen there are many different models of decision-making and behaviour to consider. Decision-making can be broadly grouped into psychological and contextual domains. Psychological elements include values, attitudes and personal norms. Contextual elements include the available choices, economic incentives, social norms, technologies, and infrastructures.

Wilson & Dowlatabadi (2007) contrast research that centres on the individual as a decision maker with that which emphasises the social and technological construction of behaviour (i.e. behaviour as a group). Despite this there are lessons to be learned from each research tradition when considering interventions. The key influences on decision-making need to be identified within a particular context. Their research cites the relevance of all the decision-making models to some aspect of residential energy use. They acknowledge that it is a challenge to combine different models of behaviour, particularly social and economic. This is an argument for further research in this area, to define the extent with which different models of behaviour can be integrated.

3.6.7 Irrationality in human behaviour and market failure
A specialist on behavioural economics, a recurrent theme of Thaler (1994) is that market-based approaches are incomplete, as they assume people are highly rational and unemotional. In his work with Sunstein (Thaler & Sunstein, 2009) he suggests that people often make poor choices because they are susceptible to many routine biases. This can mean they make poor choices in education, personal finance, healthcare, in what makes them happy, and the interaction with the planet itself. Nudge theory, which uses Daniel Kahneman's work on heuristics as its basis, implies public and private organisations can help people make better choices in their daily lives. The theory attempts to improve understanding of heuristic influences on human behaviour. These heuristic influences are central to decision-making, from the available choices a person is faced with. Nudge theory accepts the reality that people have certain tendencies, and tries to design choices for people which encourage positive, helpful decision-making. These choices ideally benefit the wider interests of society. Table 13 outlines some of the heuristics in nudge theory.
### Heuristics in 'nudge' theory - overview

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Anchoring and adjustment</strong></td>
<td>Using known facts and adjusting them to estimate or decide something which is unknown.</td>
</tr>
<tr>
<td><strong>2. Familiarity</strong></td>
<td>The more familiar something is, the more frequently, it is used/communicated. A misplaced sense of trust may be developed in behaving in a particular way, as well as a belief that this behaviour is valid. This heuristic is influenced by advertising and mass media.</td>
</tr>
<tr>
<td><strong>3. Similarity</strong></td>
<td>People make heuristic assumptions on the basis of perceived similarities to stereotypes.</td>
</tr>
<tr>
<td><strong>4. Over-optimism</strong></td>
<td>People tend to under-estimate costs, timescales, and challenges, and to over-estimate rewards and the ease of dealing with unknown things.</td>
</tr>
<tr>
<td><strong>5. Loss aversion</strong></td>
<td>The tendency for people to value possessions more than potential possessions - this creates an inertia to making changes. Irrationally, people do not like to lose possession of things, irrespective of their actual value/importance. (The assumptions in Kahneman and Tversky Prospect Theory are set out below this table).</td>
</tr>
<tr>
<td><strong>6. Status quo bias</strong></td>
<td>People prefer the status quo and fear changing to the unknown. Status quo bias is also caused by heuristic aversion to complexity.</td>
</tr>
<tr>
<td><strong>Table 13 Nudge Theory (Cont)</strong></td>
<td></td>
</tr>
<tr>
<td>---------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>7. Framing</strong></td>
<td>Framing is an individual's method of heuristically understanding reality. It can therefore include many ways of distorting the attractiveness/unattractiveness of something.</td>
</tr>
<tr>
<td><strong>8. Temptation</strong></td>
<td>Generally people are naturally biased towards preferring short-term rewards rather than long-term rewards.</td>
</tr>
<tr>
<td><strong>9. Thoughtlessness</strong></td>
<td>Often people tend to form views and make decisions heuristically without concentrating. This can mean they can miss making important decisions.</td>
</tr>
<tr>
<td><strong>10. Conforming with the population</strong></td>
<td>People have the need for affirmation, and wish to avoid risk or embarrassment. Cultural factors add to these effects.</td>
</tr>
<tr>
<td><strong>12. Self spotlight effect</strong></td>
<td>People tend to over-estimate the significance of their own decisions and actions, and how others view them. This can influence decision-making.</td>
</tr>
<tr>
<td><strong>13. Choice architecture</strong></td>
<td>This major area overlaps several individual heuristics, and refers to the degree to which something is designed to help people understand and make the best response to it. For example, green usually means &quot;go&quot; and red means &quot;stop&quot;.</td>
</tr>
</tbody>
</table>
The assumptions in Kahneman and Tversky (1979) Prospect Theory are:

- Changes to wealth are evaluated rather than the total wealth outcome to reflect reference dependence, i.e. the change \( x \) embodied in the project relative to no project is all that is considered.

- The subjective value is an increasing function of the positive outcome changes and a decreasing function of the negative outcome changes. The rate of decrease of subjective value for a negative change exceeds the rate of increase of subjective value for a positive change to reflect loss aversion. For example:

\[
\nu(x) = \begin{cases} 
\beta_p x^\alpha, & x \geq 0 \\
-\beta_N (-x^\alpha), & x < 0 
\end{cases}
\]

Equation 17  Outcome Changes in Prospect Theory

Please see figure 12 below. To interpret this idea, the argument proceeds as follows. The change in income or wealth resulting from an investment decision is symbolised by \( x \) and this change in income will have a subjective value for the investor, symbolised by \( \nu(x) \). For positive income or wealth changes, there will be a positive value for the investor given by the formula \( \beta_p x^\alpha \). For example if \( \alpha = 0.5 \) and \( \beta_p = 0.25 \), and the outcome is that income or wealth will increase by a factor of 2 from a base of 4.5, the subjective value of this change will be:

\[
0.25 \times (2 \times 4.5)^{0.5} = 0.75
\]

On the other hand, if \( \beta_N = 1.5 \) then a negative income or wealth change of the same absolute magnitude will have a subjective value of:

\[
-1.50 \times (2 \times 4.5)^{0.5} = -4.50
\]

This much higher subjective penalty on income or wealth loss as opposed to income or wealth gain is referred to as loss aversion. Advocates of prospect theory and behavioural economics in general believe that this contrast between
the subjective value of losses and gains of equal but small arithmetic value is an observable reality, whereas conventional expected utility theory is based on the assumption that for income or wealth changes of small arithmetic and proportional value, the subjective valuations will be equal in absolute value (although opposite in sign of course). This is referred to as risk aversion. The factor which causes the displeasure is the variability of outcomes, but the displeasure is the same for both small-scale positive variability and small-scale negative variability.

In Prospect Theory the preference weight is correlated non-linearly with the objective probability through the weighting function: \( \pi_i = w(p_i) \), for example:

\[
\pi = \frac{p^\delta}{(p^\delta + (1-p)^{1-\delta})^{1/\delta}}, 0 < \delta \leq 1
\]

\( w \) is a weighting coefficient of \( (p_i) \) which represents probability as an independent variable. \( p^\delta \) denotes a probability between 0 and 1. Probability is quantified as a number between 0 and 1, where 0 indicates impossibility and 1 indicates certainty of a theory or a projection of some event coming to pass.

This preference weight non-linear correlation leads to over-weighting of low probabilities and under-weighting of high probabilities to reflect the role of decision weights instead of objective probabilities.

Figure 12 indicates Loss Aversion through the Prospect Theory (PT) value function. Starting from the status quo, people in experimental situations appear to evaluate the preference loss of a given negative change in wealth (or endowment) much more heavily than the preference gain of a positive change in wealth of the same absolute magnitude. This factor alone can explain many apparently "irrational" decisions. It is a behavioural property explicitly rejected by standard expected utility theory in economics where the marginal utility of a loss in wealth is simply the negative of the marginal utility of a gain in wealth of the same absolute magnitude.
One can also consider routine heuristic biases to some degree to be a function of local culture. The approach of large organisations embedded in that culture can therefore make a difference. An interesting example of culture change in the UK on a national level is the success of the seat belt campaign (see figure 13, Clunk Click Every Trip, 1971) which prepared the ground for legislation. By 2009, 95% of car drivers were wearing seat belts (Dept. of Transport, 2009)
In a development of Thaler's work, Akerlof & Kranton (2010) argue that individuals do not have preferences only over different goods and services, but that they also adhere to a social norm which determines how different people should behave. These norms are linked to a person's social identity, a concept that first appeared in previous work by Akerlof & Kranton (2000). For example, people form an identity that may fit with their subculture. People from some communities may tend not to finish their education, while others may see themselves as expected to conform to certain standards of behaviour, such as not taking pens home from work.

On an economy wide scale, Akerlof & Shiller's (2009) analysis of the interaction of human psychology between the group and the individual gives a more plausible account than classical economic theory of the cause and effect leading to the financial collapse in 2008. Their book invokes the phrase "animal spirits" which Keynes (1936) employed to describe the emotional psychology that in some part explains why the economy doesn't behave in the manner predicted by classical economics.

Stern (2009) argues that climate change is an enormous example of market failure, where the price mechanism does not reflect the true cost of our behaviour around energy use. The effect of this is to potentially create a huge burden for future generations due to large scale externalities represented by emissions. The true cost of using fossil fuels includes the production of greenhouse gas emissions, which spurs the development of climate change.

However, he does not suggest that markets should be replaced, merely that they should be reformed to take account of the effect of carbon emissions. To do this he suggests taxation, carbon trading and regulation as corrective mechanisms. While Stern regards the development of a low carbon economy as potentially leading to more jobs and prosperity, he provides no analysis of the effect of the burgeoning world population growth.

Kahneman (2011) in his work on cognitive bias, prospect theory and happiness contends that there are two modes by which humans think:
System 1, which is fast, instinctive and emotional.

System 2, which is slower, more deliberative, and more logical.

He postulates that we use both systems. System 1 is informed by natural drives and instincts, and relies on heuristics (mental shortcuts) which an individual will evolve over time. While system 1 is a kind of fast mechanism to avoid danger, it feeds its experience into the slower system 2. While system 2 can take a logical view over positives and negatives in terms of decision-making, Kahneman contends that it is naturally very poor with probability and statistics (although it can be trained to improve in this respect). It is also poorly equipped to correct the errors fed through to it from system 1. As such it is not a paragon of rationality.

There are cognitive biases associated with each type of thinking. One conclusion he makes is that we place too much confidence in human judgement. If this construct is accepted, one possible lesson might be to devise energy policy to appeal to heuristic norms. Additionally, incentives may need to be large enough to outweigh any doubts about the probability of their benefit. As Akerlof and Kahneman, amongst others have argued, behavioural factors have to some extent undermined the concept of utility in economics.

3.6.8 Utility Theory in Economics

Mainstream Expected Utility Theory purports that decision makers choose between alternative choices based on their utility value (Mongin, 1997). This value is based on the probability of a certain outcome for each choice made. While it can be argued that utility can be conceptualised more easily when making, for example, investment decisions (increased monetary gain equals increased utility) it can be a difficult concept to define when making choices which involve such nebulous factors as emotion or culture.

Mongin explains the development of the expected utility hypothesis to incorporate a theory where preferences of people with regard to uncertain outcomes are represented by a function of the size of the payoff, the probability of the payoff
occurring, a risk aversion factor, and the different utility of the same payout to people with different assets or personal preference profiles.

Starmer (2000) contends that while it is easy to undermine theoretical constructs, such as that of utility in economics, imperfect theory can be said to be better than no theory of all. He concludes that the theoretical alternatives to Expected Utility Theory are relatively undeveloped, and that a general descriptive model of choice has to overcome the theoretical challenge of explaining the complex behaviour behind decision-making which include:

- incorporating the common consequence effect where an individual's attitude to risk is affected by the size of payout
- the common ratio effect where an individual's attitude to risk is affected by the size of the probability factor of success
- the event splitting effect enhancing an outcome in a decision maker's eyes by splitting it into sub events
- evolutionary preferences modelling the cultural change in preferences over time
- and prospect theory where outcomes are interpreted firstly heuristically and then as gains and losses relative to a reference point, such as status quo wealth

However, while alternative non-standard models have not displaced Expected Utility Theory (EUT) in modelling human behaviour, they have helped provide some insight into why and in what circumstances EUT applies.

3.6.9 A consideration of the barriers to energy efficiency uptake
The research by Painuly (2001) highlights the many types of barriers to the uptake of renewable energy technology. These can be grouped under the general headings of cost effectiveness, technical barriers, market barriers (such as inconsistent pricing structures), political barriers (institutional and regulatory), social barriers and environmental barriers. An evaluation of the barriers identified and their relevance are outlined in table 14 below:
Table 14 Barriers to the uptake of renewable energy technology (Painuly, 2001)

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Barrier Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Market failure</td>
<td>A highly controlled energy sector, with government control over generation, transmission, and distribution. This can mean restricted information, poor technology transfer, high barriers to entry leading to lack of competition, high transaction and investment costs, and a poor market infrastructure. This is not an insurmountable issue in either the UK or Australia, as both governments (and also state governments in Australia) are actively promoting renewable energy.</td>
</tr>
<tr>
<td>3. Economic and financial barriers</td>
<td>Lack of economic viability due to high costs, both of capital equipment and operation and maintenance. High discount rates on investment due to perceived risk and uncertainty of new technology. Inadequate market size to suit particular renewable energy sources, leading to unacceptable rates of return. Problems accessing capital for investment due to its high cost or limited availability. In both the UK and Australia, risk and uncertainty remain an issue in the development of new energy technology. However, many renewable technologies are more suitable for smaller markets than conventional power sources (distributed generation, such as community energy systems from local wind or solar farms).</td>
</tr>
<tr>
<td>Institutional barriers</td>
<td>Lack of institutions to properly regulate the energy sector. Lack of the capacity for the required research and development, and understanding of its value. An unstable macroeconomic environment, corruption, and a clash of interests with existing powerful conventional energy producers. The UK and Australia have adequate institutions to allow the development of renewable energy.</td>
</tr>
<tr>
<td>Technical barriers</td>
<td>Lack of suitable standards, codes and certification. Lack of skilled personnel to manage entrepreneurial, development, and operational and maintenance tasks. Capacity constraints, such as an insufficient current grid system. Unreliable, poor quality products used to deliver energy. While in the short term in the UK and Australia, there may be capacity constraints in the grid system, these should be short term as both countries have access to a wide range of resources.</td>
</tr>
<tr>
<td>Social, cultural and behavioural barriers</td>
<td>Lack of consumers/social acceptance of new renewable energy sources. As has been discussed in this study, there are social, cultural and behavioural barriers that slow the adoption of renewable energy technology. These need to be addressed through the implementation of suitable energy policies.</td>
</tr>
<tr>
<td>Other barriers</td>
<td>Uncertain government policies, environmental issues, risk and uncertainty as to the benefit of new energy technology. Investments tend to be relatively large-scale and are irreversible. Lack of suitable infrastructure to connect the new technology to the existing energy delivery system. While there is some uncertainty over the effect of federal government policy in Australia, in the UK energy policy is clearly defined and supportive of the development of renewable technology. Energy companies such as E-on, a giant energy provider, has completely revised their business model to focus on renewable distributed energy alongside their existing conventional power generation.</td>
</tr>
</tbody>
</table>
3.7 Discussion

In any discussion of the nature of energy saving incentives associated with residential energy use, apart from the market dynamics of supply and demand, a key part of appreciating energy economics is the importance of regulation. The special place that energy producing fuel has as a critical element in human survival, means that welfare maximising models of energy use are particularly appropriate. Thus, there is an implicit assumption that regulation and subsidy can, and some would argue should, form part of any incentives to use energy more efficiently.

There is agreement politically (Lomas, 2010) from the current coalition government (DECC, 2011) and the previous government (Great Britain, National strategy for climate and energy, 2009) that the necessary energy adjustments (which includes improving the fabric efficiency of existing domestic buildings) in order to meet the 2050 target of reducing greenhouse gas emissions by 80% from 1990 levels must be met. The UK government’s latest initiative to encourage greater residential energy efficiency, the Green Deal, is an example of a key policy to achieve this.

In addition, the fact that there is a social cost caused by the use of fossil fuels (Tol, 2007) makes an understanding of the motivating factors behind energy use even more important. However, the work by James (2012) which shows that greenhouse gas emissions in the residential sector are declining by less than 2% a year, when reductions of 6% are needed, highlights the lack of progress in fully understanding these factors.

According to Lomas (2010),

"...information about the house occupiers is limited and so the way in which information, expectations, lifestyle considerations, and design and ergonomics should be tailored to different individuals and different households cannot be established. This would seem an area ripe for exploration, not in a general sense but in the very specific circumstances of the UK and its housing stocks".
His research, along with the many other studies reviewed in this report, highlight the research gap that remains with regard to understanding residential occupant behaviour.

Interestingly, Summerfield et al (2010) contend that energy prices and temperature are the main drivers of energy consumption, with improved energy efficiency only having a small impact on overall usage. If we treat temperature as a constant (over the near term) this points to the necessity of a continuing price subsidy (or an effective European Union trading scheme) to influence how people behave with respect to energy consumption. It also supports Hassett and Metcalf’s analysis that uncertainty over future energy prices will be given greater weight than predicted savings from energy efficiency measures. However, if the price elasticity of demand is very low, which the empirical results of this work suggest in chapters 6 and 7, the necessary subsidy to be effective may need to be very large (or there needs to be an equally large emissions tax).

While some research such as Gyberg & Palm (2009), focuses strongly on how occupants can be influenced to use energy more efficiently, as we have seen there is a body of research, for example Vale and Vale (2010), that regard cultural change as the key to reducing residential energy use.

Relevant to both these approaches is the behavioural research which looks at residential occupant's decision-making. Hassett & Metcalf (1993) highlight consumers perceptions of future energy price uncertainty as a potential economic reason for delaying making energy-saving decisions. However, the fact that their analysis is contradicted by Baker (2012) reinforces the potential value in a deeper understanding of the incentives associated with household energy use.

Of course the complexity of human behaviour is likely to mean that the decision-making process is a multifaceted composite of economic, technical, psychological and cultural aspects as proposed by Wilson & Dowlatabadi (2007). The weighting of these factors in their view is largely contextual, and they cannot be readily integrated into one model of residential efficiency behaviour.
As Johnson et al. (2006) point out, investigating subjective behaviour is difficult and empirically unreliable, even if the researcher assumes he is a neutral observer of an external reality and is interested in observing behaviour within this context.

If, for example, the intervention of cavity wall insulation is applied to an existing building which is tenanted on the basis that the rent is inclusive of energy bills, it is entirely possible that no energy saving might be made. The tenants might open a window to cool the building rather than turn the heating down, and the only effect of the increased insulation might be longer periods when the windows are left open. While there is no economic incentive for the tenants to save energy in this case, there could be a positive social incentive (if they feel a moral obligation) or a negative social incentive (they may be resentful of the landlord). Either way their behaviour may not be easy to understand or uncover. Interviews or questionnaires may not be answered truthfully.

Alternatively, as revealed in social research by Sorrell (2007) and previously Saunders (1992), increased energy efficiency can result in a “rebound effect” where energy savings from improved energy efficiency are thought to have encouraged greater use of the services of, for example heat or transport, which that energy provides. Thus predicted savings from energy saving measures may not occur.

Of course occupant behaviour can include positive social drivers such as ethical values, which may enhance the desire to improve energy efficiency in order to avoid climate change and the slow degradation of the planet.

The state of technology can also influence occupant behaviour. There are likely to be substantial technical developments in low carbon energy systems in the coming years. The speed of progression of these in terms of efficiency, cost and new technologies will no doubt have an influence on an individual’s willingness to engage in a energy improvements. As an example of how quickly energy efficiency technology has improved we can consider the impact of new domestic buildings. Already total CO₂ emissions from new dwellings in the UK are 40–50%
lower than the housing stock average as a whole, largely driven by more rigorous building standards (Lowe, 2007).

However these same technical developments can have a negative impact on a consumer's willingness to undertake a retrofit. A new type of solar panel (The Economist, 2011) is a system that converts 37% of sunlight directly into electricity. This compares with a maximum 28% efficiency by standard silicon-based solar panels (that have not had the incident light concentrated by parabolic mirrors). Existing micro generation photovoltaic solar panels used to be one of the most expensive forms of power generation (MacKay, 2008), but costs are approximately 75% lower in 2014 than they were in 2009 (IRENA, 2015). Nevertheless, the belief that new technology is likely to keep developing to be much more efficient is a disincentive to invest in retrofitting today, if people follow the option value framework (Hassett & Metcalf, 1993).

Another factor to consider with regard to reducing household energy use is the heterogeneous nature of houses. The potential savings with associated with various energy efficiency options will vary, meaning that an energy saving measure that makes economic sense for one existing property may not be viable for another. There is also the possibility of a wealth effect, with wealthier individuals less likely to be deterred by the capital costs of introducing energy-saving technology.

Further complicating the analysis of how to incentivise reduced household energy use is the fact that the cost of improving energy efficiency in a property can either be considered an investment or possibly a part of household consumption (say in the case of draught proofing or energy saving light bulbs). There is a relationship between the two.
According to Andrew Benito (Benito et al, 2006) the above correlation in figure 14 between house prices and spending also reflects the influence of common factors such as expectations of future income. Energy saving measures are therefore likely to be influenced by income expectations. This has resonance today as the UK recovers from recession, but how rational consumer expectations are with regard to future income is unknown.

Indeed, when considering the irrational human behaviour as contrasted with standard economic utility theory when it comes to decision-making as postulated by Thaler (1994), Ackeralof & Kranton (2009) and Kahneman (2011) amongst others, it makes it especially difficult to unpick the factors that will incentivise people to improve their residential energy efficiency.

Research that can shed further light in this area can thus add useful value.
3.8 Conclusion and Research Gap

This review considers the historical and theoretical background to energy use. The fact that there is an economic and social cost to the continuing exploitation of fossil fuels as our primary source of energy is recognised as an issue requiring action. The development of historical energy efficiency schemes and the contemporary Green Deal are assessed. A major problem in developing effective policy to incentivise more efficient energy use in the residential sector is the lack of empirical evidence on the role of occupancy behaviour in energy use. There are myriad approaches to examining residential energy demand behaviour, with many contradictory points of view as to the effect of economic and social incentives. The projected further research in this area should clarify how to more effectively incentivise efficient energy use in the household sector.

The next chapter considers the research philosophy and methodology adopted in this study.
CHAPTER 4. Research Philosophy and Methodology

This chapter classifies (and justifies) the methodological approach towards the proposed research in this thesis. It describes the mainstream philosophical research perspectives. Based on this assessment it can be seen that this investigation has some elements in common with both positivist and interpretivist approaches. Section 4.1 summarises the basic research viewpoints that can be taken by a researcher. Section 4.2 summarises the possible methodological choices. Section 4.3 then clarifies the chosen method of research.

4.1 Research Viewpoints

Metaphysics is the theoretical philosophy of being (ontology) and knowing (epistemology). It is axiomatic that a researcher must have a view on the nature of reality as well as a view on the nature of knowledge, especially with regard to methods and validation, even if these views are unconsciously held and inconclusive.

A researcher’s ontological perspective will define their view of reality. While they may hold a positivistic view that reality is external and objective, this position is ultimately derived from a human subjective qualitative opinion. Also in a fundamental sense the approach to a study will depend on one’s view of epistemology, which addresses the questions:

What is knowledge?
How is knowledge acquired?
What do people know?
How do we know what we know?

Table 15 Simple research paradigm framework (Amaratunga et al, 2002)

<table>
<thead>
<tr>
<th>Theme</th>
<th>Positivist paradigm and</th>
<th>Realism paradigm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic beliefs</td>
<td>The world is external and objective. Observer is independent. Sciences value free</td>
<td>The world is socially constructed and subjective. Observer is part of what is observed. Sciences driven by human interests</td>
</tr>
<tr>
<td>Researcher should</td>
<td>Focus on facts look for causality and fundamental laws. Reduce phenomena to simplest elements. Formulate hypotheses and test them</td>
<td>Focus on meanings. Try to understand what is happening. Look at the totality of each situation. Develop ideas through induction from data</td>
</tr>
<tr>
<td>Preferred method in the research</td>
<td>Operationalising concepts, so that they can be measured. Taking large samples</td>
<td>Using multiple methods to establish different views of the phenomena. Small samples investigated in depth or over time</td>
</tr>
</tbody>
</table>

The more complex framework is summarised in table 16 below:

Table 16 Complex research paradigm framework (Johnson et al, 2006)

<table>
<thead>
<tr>
<th>Four approaches to research</th>
<th>Modes of engagement in research</th>
<th>Ontological status of human behaviour/action</th>
<th>Epistemology</th>
<th>Ontological status of social reality</th>
<th>Methodological commitments</th>
<th>Examples of research questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Positivism</td>
<td>Determined</td>
<td>Objectivist</td>
<td>Realist</td>
<td>Qualitative methods to enable <em>erklären</em>.</td>
<td></td>
<td>What are the causes of variable x?</td>
</tr>
<tr>
<td>2. Neo-empiricism</td>
<td>Meaningful - Inter-subjective</td>
<td>Objectivist</td>
<td>Realist</td>
<td>Qualitative methods to enable <em>verstehen</em>.</td>
<td></td>
<td>How do people inter-subjectively experience their worlds?</td>
</tr>
<tr>
<td>3. Critical Theory</td>
<td>Meaningful - Inter-subjective</td>
<td>Subjectivist</td>
<td>Realist</td>
<td>Qualitative methods to enable a structural phenomenology or critical ethnography</td>
<td></td>
<td>How do people inter-subjectively experience the world in a particular socio-historical period and how can they free themselves from this domination?</td>
</tr>
<tr>
<td>4. Affirmative Postmodernism</td>
<td>Discursive - Inter-subjective</td>
<td>Subjectivist</td>
<td>Subjectivist</td>
<td>Qualitative methods to enable deconstruction</td>
<td></td>
<td>How and why are particular inter-subjectively derived discourses being voiced while others are silenced?</td>
</tr>
</tbody>
</table>

While the positivist approach could be considered a paradigm, which is a theoretical framework which includes a system by which people view events (Fellows &Liu, 2003), the other approaches outlined above by Johnson et al in
table 16 are only mutually exclusive when assessing a particular piece of work. They argue it is entirely appropriate to use different structures to assess different pieces of research. For example a study of the contrast between natural selection and creationism might take an affirmative post-modernism approach, if the researcher held belief that the arguments for creationism were being unfairly silenced by society.

4.1.1 **Positivism** regards human behaviour as a response to observable and measurable variables which can be generalised into theory and tested as a hypothesis. Nothing can be proved with certainty, but the approach uses quantitative statistical methods to try to disprove a theory within certain statistical limits based on mathematical probability. If the theory or hypothesis cannot be disproved within these limits it is accepted, not as a definitive truth but as a likely outcome. This agrees with the basic approach of natural science, which tends to follow deductive reasoning. For example accepting propositions such as:

1. All men are mortal
2. I am a man
3. Therefore, I am mortal

This approach is deterministic with human behaviour determined by, and responding to, an external reality over which it has no power. So in positivism the observer is regarded as independent of that which they are observing, with human inter-subjectivity ignored along with qualitative links with the social world. The aim is to explain phenomena through the interplay of cause and effect variables. The value of the research is partly measured by its reliability (whether someone else using the same methods would get similar results) and its validity (how easily the results can be generalised (Yin, 1994)).

The other three approaches to research can be classified as interpretivist because they all use qualitative methods (see Fig 2 above) rather than quantitative to gain a deep understanding rather than a causal explanation (Outhwaite, 1975). They also eschew monism as they see a duality between matter and mind.
4.1.2 Neo-empiricism sees human behaviour as inter-subjective rather than determined, where an individual behaves subjectively in response to the subjective behaviour of others. However, as Johnson et al (2006) point out investigating human subjectivity is difficult and empirically unreliable. Non positivistic approaches recognise human beings as free to make choices, and see these choices as inter-subjectively derived. In other respects neo-empiricism is like positivism except that the methods used are qualitative rather than quantitative. The researcher assumes he is a neutral observer of an external reality and is interested in observing behaviour within this context.

4.1.3 Critical Theory differs from Neo-empiricism in that it adopts a subjectivist epistemology which allows for reflexivity. Observers are not neutral and there is interaction between the knower and what is known. Knowledge is partly socially constructed but is also contained by a reality independent of human subjectivity. Knowledge is considered to be contaminated by power relationships and the researcher seeks a collective truth brought about by a discursive democratic consensus. The researcher must help the people being researched arrive at this collective truth through a range of understandings of themselves and others which ultimately serves to empower them. The philosophy behind Critical Theory demands the researcher reflexively investigate his/her own values and interests, becomes sensitised to the effect of hegemonic regimes of truth on the disadvantaged, rejects positivistic concepts of validity and reliability, and embraces catalytic validity, which is the extent to which research changes those being researched so that they have new understanding, knowledge and power. Critical Theory aims to engender new democratically grounded self-understanding which can challenge the status quo.

4.1.4 Affirmative Postmodernism is like Critical Theory except that this approach sees the representation of social reality as polysemous, where social reality is subjective with many interpretations. Discourse creates rather than discovers reality; so that knowledge, truth and reality are represented by linguistic constructs open to constant revision. Any representation, even by the researcher, can be rejected as a rhetorical device. So we might wonder what use this approach is. In fact the researcher hopes to gain deeper understanding through deconstruction of
texts so that layers of meaning are removed to reveal those meanings that have been suppressed or forgotten. No conclusions or answers are reached, merely a deconstruction of the research to open the readers mind to self-analysis and their assumptions of reality.

4.1.5 Philosophical Classification of this Research
This research cannot be classified as wholly positivist, but rather a mixed method exploration incorporating neo-empiricist and positivist paradigms which are not mutually exclusive. Quantitative methods determine the energy used by the case study participants, while qualitative methods help develop an understanding of the reasons for this energy use.

4.2 Methodological Choices - A summary of possibilities
The decision on whether to use a qualitative approach to gather data, which tries to establish the meaning behind behaviour and motivation, but does not attempt to generalise, or a quantitative approach which seeks to generalise conclusions derived from data as pertinent to other appropriate scenarios needs to be taken (or a mixture of both). To go down the quantitative route in terms of interviews or surveys (as opposed to the proposed case study energy measurements), a large amount of data that can be analysed in a statistically reliable way would be necessary. If this type of approach were adopted, the number of data points it is necessary to sample would need to be considered (Carlin & Doyle, 2000). If a survey was sent to 100 people, one would need a response from 79 people to achieve a 95% degree of confidence with a 5% margin of error. The margin of error level is the mathematical probability that a margin of error around the reported percentage would include the "true" percentage. However, it is important to realise that this margin of error is based on an assumed standard deviation from the mean of a particular population. The actual statistical margin of error depends on two aspects:

One is the size of the sample tested. The closer the sample size is to the actual population size being assessed, the smaller the margin of error is likely to be. The
ideal situation is to test the entire population of interest, although this is rarely feasible.

The second element of importance is the spread in the standard deviation from the mean. If this statistical distribution is "normal" or "Gaussian", then 67% of the data points are within one standard deviation of the mean. If this distribution which forms a "bell curve", is more spread out, then it indicates a probability that the margin of error will be greater. If it is a very narrow "bell curve" it will indicate a probability of a smaller margin of error.

Assuming a response rate of 50% (which is optimistic given the experience of some previous surveys where responses were as low as 14%) the survey would need to be sent to almost 400 people for a 95% degree of confidence with a 5% margin of error. (For purposes of clarity, to achieve a 90% degree of confidence with an error of 5%, it means that if one were to conduct the same survey 100 times, the results would be within +/- 5% of the first time the survey was conducted 90 times out of 100. However, this is based on a theoretically accurate measure of the degree of confidence, which in terms of statistical probability is not always the case).^4

Choosing a random sample may not be appropriate, as explaining the costs and benefits of renewable energy and energy conservation (which are themselves open to challenge) through a questionnaire may be too complex. A convincing explanation of the likely effects of climate change, the need for energy security, the limited future supply of fossil fuels and their effect on pollution could be difficult to convey in a questionnaire.

^4 There are many online calculators to work out required response rate and the effect of error levels due to non response. E.g. http://www.custominsight.com/articles/random-sample-calculator.asp
Interviews (with open questions), focus groups, case studies or individual observational analysis are recognised means by which to pursue a qualitative study.

A case study method of how residents use energy and how they are, or might be, influenced by energy availability and its means of delivery can accumulate data from a variety of sources including observation, interviews, questionnaires and quantitative measurements (Fellows and Liu, 2008). This wide ranging approach can uncover large amounts of data, but its analysis may be complicated by its diversity. Additionally the ability to undertake such a study depends not only on the resources available to the researcher, but also on those of the target participant.

Collecting data through observation is another possible qualitative method (which can also be quantitative). Using this approach would involve accompanying residential consumers as they go about their work/home routine, and observing how they accomplish their tasks. Some bias in the observed data could result from the Hawthorne Effect. The Hawthorne Effect states that workers react to the attention they are getting from the researchers and in turn, productivity increases (Bernard, 1994). Additionally, apart from sensitivity issues involving, for example, issues of personal confidentiality, the time required to engage the research on this basis would likely be prohibitive.

A focus group approach is a form of qualitative research in which a group of people are asked about their perceptions, opinions, beliefs and attitudes towards a concept under research (Marshall & Rossman, 1999). Questions would be asked in an interactive group setting where residential energy users were free to talk with other group members. This type of group discussion produces data and insights that can be less accessible without the interaction found in a group setting. Listening to others’ experiences can stimulate ideas, memories, and understanding in the group participants.

Focus groups also provide an opportunity for disclosure among similar group members in an atmosphere where participants are validated. A collective group of interested and informed individuals might relish the opportunity to exchange ideas and information with their collegiate group. From this researcher’s point of view
such an arrangement would be fascinating, and worth considering as part of this study.

An inductive study through a series of interviews could provide increased clarity on perceptions around energy use. Sampling would need to be purposive to give the results greater credibility (Bryman, 2008., Saliby, 1990). Choosing individuals who can offer a valid insight into energy demand would be important.

4.3 Chosen Method of Research

4.3.1 The sampling process

Given the constraints of research of this type, where just one researcher is carrying out the entire investigation, a limited number of participants were selected. Part of the reason for this was the depth of knowledge the researcher hoped to acquire from each participant. Once the number of participants was decided, and a figure of 19 or 20 participants was considered by the researcher and his supervisors to be a manageable maximum, the next item of importance was to determine the sampling strategy that was to be used in selecting them. The attributes of the sample population was considered important. Of significance was the awareness of the study participants of the relationship between energy use and climate change, energy security, pollution and resource availability. This awareness allowed the researcher to extract a deeper understanding of the motivating factors behind the study participant's views on energy choice, using a case study approach. A truly random sample of participants who were part of the wider population might have led to viewpoints which were based on a lack of factual information regarding the use of fossil fuels, and thus yielded less constructive opinions and possibly containing more bias, than opinions garnered from the purposive sample of participants who took part in the research.

Having decided the type of participant that was required, it was important to have some understanding of the research population that was available. This is the total number of people in the UK who would meet the requirements of having a reasonable understanding of relationships between energy use and climate
change. For people outside of this population, motivations to change their behaviour with regard to energy use might not be pertinent. While the total research relevant population was not estimated in detail, it would include students and researchers involved in energy and climate change, members of environmental groups, people involved in the energy sector, and people with official or quasi-official governmental roles which necessitated knowledge of the energy sector and its effect on the environment.

It would have been ideal to obtain a representative and unbiased subgroup from this population. Certainly there would have been enough choice from which to choose a random sample of participants. However, the researcher felt that due to the constraints of the study in terms of time and cost, it was not feasible to obtain a random sample from this population. This was partly because random sampling requires the researcher to have a fair amount of knowledge and control regarding the research population as a whole, which was not the case for this study.

Given that the researcher did not have access to detailed information about the whole potential study population, the option was used to employ the technique of "snowballing", which involves starting with one or two representative participants who were known to the researcher, and then asking these participants to introduce the researcher to other members of the relevant population.

Once the research participants had been decided (and each person had ethically agreed to take part), the researcher had to consider whether the sample of participants chosen had any innate bias. However, there are two reasons why potential bias was not considered a problem in this study. Firstly, the researcher did not personally know what the opinions of any of the participants were with regard to energy use and climate change. Secondly, the precise questions which the participants were going to be asked, had not been decided at this stage.

It has to be said that the sample participants chosen were considered to be representative of the total potential study population only in the sense that their knowledge of energy use and climate change would have been similar. There was no attempt in the study to choose participants who were representative of the
general potential study population in other respects. For example, there was no deliberate choice made to achieve any balance in terms of gender, age, income or any other variable. However, the particular way in which the sample participants were representative of the total study population was considered sufficient in order to assess their motivations with regard to this research. As such, the results and conclusions drawn from both the qualitative and quantitative data produced by the research are considered valid.

4.3.2. Data Collection
While a frequency analysis on gathered data was conducted, probabilistic statistical inferences to be applied to the general population were not derived from this research, so the importance of random sampling was less significant. More significant was the awareness of the study participants of the relationship between energy use and climate change, energy security, pollution and resource availability. This awareness allowed the researcher to extract a deeper understanding of the motivating factors behind the study participant's views on energy choice, using a case study approach. A truly random sample of participants might have led to viewpoints which were based on a lack of factual information regarding the use of fossil fuels, and thus yielded less constructive opinions and possibly contained more bias, than opinions garnered from the purposive sample of participants who took part in the research.

Apart from the quantitative assessment of actual and predictive energy use amongst the case study participants, which involved measuring their actual energy use, and assessing thermal comfort in their homes, qualitative focussed interviews with semi-structured open questions were a key research technique. The combined assessment generated participant data on the use of heating, lighting and other equipment over the winter period. It also predicted their household energy use through computer modelling. Important information was also gathered on their views of motivating factors around energy use, through personal interviews, and for some participants through a focus group.
In addition, the research was inductive rather than deductive, with no predetermined hypothesis to be tested. The quantitative data was collected using a positivist framework, while the qualitative data used a neo-empiricist approach, which allowed some subjective interpretation of the data. However, the research had a clear aim and objectives, which when explored helped elucidate the motivations and mechanisms which encourage greater domestic energy sustainability and efficiency.

Janes (2001) suggests that the face-to-face interview method can result in the highest quality data (although he does not define this), and that this method of data collection can result in a higher response rate, allow for more specific questioning, decrease the number of "don't know/no opinion" type responses and allow the researcher to know whether questions are fully understood or not. In addition non-verbal behaviours can be taken into account by the researcher, to assess the validity of the responses.

While semi structured interviews can incorporate different material such as dilemmas, practical situations to be solved, drawings, video, stories, object manipulation, etc, as a basis to ask a question on a particular topic area, it was not felt essential for this research to use these methods, as the participants interviewed were chosen for their relative knowledge and awareness of issues around energy demand.

The chosen interview questions were designed to gather a rich data set which could lead to the development of potential hypotheses which can be tested with further research.
CHAPTER 5. Research Methods

This chapter explains the research methods used in this study to both collect and analyse data. Section 5.1 briefly describes the nature of the research undertaken in the UK and Australia. Section 5.2 describes the quantitative research that was carried out on seven UK case studies. It includes the measurement of actual temperatures and energy use over the winter period, as well as predictive energy modelling. Section 5.3 examines the qualitative research carried out in the UK. This involved in-depth interviews, which were analysed using NVIVO software. In addition to the UK case study participants, interviews took place with UK landlords, a UK Energy Company, a UK Environmental Group and a UK member of Parliament who is also a member of the current and previous Cabinets. Section 5.4 presents an analysis of the qualitative research undertaken in Australia. Section 5.5 focuses on validating and integrating the empirical, predictive and interview data gathered in this research. Section 5.6 examines how the research methods link to the aims and objectives of this study.

5.1 Introduction

In order to achieve the aims and objectives of this research, research was undertaken in both the UK and Australia. In the UK, the research was mixed method, involving both qualitative and quantitative techniques. In Australia, for practical reasons, only qualitative research was carried out.

5.1.1 The UK

The UK research involved modelling predicted energy use in seven case study properties. Actual energy use was also measured at these properties, and temperatures recorded in the main living area and the main bedroom at each property. One case study participant at each property was also interviewed using semi structured interview questions. The original intention was to use just six case studies, but a pilot study, which was undertaken at the beginning of the research period was deemed by the researcher to be suitable to include as a seventh case
study, as it was possible to continue monitoring the property over the complete research period.

The UK research also involved semi structured interviews with landlords, an environmental group, an energy company, and a member of parliament representing the local area. UK participants also took part in a focus group session, after most of the empirical research had been completed.

5.1.2 Australia
In Australia, background research was done on Australian energy policy and six case study participants were interviewed with semi structured questions. The interviews were conducted in Melbourne, Victoria. The viewpoints of Australian case study participants was considered to be of interest, as there are points of difference between Australia and the UK with regard to energy demand. Energy demand peaks in their summer period to facilitate air cooling, so their energy requirements vary from the UK. There is no integrated supply network covering the whole country. Australia is a country blessed with substantial energy resources, which include coal (Australia's second largest export after iron ore), gas, hydroelectric power, wind power and solar power. In addition, between July 2012 and July 2014, Australia levied a carbon tax. This tax has now been scrapped by the current Australian government. It is intended to be replaced by a reverse auction process which as yet is undefined. The study wanted to understand the perceptions of this tax in the residential sector.

5.2 UK Quantitative Research
Quantitative research was carried out on the seven UK case studies.

5.2.1 UK Case Studies
All participants in the UK case studies were treated anonymously, but to give the research a more personal feel, participant names were substituted with false names. The names were randomly chosen and bear no relationship to the participants’ ethnicity or nationality, but do reflect the gender of the participants.
5.2.1.1 Winter Temperature Measurement

Hobo Pendant Temperature Data Loggers (UA-001-08) were placed in the main living room and the main bedroom in each case study property, recording temperatures every 30 minutes. Monitoring took place from midnight 16 October 2013 until midnight 11 February 2014, covering most of the autumn and winter months, when energy demand would be highest. The Hobo Pendants were calibrated prior to use, with four pendants calibrated in the University laboratory at three different control temperatures. These four pendants were then used to calibrate the remaining pendants used in the study. In addition to temperatures being recorded in the case study properties, external temperatures were measured with a Hobo Pendant Temperature Data Logger in the garden area of the researcher's property. All temperature data was collected from the Loughborough area of the East Midlands, so the single external temperature data is relevant to all the case study properties. The data from the hobo pendants was downloaded at the end of the monitoring period onto Hoboware software and was exported in CSV format onto an Excel spreadsheet.

5.2.1.2 Winter Energy Use

Actual energy use over the winter monitoring period of approximately 4 months was measured by taking readings from the gas and electric meters at the case study properties at the beginning and end of the monitoring period. Gas meter readings were taken in cubic feet or cubic metres, depending on the meter configurations. It was necessary to convert the readings to kilowatt hours.

Readings in cubic feet were multiplied by 0.0283, to give the number of cubic metres of gas used. This figure was then adjusted by the temperature and pressure conversion factor which is set in The Gas (Calculation of Thermal Energy) Regulations 1996. The legislation is designed to ensure gas suppliers charge for gas in the same way they have been charged for the transportation of that gas (CTE,1996).

The conversion factor is 1.02264, and adjusts the calculation for energy used as if the volume of gas passing through the meter is at the standard temperature of 15
degrees C and the standard pressure of 1013.25 millibars. After the conversion factor is applied, the resulting figure needs to be multiplied by the calorific value (CV) of the gas. The CV is the amount of energy released when a known volume of gas is completely combusted at standard conditions of temperature and pressure (as above). The CV of domestic gas supplied through the National Grid pipeline (ranging between 37.5 MJ/m3 to 43.0 MJ/m3) is measured daily by the National Grid and customers are billed based on the daily averages of the charging area in which they are situated. This research used 40.0 MJ/m3 to calculate calorific value, to reflect a reasonable average value as a whole number. Once CV has been calculated, the figure is divided by 3.6 to get the number of kilowatt hours used.

The following link can be used to simply convert gas consumption to kilowatt hours: http://energylinx.co.uk/gas_meter_conversion.html

Electricity meter readings are already represented in kilowatt hours. When meters are dual rate, each reading is in kilowatt hours. So combined together, the total units represent the amount of energy used from the electricity supply. Receiving electricity on a dual rate basis may or may not be cost-effective, depending on the time of day when most energy is used. The cost will depend on the particular supplier tariff, and this can change over time. So for the purpose of this study, the comparative figure of interest was the actual energy use, rather than its cost.

Total energy use from each case study was calculated by combining gas consumption (where appropriate) and electricity consumption over the measured period.

5.2.2 Predictive Energy Modelling

Predictive energy modelling is a useful tool for estimating energy use in particular buildings. It is used in the residential sector as a method to calculate whether a property is suitable for support under the UK government’s Green Deal scheme.
The modelling method used is the Standard Assessment Procedure (SAP) 2009 (BRE, 2011), which is the UK government's preferred method for assessing energy use in the residential sector. Other more complex modelling methods are available, and will briefly be discussed in section 5.2.2.3.

5.2.2.1 The Standard Assessment Procedure (SAP)

SAP seeks to establish energy performance by looking at annual energy consumption per unit floor area, conveyed in kWh/m²/year. It also expresses this performance with three indicators, a SAP rating, an Environmental Impact rating and a Dwelling CO₂ emission rate. Because of the adjustment for floor area, SAP ratings are essentially independent of size of building for a given built form.

The SAP procedure was applied to the case study properties in this research. Calculations were entered via computer software (Stroma Certification, 2014) into a SAP 2009.9 worksheet. Overall dimensions of the properties were entered by number of floors (area x height). SAP ignores internal walls in the area calculation. Ventilation rate data such as number of fans, flues, etc. were also important inputs. The ventilation rate is the rate at which air enters or leaves a building and it is important to estimate this as it impacts on the overall heating requirement. In this section of the SAP, either the pressure test (air leakiness from the house) results are noted or the predefined values in the SAP appendices are applied. Pressure tests had not been undertaken on the case study properties so default values were used. Had these tests being conducted, it could have meant small differences in total predicted energy use in each property. SAP uses a property's age as a key metric in determining predicted energy efficiency. This is because methods of construction, building fabric, and insulation levels tend to closely relate to the year of construction. None of the properties surveyed as part of this study were particularly untypical of the period in which they were built, so where there was an absence of property specific data, the use of default values in the modelling was unlikely to result in large errors in predicted energy use.

U-values, which indicate the insulation properties of materials or composite materials such as windows, doors, floors and walls, were included in the software worksheet. As there were no known actual values, reference was made to performance data tables in the SAP manual.
SAP estimates a thermal mass parameter based on the noted construction elements, such as walls, floors, doors, etc. and the total floor area. The heat loss associated with thermal bridges is the linear thermal transmittance. If this data is unknown (which was the case for the properties under study) the transmission heat transfer coefficient is calculated by reference to Appendix K in the SAP manual.

The number of occupants (which is assumed in SAP, depending on the floor area) is used to calculate water heating energy use. SAP takes account of heat loss from water storage, but this is not applicable to properties which have a combi boiler. Boiler efficiency and standing heat loss is also included in the SAP calculation, with figures provided from the Product Characteristics Database or the manufacturer’s specification.

Internal gains from occupancy (typically 60 watts x number of occupants) and lighting (from SAP Appendix L) are included in the calculation of heating requirements. However electricity for other electrical items and energy required for cooking are ignored in the SAP calculation. Solar gains are calculated by inputting the latitude of the property and window orientations.

SAP assumes a heating period average temperature of 21°C for the living room area of the house with an average of 18 °C for the other areas. To work out the energy use SAP adds up energy use from space heating, water heating, ventilation and lighting minus any energy savings from renewable energy saving technologies, such as solar PV panels. It converts the calculated total energy use which is in kWh into a power consumption figure of kWh/annum. The total energy cost for the dwelling is then worked out using standardised fuel prices (which are averages by region of prices over the previous three years).

The final SAP rating and the Environmental Impact (EI) rating is derived from a scale between 1 and 100. Higher values on the scale are associated with lower energy costs for the SAP rating or lower CO₂ emissions per annum for the EI rating.
5.2.2.2 FSAP Software

FSAP software is produced by Stroma Certification (2014). This company runs government approved certification schemes which use their software to measure building sustainability and compliance to building regulations. Typically, installers, inspectors and assessors in the built environment use this software to conform to government policies promoting sustainable energy use and energy efficiency. These policies include the Green Deal, the Energy Company Obligation (ECO) and the Energy Performance of Buildings Directive.

FSAP calculates the energy performance of buildings based on the range of factors that influence energy efficiency included in SAP. These are:

- the construction materials used in the building
- the ventilation parameters of the building and the type of ventilation equipment
- the thermal insulation of the building fabric
- the control and efficiency of the heating system
- the effect of solar gain on a dwelling
- the type of fuel used to provide space and water heating, lighting, and any ventilation requirements
- the control and efficiency of any space cooling system
- the effect of any renewable energy technologies

The software calculates energy performance without taking account of the individual characteristics of a household occupying the dwelling. It assumes a standard number of occupants per unit area, and thus a standard heat gain from those occupants. It also assumes standard temperatures for the living area and other parts of the building. Household size and composition, efficiency of particular domestic electrical appliances and individual occupant heating partners and temperatures are ignored.

FSAP produces a predicted energy assessment based on inputs into the software. One of the most important inputs is the year in which the property was built. This is because the SAP analysis assumes typical values with regard to fabric and
insulation, depending on the year of construction. If known, the default values can be overwritten to improve the output accuracy of the programme.

Standard occupancy is assumed by the software:

- number of occupants based on floor area
- 9 hours heating per day on weekdays (two hours in the morning and seven hours in the evening)
- 16 hours heating on the weekend
- main living area, heated to 21° C, rest of the dwelling, heated to 18° C when occupied

Other inputs required for the software include:

- overall dimensions
- number of floors
- openings, including doors and windows
- internal and external opaque elements (e.g. walls) and their U-values
- ventilation provided by chimneys, flues and fans
- building orientation
- main space heating system and any secondary systems
- water heating system
- other factors such as type of electricity tariff, renewable energy generation, percentage of low-energy lighting, and whether the property has a conservatory (heated or un-heated)

The software generates a predicted running cost for a building. This is then divided by the floor area and this figure is converted into an energy efficiency rating and an environmental impact rating, represented by an A to G scale.

This calculation can then be used to estimate savings from installing energy efficiency improvements, such as better insulation, more airtight openings or installing more energy efficient capital items, such as a new condensing boiler.
5.2.2.3 Comparison with other modelling approaches

While SAP is the chosen standardised approach by the UK government to estimate energy use and residential properties, there are other modelling approaches available. One of the main alternative modelling methods is the IES Thermal Dynamic model (IES, 2011).

IES software gathers information on building geometry, the materials used in the building envelope, occupancy patterns, local climate data and energy using equipment. Each room is drawn using length, breadth and height measurements and windows and doors added to the appropriate surfaces of each room in the model.

The modelling allows for a high level of complex detail, such as adding other components like tables, chairs and trees which can influence thermal mass calculations and solar gain shading, etc.

Creating the model is a hierarchical process which segments the model into a series of spaces (rooms), where each space is comprised of a series of surfaces (floor, walls, roof, etc.). The building is viewed and worked on at the overall, space and surface levels.

Doors and windows are added according to their measurements and height above floor level to the model surfaces, and radiators added to applicable rooms.

The IES Building Template Manager is used to assign information to all the spaces in the model. This includes occupancy profiles and construction types. Surface colours and building control information can also be added. The Building Template Manager is split up into 6 template types which are:

**Room Attributes**
These consist of the lettable floor area and the circulation floor area of the building. In surveying terms this defines which parts of the building are discrete occupancy spaces and which are common areas required for collective access.
Constructions
This is where opaque (Roof, Ceiling, External Walls, Internal Partitions, Ground Floor, Solid Doors) and glazed (Rooflights, External and Internal Glazing) constructions are specified. These are edited using the Apache Constructions Database in the software. Designated constructions in the model are chosen to reflect the assumed or known u-values.

MacroFlo Opening Types
These are the elements which can be open or closed to provide ventilation flow, and include Rooflights, External Glazing, Internal Glazing and Doors.

Thermal Conditions
There are five categories for thermal conditions data:

- Building Regulations – This is to assign building type and activity to a space so it can be assessed against building regulations (applicable when using VE Compliance modules).

- Room Conditions – Occupied rooms are assigned an annual heating profile with a simulated heating setpoint. Individual room temperature set points can be specified (if known) to provide greater modelling accuracy.

- System – This is Heating plant properties. Typically this might be gas central heating using radiators.

- Internal Gains – Internal gains caused by people, lighting, and small power are specified here.

- Air Exchanges - This category allows the user to set default room air exchange settings for infiltration, natural ventilation and mechanical ventilation (if appropriate).

Profiles are also specified for occupancy, lighting and small power, which allows the model to predict energy inputs on a daily, weekly and annual basis. The profile associated with small power includes cooking and all miscellaneous electrical equipment such as computers, television, etc.
**Electric Lighting**

Lighting data can be assigned if using the appropriate VE Lighting section software: Lightproof, FlucsPro and IES-Radiance.

**Radiance Surface Properties**

Thermal conditions are partly dependent on the radiance surface properties of the opaque and glazed construction elements of a building, and factors can be assigned to these elements in this section of the model.

As is apparent, the model allows for a highly complex dynamic assessment of a building’s thermal properties.

One of the differences between using models like IES and SAP is that SAP disregards electricity use for cooking and other small power electrical items. This limitation can lead to a large variation between predicted and actual energy use in fully occupied properties where all the occupants use a large number of electrical gadgets. Also, SAP has little capacity to change the variable of occupancy behaviour (when the property is actually occupied), apart from the number of occupants, while IES can provide much more detail in this regard, provided it is available. IES has a wide range of interventions that can be modelled, both with the fabric of the building (such as different types of windows, different opening times, etc.) and with occupant behaviour (such as different times the building is occupied, and the internal gains associated with different numbers of people, etc).

It seems likely that an experienced consultant could do an energy assessment of a typical house using SAP in perhaps half a day against possibly a week with IES. However IES would seem to provide a greater degree of accuracy.

In practice, however, it seems clear that using alternative methods of modelling energy consumption, such as IES, would be excessively expensive in comparison with SAP due to the time it takes to do the modelling exercise and thus the resulting cost. For this research project the time constraints in using IES would be prohibitive, and the use of SAP is appropriate, as it is endorsed by the government.
5.3 UK Qualitative Research

The UK qualitative research consisted of semi-structured interviews to explore attitudes to energy with the seven case study participants, three landlords of residential property, two energy company executives, one environmental group executive, and a senior politician who represented the local area as a member of Parliament. While all the other participants agreed to face-to-face interviews, the political representative responded to a number of written questions.

This UK qualitative research is intended to combine with the quantitative research in order to triangulate the findings. Data will be triangulated by not only comparing predicted energy use with actual energy use, but also by comparing participants interview responses with their actual behaviour. Measured temperatures in each case study property should give some appreciation of the participants thermal comfort range and the influence this has on their energy use. The questions they were asked were linked to the key questions listed in section 5.3.1.

5.3.1 Semi-Structured Questions

The questions asked to each group, and indeed to each individual, varied slightly depending on what the researcher felt was appropriate. For example, Australian participants were asked to what extent they felt solar panels might meet their energy needs. However, they were devised on the basis of a number of key questions which arose from previous research, as outlined in the literature review. These are listed below.

Key Questions used to devise interview questions

1) How do domestic residents think about their energy use?

2) How does the form of energy residential consumers use appeal to their ideological, health or materialistic/economic consumer needs?

3) What impact has culture on energy use and can this be changed with education policy or through commercial/political marketing?
4) How does more information on domestic energy consumption, such as smart meters which provide real-time information on energy use, automatically encourage greater energy efficiency or is it more complicated than this?

5) How important, or possible is it, for domestic consumers to measure their energy use in all energy related activity (so they can be aware of technology efficiency rebound effects)?

6) How responsible do domestic consumers feel for their efficient use of energy?

7) How could tax incentives (which replace up-front subsidy or future government cost) be devised on a sectoral basis to make a difference? For example, could 10 years capital gains tax be waived in return for buy-to-let and commercial landlords upgrading their property to a certain level within a 2 year time frame? Could the inheritance tax threshold be increased for residents who upgrade their property? Could a large tax credit be given to working people who upgraded their property?

Interviews were arranged by contacting suitable participants (i.e. people who had a reasonable understanding of the subject matter being explored) and explaining the purpose of the study. If they agreed to participate, they were provided with an outline of what was required from the interview and had to confirm their agreement in writing. Interviews took place at a time and location decided by the interviewee. For the UK case study participants, interviews took place during the period in which their actual energy use was being monitored and their predicted energy use was being calculated. These metrics did not therefore form any part of the interview.

5.3.2 Data analysis
There are a number of approaches to analysing qualitative data (Myers, 2013). A top-down approach uses the concepts derived from the research literature to analyse the collected data. A bottom-up approach means that concepts will emerge from the researcher’s detailed analysis of the data that has been collected. As this research was inductive with the intention of building some theory, especially as regards energy policy in the residential sector, a bottom-up approach was considered to be more suitable. However, this does not mean that the concepts uncovered from the data analysis were not linked to the literature review.
Indeed, it only means that the inferential data derived from the analysis was not constrained in any way by predetermined theory.

In order to uncover concepts from the gathered data, it has to be decided how to analyse that data. One of the most common ways is to code the data in some way. Codes are a way of assigning meaning to the descriptive or inferential information revealed during a study (Miles & Huberman, 1994). Codes can be attached to words, phrases and sentences or whole paragraphs.

Transcription of interviews allows the texts that are to be analysed to be identified. Themes can be then introduced from the text itself or from the literature review. Lists of codes can be derived to fit into these themes (possibly in hierarchies). Texts can then be assigned to a range of codes. A model can then be constructed which identifies how the themes and concepts raised by the research can be linked together. This model can then be tested on a wider set of data as the researcher progresses through the analysis. Of course one of the limitations to coding is that it is to some extent subjective, and depends on the skill of the researcher to draw reasonable inferences from answers provided by participants.

As well as coding, memos are an additional way of analysing qualitative data. They are the researcher’s commentary on the coding of data and may be procedural (summarising what and how coding was done) or analytical (containing ideas or thoughts on what the data might mean).

Other data analysis approaches include:

- Analytic Induction. Ryan & Bernard (2000) define this as describing a phenomenon that requires explanation, and then proposing an explanation. Apply this explanation to a case and see if it fits. Then applied to another case and see if it fits, etc. The explanation is accepted while it fits all known cases of a phenomenon. So this fits the scientific method, insofar as it accepts a hypothesis until it is disproven.

- Another way to analyse qualitative data is to list a series of events, which can then possibly be sorted into categories. Chronological time periods can be
assigned to these events. Miles and Huberman (1994) suggest the events can be described in their narrative form or summarised in a table or chart.

- Data can be analysed in terms of Critical Incidents. This is in effect a shorter form of the series of events approach. People are asked by the researcher to discuss incidents that are deemed to be particularly important are pertinent to the research. For example, a structured interview might be designed with this approach in mind. One disadvantage, however, is that it may preclude other information being picked up that might, in fact, have been extremely pertinent.

- Another way to approach qualitative data is to use Hermeneutics. As well as an underlying philosophy, it is also a specific approach to qualitative data analysis (Bleicher, 1980). Hermeneutics is an approach to understanding textual data, and is mainly concerned with the meaning of a text or a text – analogue (a text – analogue could be an organisation, for example, which the researcher comes to understand, through text or pictures). So the meaning of the text is the basic question in hermeneutics, and this can be a useful approach if the text appears to be confusing and contradictory. A key concept is the circular idea of interpreting the text as a whole, as well as understanding its parts. Different stakeholders may have contradictory or incomplete views on a topic. Making sense of the relationship between the stakeholders and the topic itself is the name of this type of analysis.

Further analytical methods include:

- Semiotics, which analysis of signs and symbols and their meaning.
- Content Analysis, which is a quantitative method of analysing the content of qualitative data, by for example counting the frequency of certain words.
- Conversation Analysis makes the assumption that the meaning of a conversation is not straightforward, and can be influenced by the verbal interaction taking place during the conversation.
- Discourse Analysis analyses the way texts are constructed, and asks the question of why they are constructed in a particular way. Using this method encourages the discovery of multiple meanings and interpretations of a text.
• Narrative Analysis looks to understand the story behind a set of text or oral communication.
• Metaphorical Analysis try to develop a systematic reflection of the metaphors we use when we speak, think, and act. In other words, a word phrase can be understood beyond its literal meaning in a particular context. The metaphors can provide inferential codes the researcher can use in data analysis.

All of the above approaches have validity, but the choice of which one to use can seem bewildering. This research uses inferential coding based on a descriptive analysis of answers to interview questions. This approach seems reasonable for this study as it is not overcomplicated, and the interview questions were linked to key questions arising out of the literature review.

5.3.3 Coding
Some organised method needs to be used to process and analyse data. This can be done without software, using any organising method the researcher chooses. For example, an excel spreadsheet can be tabulated with a code assigned to each interview question, and a sub code to a variety of the answers. Codes can emerge on inductive basis (as practised in grounded theory), appearing as each interview is reviewed. Interviews can be carefully and repeatedly analysed, either by reviewing text are listening to the audio, and where respondents’ answers are closely aligned, they can be assigned the same code. These results can then be scrutinised and the relevant thematic statements they imply added to a spreadsheet (see example table? below). These thematic statements can then be grouped under the appropriate key questions, producing results that can then be used in the interview analysis.

In some cases, to derive the thematic statements, answers which overlap by different respondents to different questions can be combined. For example, the potential theme of efficiency in residential energy use might overlap with questions on financial affordability, cultural mores, or consumer knowledge and education. All of these answers to different questions could contribute to understanding the answer to one key research question.
5.3.4 Analysis of Codes

In the example spreadsheet below, which is taken from a research project into property valuation, a summary excel raw data spreadsheet is used, with the interview question in red, the descriptive analysis on the left and the inferential analysis on the right.

A frequency analysis can be done on the inferred responses from all the property valuers who are interviewed. For example, in figure 15, half the valuers interviewed tried to find out the motivation behind their client putting their property up for sale. This was inferred from part of the descriptive answers to question 1 in the spreadsheet and coded as 1.1.
Raw Data - Descriptive Analysis

Respondent Code

<table>
<thead>
<tr>
<th>V1</th>
<th>V2</th>
<th>V3</th>
<th>V4</th>
<th>V5</th>
<th>V6</th>
<th>V7</th>
<th>V8</th>
<th>V9</th>
<th>V10</th>
</tr>
</thead>
</table>

1.1 Talk to vendor re their opinion and position

1.2 Look at history/archive of property, any improvements

1.3 Comparable evidence more important

1.4 In boom times could overprice

1.5 Part of a residential valuation is a Marketing Exercise and subjective

1.6 Valuation is not a cost free exercise - Marketing Costs are circa £300 - £600 per house

1.7 Two types of comparables. Sold and For Sale.

1) How do you go about a valuation?
After looking at comparables, how do you think about adjustments you need to make?

Raw Data - Inferential Analysis

Valuers talk to clients to determine their motivation/need to sell. It also confirms the hope value necessary to retain the client.

Most agents have archives of their own historical transactions to which they can apply a relevant adjustment to bring it up to date e.g. House Price Index percent, etc.

All valuers look for accurate and recent comparable evidence, using Land Registry and current For Sale figures.

Valuers need to be aware of the market conditions See 1.8

No Sale No Fee is the norm. This creates pressure to take on clients, but also to achieve a sale.

Figure 15 Summary excel raw data spreadsheet
5.3.5 NVIVO software

However, use of computer software can make a more complex analysis more manageable. It can effectively manage data as done in the above spreadsheet, but also allow easier analysis of detail.

Using a computer program, such as NVIVO can be helpful for:

- correcting, extending revising interview data
- making reflective memos which are a commentary on some aspect of the data and perhaps reveal subtle connections between data
- coding segments of text or whole paragraphs or sentences for easy retrieval later on
- allowing storage of data in electronic form which can be easily organised
- search and retrieval of data in order to locate relevant sectors of texts
- easy linking of data, allowing the formation of categories or clusters relevant to the research
- content analysis, where that is deemed appropriate. For example, the frequency of the use of certain words or statements can be useful evidentially to argue a point of view in the research
- creating graphics that can help summarise theories

NVIVO software is designed for qualitative and mixed method research, where there is non-numeric data. It is organised to group data into Sources, Themes, Analysis, and Findings. Within these groups Sources are subdivided into text, audio, web data, and datasets. Themes are divided into subcategories chosen by the researcher. Analysis is typically subdivided into query results, research notes, models, and charts. Findings are divided into reports, papers, extracts, and presentations.

NVIVO uses nodes which are akin to containers where data from ideas or themes from the research analysis can be gathered and stored. This data is coded data taken from text, images, audio, or video. In this project source data was divided in NVIVO into the subcategories of Australian case studies, UK case studies, UK
focus group and other UK stakeholders. Nodes were then given the same categories and inferential answers were assigned for each category. Nodes were also included for positive, negative and mixed views. Inferential answers could then easily be assigned a particular viewpoint by dragging and dropping it into the relevant node in NVIVO.

Research categories such as participants can easily be classified using the software. Various chunks of data can be coded to many different nodes. Nodes can be linked with each other or memos which can be attached to particular nodes. In an NVIVO project named items can easily be searched. Also queries can be conducted for content within the project, such as:

- word frequency search
- coding search
- text search
- group search

The software allows models to be developed graphically. This can make it easy to see links between various elements of the research and the relationship between these elements. Part of the advantage of using computer software is the ability to visualise data relationships through the use of charts and models. It also allows users to easily drag and drop coded information into various nodes. Highlighted text can easily be assigned to pre-existing nodes, which can then be easily viewed revealing any text coded there and its source. This can ease analysis of the data. It is also easy to find out all the node names in which a particular chunk of text is coded. Nodes can be structured up to 9 levels of sub nodes, with double coding of text easily entered into different nodes. Linked memos to the nodes can be used to develop an understanding of the research analysis are parts of these memos can also be coded and assigned to nodes. Nodes can also be classified into separate categories. For example, while each individual interviewee might have their own node, they might all be also included in a participant node. Demographic attributes can be included as a classified node which is linked to the research participants.
Matrix coding queries can be done to combine results from different nodes. For example, attitudes towards climate change might be inferred from participants attitudes towards other factors, such as finance, how responsible people feel for their energy efficiency, etc.

In general, then, software, such as NVIVO allows qualitative data analysis to be managed and understood more easily than manual data analysis. This is why NVIVO was used in this research. Figure 16 is an example of an NVIVO layout.
Figure 16 NVIVO layout
5.3.6 Summary of qualitative data collection and analysis

The process by which qualitative data was collected and analysed (both in the UK and Australia) was as follows:

1. Key questions were drawn from the literature review.
2. For each subset of participants (e.g. UK participants, landlords, etc) actual interview questions were drawn up designed to elicit the information needed to answer the key questions.
3. Interviews were conducted with participants using prepared interview questions, however, these were "open" questions as the research approach was inductive, rather than deductive. Interesting points made by the participants were followed up by further impromptu questions from the researcher.
4. Interviews were transcribed, and from the resultant text, inferential statements were associated with participants’ answers (these inferences were considered and agreed by the research supervisors, as well as being philosophically in tune with the research perspective, which incorporates neo-empiricist and positivist paradigms as outlined in section 4.1).
5. A frequency analysis was conducted in order to understand the degree to which participants’ views were aligned with the inferential statements (these inferential statements generally, but not always, could be related to perspectives in the literature review).

Figure 17 is a summary diagram of the qualitative data collection/analysis process:
Figure 17 The qualitative data collection/analysis process

Key Questions from Literature Review

Actual Questions for each participant group

Inferential Statements drawn from interviews

Inductive Interviews

Frequency analysis to determine participant’s alignment with Inferential Statements (and the relationship with the Literature Review)
5.3.7 UK Case Studies

Purposive sampling (Bryman, 2008), as described in section 4.3, was used to select six case study participants. An additional participant from a pilot study was added to the group, so a total of seven primary case studies were used in the UK. It was felt that purposive sampling was desirable for this research, as the subject matter was complex and it would be impractical to interview people who had no prior knowledge or understanding of energy use in the residential sector. All case study participants, and other participants in this research are treated anonymously.

The geographical location of the UK research participants had no primary foundation other than practicality for the researcher. Further study of other regions or nationally may determine if geography is a factor influencing the study results. However, the study allows some account to be taken of gender and age. Details of the UK case study participants, who took part in quantitative as well as qualitative research are summarised in table 17.

Table 17  UK Case Study Participants

<table>
<thead>
<tr>
<th>Participant</th>
<th>Gender</th>
<th>Age Range</th>
<th>Occupation</th>
<th>Property Type</th>
<th>Property Age</th>
<th>Tenure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robert</td>
<td>Male</td>
<td>18 to 29</td>
<td>Research student</td>
<td>Terraced House</td>
<td>2012</td>
<td>Owner</td>
</tr>
<tr>
<td>Gwen</td>
<td>Female</td>
<td>18 to 29</td>
<td>Research student</td>
<td>Flat</td>
<td>2000</td>
<td>Tenant</td>
</tr>
<tr>
<td>Jane</td>
<td>Female</td>
<td>30 to 40</td>
<td>Research student</td>
<td>Terraced house</td>
<td>1890</td>
<td>Tenant</td>
</tr>
<tr>
<td>Wendy</td>
<td>Female</td>
<td>30 to 40</td>
<td>Research student</td>
<td>Flat</td>
<td>1880</td>
<td>Tenant</td>
</tr>
<tr>
<td>Anne</td>
<td>Female</td>
<td>18 to 29</td>
<td>Research student</td>
<td>Semi-detached house</td>
<td>1930</td>
<td>Tenant</td>
</tr>
<tr>
<td>Arabella</td>
<td>Female</td>
<td>30 to 40</td>
<td>Research student</td>
<td>Semi-detached house</td>
<td>1935</td>
<td>Tenant</td>
</tr>
<tr>
<td>Juliette</td>
<td>Female</td>
<td>30 to 40</td>
<td>Teacher</td>
<td>Semi-detached house</td>
<td>1931</td>
<td>Owner</td>
</tr>
</tbody>
</table>

Robert lives in a new build (2012) terraced house with three bedrooms. The property has insulated cavity walls and 250 mm of loft insulation. Windows are
double glazed. Space heating is via gas central heating. He is usually the sole occupant in the property. Robert owns the property.

Gwen lives in a top floor flat in a relatively new purpose-built block (2000). The apartment has cavity walls which are insulated and the loft insulation above the flat is 250 mm. Windows are double glazed and space heating is via gas central heating. She is usually the sole occupant in the two bedroomed dwelling. Gwen is a tenant.

Jane lives in an older terraced house (1890), with two bedrooms. The walls are of solid brick in the loft insulation is 100 mm. Windows are double glazed and space heating is via gas central heating. She is usually the sole occupant in the property. Jane is a tenant.

Wendy lives in a mid floor flat within an older terraced house (1880). The walls are solid brick. Windows are double glazed. Space heating is via electric radiators. She is usually the sole occupant in this one bedroomed property. Wendy is a tenant.

Anne lives in a semi-detached house (1930) with three bedrooms. The walls are solid brick and there is 250 mm of loft insulation. Most windows are double glazed. Space heating is via gas central heating. She is one of three people living in the property. Anne is a tenant.

Arabella lives in a semi-detached house (1935) which has two bedrooms. The walls are made of solid brick and is 250 mm of loft insulation. Windows are double glazed with single glazing on the front and back door. Space heating is via gas central heating. She is one of two people living in the property. Arabella is a tenant.

Juliette lives in a semi-detached house (1931) which has three bedrooms. The property is interesting, as it is made up of part cavity walls and part solid brick. The cavity walls are not insulated, but there is 250 mm of loft insulation. Most windows are double glazed. Space heating is via gas central heating. She is usually the sole occupant living in the property. Juliette owns the property.
5.3.8 UK Landlords

UK private residential landlords have been considered in this research as they represent a significant proportion of the UK residential housing stock. Buy to let landlords accounted for 12\% of all UK mortgage lending by 2007 (Leyshon and French, 2009). While there may have been some diminution in the housing stock held by residential landlords due to the collapse in house prices in 2008, this sector is still substantial. Out of 22 million households, 4 million were in the private rented sector in 2013 (DCLG, 2014).

This researches the attitude of residential landlords towards sustainable energy use and energy efficiency in their properties. While some people might consider that landlords are likely to be disinterested in the energy used by their tenants, there are reasons why this may not be the case. For example, many tenancies include the cost of all the utility bills and this is particularly common in the case of undergraduate student lets (although all the rental participants in this study pay their own utility bills). In these cases where utility bills are included, it is as much in the interest of the landlord as the tenant to save or use energy efficiently (Levinson, & Niemann, 2004). Indeed, the interrelationship between the landlord and tenant make the issue of sustainable energy use and energy efficiency, more complicated.

If, for example, a landlord installs cavity wall insulation to an existing building which is tenanted on the basis that the rent is inclusive of energy bills, it is entirely possible that no energy saving might be made. The tenants might open a window to cool the building rather than turn the heating down, and the only effect of the increased insulation might be longer periods when the windows are left open. While there is no economic incentive for the tenants to save energy in this case, there could be a positive social incentive (if they feel a moral obligation) or a negative social incentive (they may be resentful of the landlord). Either way their behaviour may not be easy to understand or uncover. Even if the landlord was aware that their energy bills have not decreased or possibly increased, he may not be able to influence this for the period of the tenancy.
From the tenant's point of view, their relationship with the landlord is important. A good working relationship might mean that they could persuade the landlord to improve the efficiency of the tenants building and its appliances, if their aim was to become thermally more comfortable and to save money on energy. There is some evidence that renters are significantly less likely to have energy efficient appliances (Davis, 2010). One reason for this may be that low income renters are likely to have less bargaining power with their landlords to be provided with energy efficient measures and appliances, as their relative contribution to the landlord's revenue is likely to be lower than high income renters. Additionally, this lower relative contribution may provide less incentive for landlords to provide energy efficient equipment, both because higher energy efficient appliances may be more expensive than lower energy efficient appliances and also because the landlord may not have to compete for low income tenants as hard as he/she may have to do to attract higher income tenants whose income will provide them with more choice.

Details of the landlords who took part in qualitative research for this study are included in Table 18.

Table 18 UK Landlords

<table>
<thead>
<tr>
<th>Participant</th>
<th>Gender</th>
<th>Age Range</th>
<th>Occupation</th>
<th>Number of buy to let properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patrick</td>
<td>Male</td>
<td>30 to 40</td>
<td>IT manager</td>
<td>3</td>
</tr>
<tr>
<td>Mike</td>
<td>Male</td>
<td>40 to 50</td>
<td>Business owner</td>
<td>3</td>
</tr>
<tr>
<td>Ava</td>
<td>Female</td>
<td>40 to 50</td>
<td>Print estimator</td>
<td>4</td>
</tr>
</tbody>
</table>

No data was collected on the type of properties in which the landlords lived. All of the landlords owned buy to let flats rather than houses. While their opinions on energy sustainability were sought, the researcher felt that to question them too closely on their property details could have been construed as an attempt to estimate their relative wealth, leading to possible disengagement or counterproductive/inexact answers.
5.3.9 UK Energy Companies, UK Environmental Groups and UK Government

The rationale for interviewing a representative of an energy company, an environmental group, and a government member of Parliament with strong links to the local area, is to understand these important stakeholders views on energy efficiency and the use of sustainable energy in the residential sector. These three groups all have potential significant influence over this sector.

Energy companies may have considerable influence from a lobbying viewpoint over government policies, as typically, their dominant size and the essential nature of the product they supply means their point of view is carefully considered. The political effects of shortages in energy supply or spikes in energy costs are considerable. If however, this influence is not carefully judged it could result in increased regulation of the energy sector.

Environmental groups, especially the larger and more established ones, also seek to influence governments with regard to the policy decisions on energy use. These NGOs both lobby and work with government to improve the quality of our environment, in various ways. Their perspectives on energy use in the residential sector can influence people's behaviour and the general culture surrounding energy efficiency and sustainable energy use.

With regard to interviewing a government representative, the aim was to find out their views on how behaviour could be changed in the residential sector with regard to sustainable energy use and efficiency. The politician's local ties were important, as they might influence her viewpoint on energy efficiency and sustainability. For example, her support was enlisted to lobby against planning permission for a waste incineration plant in the local area.

Section 3.5.1 highlights the importance of regulation in improving the use of sustainable energy and energy sufficiency schemes over time. It was of interest to find out the local political representative's views on how to influence energy use behaviour in the residential sector, whether through regulation or other means. Details of the energy company, environmental group, and political representatives who took part in the study are set out in table 19.
Table 19 Environmental, Energy and Political representatives

<table>
<thead>
<tr>
<th>Participant</th>
<th>Gender</th>
<th>Age Range</th>
<th>Occupation</th>
<th>Representing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pauline</td>
<td>Female</td>
<td>30 to 40</td>
<td>Climate and energy specialist</td>
<td>Large environmental group</td>
</tr>
<tr>
<td>Daryl</td>
<td>Male</td>
<td>30 to 40</td>
<td>Senior policy executive</td>
<td>Large energy company</td>
</tr>
<tr>
<td>James</td>
<td>Male</td>
<td>30 to 40</td>
<td>Senior policy executive</td>
<td>Large energy company</td>
</tr>
<tr>
<td>Alice⁵</td>
<td>Female</td>
<td>40 to 50</td>
<td>Government Minister</td>
<td>UK Coalition government</td>
</tr>
</tbody>
</table>

5.4 Australian Qualitative Research

This research sought to incorporate some Australian qualitative research, to see to what degree there may be differences in attitudes with regard to energy conservation and sustainability. Australia is blessed with a multitude of natural resources, one of the largest of which is coal (in export terms), much of which goes to China. This contributes directly to carbon emissions produced outside of Australia.

The Australian Energy Regulator (AER, 2013) reports annually on the state of the energy market in Australia. The report explores conditions in the energy markets in those jurisdictions in which the regulator has regulatory responsibilities. There is a slow transition to national regulation in the retail sector. So far, New South

Written questions to the MP were:

1) What do you think will be the effect of technology on domestic energy use? (Use less, more or the same over time)

2) Researchers such as Saunders, Sorrell and others have found that energy saving measures can result in less energy saving than anticipated (the Rebound Effect)....... Instead of the Green Deal, would the government not be better to target fossil fuel use through a carbon tax?

3) How would you feel about being given a personal carbon allowance?

4) What are the key things you can do in current your role as an MP to influence domestic energy use?
Wales, South Australia, Tasmania and the ACT have implemented the National Energy Retail Law, which seeks to protect small energy customers with respect to their electricity and gas supply arrangements. Operating with the Australian Consumer Law, it also transfers significant functions from state and territory governments to the Australian Energy Regulator (AER). However, retail energy prices are not regulated, but can be easily compared on the regulator's Energy Made Easy website, which provides a tool for consumers to compare retail energy market prices. The website also provides a benchmarking tool which allows households to compare their consumption with other similar households. It also has information on consumer protection, energy efficiency, and the energy market. However, the emphasis is clearly on consumer information on energy supply rather than energy efficiency.

Victoria State, where this qualitative study was carried out, does not so far implement residential energy regulation as part of a national structure, and as such has not implemented the National Energy Retail Law.

5.4.1 An outline of Australian Energy Policy
Around the time of the publication of the Stern review (Stern, 2006), John Sandeman (Sandeman, 2006) presented a critique of Australian energy policy. He explained that Australians' dependence on cheap coal for electricity generation (approximately 80%), combined with no allowance for carbon emissions in its pricing, meant that Australia was level with the United States of America as top carbon dioxide emitters per capita. The dependence on other mining industry, which was CO₂ intensive, contributed to this.

However, on a global scale Australian carbon dioxide emissions represented just 2% of the world's total, and this fact had been the driver behind the Federal Government of Australia's policy on fossil fuel emissions. Australia had up to that time refused to sign the Kyoto protocol and the government believed that implementing a carbon price would seriously damage the economy. Even so, the greater level of awareness of the impact of fossil fuels on climate change
increased the pressure for legislation of action on carbon pricing, and the federal government support for "voluntary reductions" in emissions.

Australia made a Kyoto protocol commitment in 2008 to limit carbon dioxide emissions to 108% of 1990 levels for the period 2008 to 2012. In a report by the Australian Department of Climate Change and Energy Efficiency in 2012 (DCCEE, 2012), projections forecast that Australia’s emissions were likely to have averaged 575 million tonnes of carbon dioxide equivalent (Mt CO2-e) over the Kyoto period, which represents 105 per cent of the 1990 level, so improving on the target level. The report suggested that without a carbon pricing mechanism or the Carbon Farming Initiative (CFI), Australia’s emissions were forecast to be 693 Mt CO2-e in 2020 and 786 Mt CO2-e in 2030.

In 2012 the Australian government signed up to phase 2 of the Kyoto protocol. An unconditional emissions target of a 5% reduction on 2000 levels by 2020 was agreed upon. A carbon pricing mechanism was introduced on 1 July 2012, and with this instrument in place Australia's net emissions were expected to be limited to 537 Mt CO2-e in 2020, which represented 155 Mt CO2-e of abatement in 2020. The scheme required enterprises which emitted over 25,000 tonnes per year of CO2-e and which were not in the transport or agriculture sectors to purchase emissions permits, initially at $23 per tonne of carbon emissions.

Projections by the DCCEE in 2012, heralded significant decoupling of the growth of carbon emissions from population and economic growth. In 2030, Australia's net emissions per person were anticipated to be 13 tonnes CO2-e, down from the current level of 25 tonnes CO2-e per person. Also in 2030, net emissions per billion dollars of GDP were projected to be around half the level they would be without the carbon price.

The pricing of carbon dioxide emissions formed part of a broader package called the Clean Energy Future Plan. This aimed to reduce greenhouse gas emissions by 5% below 2000 levels by 2020 and 80% below 2000 levels by 2050. The scheme was managed by the Clean Energy Regulator, with the intention that industry and households could be compensated for increased costs by the
revenue derived from the carbon pricing. Initially the price of a permit to emit one tonne of carbon was fixed at $23 for the 2012–13 financial year, with unlimited permits being available from the Government. This fixed price rose to $24.15 for 2013–14. The government announced that the scheme would transition to an emissions trading scheme in 2014–15, where available permits would be limited in line with a pollution cap.

However, in September 2013 in a federal election a Liberal Government replaced the incumbent Labour Government. One of the election pledges of the new government was their intention to scrap the carbon tax, and this was formally abolished on 1 July 2014. While the commitment to reduce greenhouse gas emissions remains in place (i.e. by 5% below 2000 levels by 2020 and 80% below 2000 levels by 2050), the new government intends to do this through their Plan for a Cleaner Environment (Department of the Environment, 2014). The emissions reductions target will be achieved through a Direct Action Plan, which is designed to efficiently and effectively source low cost emissions reductions and improve the Australian environment. The intention is to do this through a Emissions Reduction Fund. This fund will operate alongside other existing programs which are already intended to reduce Australia's emissions growth. These other programs include the Renewable Energy Target and mandatory efficiency standards on appliances, equipment and buildings.

The Carbon Farming Initiative Amendment Bill 2014 has now been passed, and the Emissions Reduction Fund has been established on 13 December 2014. It replaces the previous carbon tax and provides a transition for the Carbon Farming Initiative. The intention is to allow the Clean Energy Regulator to approve a broader range of emissions reduction projects and amend project eligibility criteria for approving and crediting carbon credit units. The Clean Energy Regulator will purchase emissions reductions at the lowest available cost, generally through reverse auctions. The Regulator will enter into contracts with successful bidders, to guarantee payment for the future delivery of emissions reductions. Emissions

---

6 roughly equivalent to UK Conservative or right of centre government
reductions will be purchased at the auction bid price, and businesses will be able to use contracts as collateral to finance projects before they are implemented.

Additionally, prior to the election of the current liberal Australian government, legislation has been in place to encourage the development of renewable energy on a federal level (*Renewable Energy Act 2000*). This act has been amended on a number of occasions up to 2013. Currently there is a Renewable Energy Target (RET), which is designed to ensure that 20% of Australia's electricity comes from renewable sources by 2020. Since January 2011, the RET is operated in two parts, a small scale renewable energy scheme (SRES) and a large scale renewable energy target (LRET). The LRET has legislated annual targets which require significant investment in renewable energy capacity over future years. It has also created financial incentives for the creation of renewable energy power stations using wind, solar, or hydroelectric power.

The SRES creates financial incentives for households, small businesses and community groups to install eligible small scale renewable energy schemes. These include heat pumps, solar photovoltaic and water heaters, and small-scale wind or hydro systems. Power stations mandated under the LRET scheme have an obligation to buy small-scale technology certificates from SRES schemes, which creates an effective subsidy for their cost.

The Clean Energy Regulator oversees the Renewable Energy Target, and receives advice from the Department of the Environment on policy and implementation support.

However, the recent Australian government has instituted a review of the RET, which was completed in August 2014. The review was done by an Expert Panel and its recommendations are still under consideration. This means there is some uncertainty with regard to the RET going forward.

As Byrnes et al (2013) point out, incentivising the deployment of renewable energy to accomplish long-term reductions in carbon emissions requires an effective policy and regulatory framework. While they regard Australia's renewable energy
policies to date to have been significant in encouraging lower emission energy generation, the current uncertainty generated by the government's review of policy could have a damaging effect. Because of the federal nature of Australia, which is a vast country with energy segmented amongst the states and territories, there are still significant policy barriers which exist at the federal and state levels. For example, current policy inherently favours mature technologies which are perceived to have the lowest investment risk. Greater support for variable renewable technologies which might prove more efficient in reducing emissions is needed, particularly solar power and wind power (IRENA, 2015).

Approximately 90% of Australian electricity is still generated from the burning of fossil fuels, primarily comprised of coal, gas and oil. Approximately 68% of this electricity is still generated by coal, which itself varies in its energy intensity. Brown coal reserves, mainly located in Victoria, are significantly less efficient than black coal reserves in Queensland and New South Wales. However, brown coal is much more easily accessible and thus a lower cost source of energy, despite its lack of efficiency.

Despite the problems Australia faces, the transition to renewable sources of electricity has the potential to allow the country to exploit some of the world's finest renewable energy resources. The country has the highest average solar energy radiation of any continent, substantial geothermal resources, and high-quality wind resources on the southern coast. Developing these resources of course requires capital investment in new technology, whereas fossil fuel producers of energy already have existing production plants.

Nevertheless, particularly in the area of solar energy, Australia has made some major strides in the adoption of renewable energy. Between the start of 2010 and the year end 2012, 900,000 rooftop photovoltaic (PV) systems were installed in Australia (Mountain & Szuster, 2014). More than one in eight household rooftops have solar panels. This is the highest market penetration of any country in the world. This level of take-up has been achieved by significant subsidies in the form of feed-in tariffs. Over a three-year period, households spent more than $9bn and will receive subsidies of $8bn over the life of the installed PV systems. The
subsidy is generous, in that it covers the majority of the cost of the installed solar panels, while additionally the average cost of electricity from these solar systems is about half average household electricity prices (around $160/MWh).

In tandem with the generous subsidy, over the take-up period of PV, the installed cost on residential roofs declined from an estimated $12 per watt in 2008 to $3 per watt in 2012. This dramatic decline in costs is attributable to 3 main factors:

- the appreciation of the Australian dollar
- large reductions in the price of solar panels manufactured in China
- greater competition amongst system installers

Figure 18 below shows a breakdown of the subsidies from solar panels, in the form of renewable energy certificates, for the various states and territories in Australia over the three-year period.

Figure 18 Renewable energy certificates created through the installation of household PV $bn (2013) (From Mountain & Szuster, 2014)
Because of the high network charges to provide electricity in Australia, there is some contention over how to charge households which have solar panel installations. There is an argument that those without solar panels are cross subsidising households with these installations. However, to counter this, it is entirely possible that many of these households could function perfectly well if they were "off grid", that is, not connected to the main network and thus avoid network charges.

Even more interesting is the Zero Carbon Australia (ZCA) Stationary Energy Plan, which was released in 2010 by Beyond Zero Emissions, a climate solutions think-tank and the Melbourne Energy Institute. This showed how Australia could run on 100 per cent renewable energy in a decade (MEI, 2011).

The backbone to achieve this would be the use of concentrating solar thermal (CST) power towers with molten salt heat storage. CST plants are already used successfully in Spain, the USA and many parts of the world. Concentrating Solar Thermal power with molten salt storage represents a key enabling technology, because its thermal energy storage provides reliable power, day and night. The ZCA plan puts forward a 60/40 mix of CST and large-scale wind developments as the main structure of a decarbonised energy system. This would combine with existing hydropower in Australia, an upgraded electricity grid, widespread energy efficiency measures and backup power from a small percentage of biomass power stations (see figure 19).

7 Operational Concentrated Solar Power Plants  http://www.desertec.org/
A key point is that the Australian Energy Market Operator (AEMO) has found that it is technically feasible and affordable to run the National Electricity Market with 100 per cent renewable energy. The only difference between the AEMO analysis and that of ZCA is the projected timescale. AEMO model their hundred percent renewable grid for 2030 and 2050, while ZCA's plan is over 10 years. Table 20* shows the supply and demand projection for 2020 (from ZCA 2020 Energy Report).
Table 20  Power generation Supply and Demand: Analysis by State (MEI, 2011)

<table>
<thead>
<tr>
<th>State</th>
<th>Solar (MW)</th>
<th>Wind (MW)</th>
<th>Hydro (MW)</th>
<th>Total generation (MW)</th>
<th>Peak Demand (MW in 2020)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western Australia</td>
<td>7,000</td>
<td>8,000</td>
<td>-</td>
<td>15,000</td>
<td>7,500</td>
</tr>
<tr>
<td>South Australia</td>
<td>3,500</td>
<td>14,000</td>
<td>-</td>
<td>17,500</td>
<td>4,300</td>
</tr>
<tr>
<td>Victoria</td>
<td>7,000</td>
<td>8,000</td>
<td>500</td>
<td>15,000</td>
<td>12,800</td>
</tr>
<tr>
<td>NSW</td>
<td>10,500</td>
<td>10,000</td>
<td>3,750</td>
<td>24,250</td>
<td>19,600</td>
</tr>
<tr>
<td>Queensland</td>
<td>14,000</td>
<td>8,000</td>
<td>700</td>
<td>22,000</td>
<td>14,000</td>
</tr>
</tbody>
</table>

*Tasmania has been neglected from this analysis as the possible use of solar thermal generation is limited. The Northern Territory is also excluded due to its low level of energy demand.

So a transition to a zero carbon future in Australia is potentially achievable using existing available technology. This technology would involve combining wind, solar, hydro and biomass resources together with the implementation of greater energy efficiency measures. The plan would involve the strategic investment of $37 billion per year over 10 years. This is a stimulus of just over 3% of projected GDP. Also in the longer run, the lower fuel costs of renewable energy recoup the initial investment. Further benefits would accrue by improving health, increasing energy security, and with the cooperation of the mining industry, the possible development of a technological edge in the renewable energy sector.

If this plan was implemented, Australia would produce low emissions domestically, although continuing export of its vast stock of fossil fuel energy could mean the continuing growth for a time of carbon dioxide emissions in other parts of the world, such as China. Eventually, however, these countries are likely to want to reduce their dependence on fossil fuels.

So the inexorable move towards using less fossil fuels around the world, as countries face the problems of climate change, pollution and energy security,
would seem to suggest that the development of a sustainable energy policy in Australia would make sense in the long run.

However, political decision-makers will be responsible for moving any sustainable energy agenda forward. The recently elected federal government are currently reviewing energy policy and it is unclear to what extent their policies will produce a truly sustainable agenda. According to Khatib (2012), in his review of the International Energy Agency (IEA) World Energy Outlook 2011 report, the use of coal has met almost half of the increase in global energy demand over the last decade and demand for coal is predicted to rise by 65% between 2011 and 2035. However, he contends that prospects for coal are especially sensitive to energy policies, particularly in China (accounting for roughly half of global demand), which is Australia's largest export market for coal. So to some extent, Australian energy policy may well be assisted or hindered by energy policy decisions in China.

5.4.2 Australian Case Studies
The Australian case study research was qualitative, consisting of semi-structured interviews with six participants, chosen by purposive sampling. To do qualitative, and predictive energy research with these participants was not possible due to time and financial constraints.

A compelling reason to involve Australian participants in this research was the developing debate on energy policy in Australia. It is a country that is actively engaged in policy debate around climate change and the environmental need to enhance sustainable energy supply. The research in Australia was also supported by access to information from the Institute for Strategic Economic Studies at Victoria University and involved discussions with other researchers involved with the energy efficiency and climate change agenda. The Institute as a whole has a strong energy-environment agenda and has been addressing a wide range of policy issues, especially in relation to buildings.
In addition, the political change involving the scrapping of the carbon tax meant that it was particularly interesting to gauge the case study participants opinions on energy sustainability in the residential sector.

Details of the Australian case study participants, who took part in qualitative research are in table 21.

Table 21  Australian Case Study participants

<table>
<thead>
<tr>
<th>Participant</th>
<th>Gender</th>
<th>Age Range</th>
<th>Occupation</th>
<th>Tenure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bruce</td>
<td>Male</td>
<td>18 to 29</td>
<td>Student</td>
<td>Tenant</td>
</tr>
<tr>
<td>Sue</td>
<td>Female</td>
<td>30 to 40</td>
<td>Mother</td>
<td>Owner</td>
</tr>
<tr>
<td>Angela</td>
<td>Female</td>
<td>40 to 50</td>
<td>Research practitioner</td>
<td>Owner</td>
</tr>
<tr>
<td>Mandy</td>
<td>Female</td>
<td>18 to 19</td>
<td>Interior designer</td>
<td>Tenant</td>
</tr>
<tr>
<td>Tilly</td>
<td>Female</td>
<td>60+</td>
<td>Research fellow</td>
<td>Owner</td>
</tr>
<tr>
<td>Ellie</td>
<td>Female</td>
<td>50 to 60</td>
<td>Librarian</td>
<td>Owner</td>
</tr>
</tbody>
</table>

As no quantitative research was undertaken with these case study participants, only limited information was gathered regarding their accommodation. Participants were chosen based on the rationale described in section 4.3. which took into account the researcher's view that they had sufficient knowledge of energy use and climate change. Bruce lived in a shared house a few miles from the city centre. Sue lived with her husband and a young child and was deeply committed to using energy sustainably and was building her own house around 40 miles from Melbourne, which she planned to power largely with solar panels. Angela, a single parent, lived in the Melbourne suburbs with her children. Mandy also shared a house a few miles from the city centre. Tilly lived in a suburb of Melbourne in a house with her husband. Ellie lived around 20 miles from Melbourne in a house with her husband.

All of the participants involved in the Australian study lived within relatively close proximity of Melbourne, the capital of Victoria State. As such, it could be argued that their opinions would be influenced by State as well as federal policy (Victoria
has its own climate adaptation plan\(^8\). As a sample group they all had a good degree of awareness of the issues around energy efficiency and climate change.

### 5.5 Validation and Integration of Empirical, Predictive and Interview Data

The UK (and larger) element of this study incorporates empirical, predictive, and interview data. This is a mixed method approach which allows cross comparison of data results from different sources. The different types of data provide evidence for the research, and theories can be formulated to explain any contradictions that occur. As previously explained, it was not possible to use mixed method research techniques in Australia, but nevertheless the qualitative data obtained is, of itself, valuable because it reveals the participants motivations behind energy use.

Quantitative data was validated through calibration of the equipment used to collect the data. This calibration ensure the accuracy of the temperature measurements taken.

Predictive data was modelled using quantitative measurements in FSAP software, a computer model designed to reproduce the government approved Standard Assessment Procedure (SAP).

The qualitative data was validated by using standard techniques to interview the research participants. All were willing participants who provided a variety of opinions on sustainable energy in the residential sector. When it comes to opinions, there is no right or wrong answer and responses are valid as long as the researcher views them as truthful. This is one reason why face-to-face interviews were chosen as a key part of the qualitative research. Body language can be an important indication of how open the interviewee is to providing a straightforward and truthful answer. People's attitude to energy use in the residential sector can only be measured to a limited extent through the use of numbers (i.e. quantitative methods). Qualitative analysis allows the study of social and cultural phenomena,

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\(^8\) [http://www.climatechange.vic.gov.au/]
and can provide a deeper understanding of the meaning of this phenomena in the research. The context in which the research takes place is of major importance. It also allows flexibility and exploration.

In this particular research, the researcher deliberately encouraged the participants to choose locations for the interview in which they were most comfortable. They were also made aware that all opinions were equally valid, and that the researcher had no expectation of their point of view. As such, body language, did not seem to be a significant factor, and participants answers were considered to be a reasonably truthful reflection of their views.

5.6 Conclusion - How research methods link to the Aims and Objectives of this study

The aim of this study is to assess how financial and non-financial incentives influence energy demand in residential property. This requires an understanding of how people respond to the available forms in which they are able to obtain a highly necessary but scarce resource, which is needed for their energy using capital equipment. It also needs to take into account the effects of using energy on a number of levels. On an individual scale, energy use is a derived demand whereby people purchase energy using capital to in some way increase their utility. However, on a broader scale energy use has costs that are not simply financial. Negative externalities, such as pollution, energy security and the effect on climate change are also costs which may or may not be reflected in the energy price. If these costs are reflected in may be through regulation or cultural traditions present in certain societies. For example, the French nation seems happy to use a significant amount of nuclear power, while in Germany people seem happy to pay large subsidies to generate renewable power.

As a starting point, the research objectives reviewed the background to energy as a resource, including the theoretical functions underlining its supply and demand. An analysis of the social cost of carbon and its abatement was considered, along with the development of historical energy efficiency schemes in the UK.
The research then concentrated on current policy in the UK in the residential sector. The flagship policy is the Green Deal, and this was evaluated in some detail. This was then contrasted with a range of viewpoints on energy demand behaviour in the residential sector emanating from various studies carried out in this area.

With this background, the research purpose was to evaluate individual case studies, both in the UK and Australia. This research took place in the context of an awareness of the various strands of research surrounding residential energy demand behaviour. As such, the research results are assessed against these viewpoints, which include:

- The effect of financial incentives. For example, the Green Deal offers an economic incentive, but problems can include potential negative NPV from retrofits (Hassett & Metcalf 1993), excessive transaction costs, and currently uncompetitive interest rate charges for taking part.

- The development of Nudge Theory (see section 3.6.7). People can make poor choices and arguably need to be nudged in the “right” direction (Thaler 1994). A problem with this approach includes targeting heuristic behaviours that are negative. Not all heuristic behaviours (mental shortcuts) are bad, indeed some are necessary to cope with the routine tasks of day-to-day life. Thaler (2015) has several comments on this:

  # 1 "Humans have limited time and brainpower. As a result they use simple rules of thumb - heuristics - to help them make judgements. An example would be 'availability'. In guessing how frequent something is, we tend to ask ourselves how often we can think of instances of that type. It's a fine rule of thumb...but the rule will fail in cases in which the number of instances is not highly correlated with the ease with which you can summon up examples."

This, to Thaler, is the ‘big idea’ of the work of Kahneman and Tversky (1979) on heuristics and biases.
"Using these heuristics causes people to make predictable errors". Thaler goes on to argue that Herbert Simon’s idea of ‘bounded rationality’ was an early precursor of this (Barberis, 2013). Bounded Rationality was a major contribution to economics in the 1950s. It helped to explain how individuals could cope with taking decisions when the effort to discover the optimal behaviour under uncertainty involved extremely large and infeasible calculations, beyond the scope of even those with a sophisticated knowledge of probability. Simon (1957) used bounded rationality (= Thaler’s heuristics) to explain how humans resolved difficult problems of discovering optimal behaviour; he predicted that people would adopt ‘satisficing’ rather than optimal behaviour. This had a profound effect on the study of industrial organization and led to important work by Baumol (1962) and Cyert & March (1963) on the theory of the firm. An example is the sales maximisation theory of managerial behaviour in place of profit maximisation. In this sense, the use of heuristics has been an important positive contribution to decision making. However, Kahneman and Tversky, and Thaler, are able to show that it allows errors in decision making to persist.

Some additional viewpoints are:

- The viewpoint that a person’s social identity determines their choices (Ackerlof & Kranton 2000, Vale & Vale 2010). Problems with this include the time and method needed to influence social identity.

- Will people respond to the “real” cost of carbon emissions, if it is priced into the market (Tol, 2007, Stern 2009). A problem with this approach includes measuring the real cost of these emissions, an incredibly complex area.

- The assertion that people are more risk averse to the prospect of losing money than gaining it because they look at potential values of outcomes rather than probabilities. Utility is reference based rather than additive (Kahneman 2011). Problems include uncovering what incentives overcome this heuristic (mental shortcut) bias.

The purpose of using a predictive analysis of the UK case study properties was, at least in part, to assess its accuracy. The Standard Assessment Procedure (SAP)
is the government's recommended method of assessing energy use for the purposes of the Green Deal. As such it was important to assess its viability as a tool to encourage energy efficiency.

The use of quantitative assessment of energy use in the UK case study properties was important, as it revealed the actual energy use in each case study and allowed an assessment of the way the various case study individuals used energy. The qualitative interviews were semi-structured, and the questions were deliberately designed to uncover opinions related to the research which has already been done in this area. The UK case study interviews were also able to be used to compare actual energy use behaviour and that predicted by the SAP model. This triangulation of research methods allow verification of conclusions with respect to individual behaviour and also highlighted any contradictions between attitudes and actual behaviour. Further confirmation of UK participants viewpoints was obtained during the focus group session.

The research also wanted to gain an additional perspective on energy use behaviour in the residential sector by conducting interviews with other key stakeholders who would have an influence over culture and opinion. This is why a research perspective from a representative of an environmental group, an energy company, and a politician (whose opinions would be influenced by local issues, as well as government policy) was important.

A further perspective was provided by conducting interviews with three landlords who also resided in the UK case study local area. Their attitude toward energy use and the extent to which they would wish to co-operate with their tenants with regard to energy efficiency was of interest.

Finally, although this research is primarily concerned with the UK, it was felt that additional research on residential energy use from participants in another country would broaden the research prospective. Australia was chosen as it represents a particularly interesting contrast to the UK with regard to energy resources and policy.
All the data collected were ultimately used to assess participants’ viewpoints on energy use in the residential sector, and to what extent their energy use would be influenced by the context in which it was supplied. This context included the pertaining culture, economic incentives, regulation, awareness of the negative externalities of using fossil fuel energy, and how people make choices.
CHAPTER 6. Reporting and analysing results

This chapter reports and analyses the results of the empirical analysis recorded in this research. Differences in data inferences are then reconciled, and the interrelationships between the results are considered. Section 6.1 outlines the data used in the FSAP modelling software to predict the UK case study participants energy use. Section 6.2 outlines the quantitative empirical data gathered from the UK case study participants. Section 6.3 presents the qualitative data obtained from the UK case study participants, UK energy company, UK environmental group, and UK member of Parliament. It also records qualitative data from the Australian participants, and the UK focus group. Section 6.4 reconciles differences in data inferences. Section 6.5 assesses the results obtained from each group of participants.

6.1 Predictive Data

The summary SAP input for the seven UK case study properties is set out below. Full details are outlined in appendix 4, with an example of Robert's property details in this section. Predicted Energy Assessments are from Stroma Certification FSAP Software. Predicted energy from the software is noted for each participant.

As the researcher is not a trained energy assessor, the FSAP software results were calibrated by comparing them with actual energy assessment results available from Gwen, one of the case study participants. The predicted energy efficiency rating at this one dwelling was 76, compared with an actual rating of 79. Both were within the band C category on the energy performance certificate (69 to 80). The predicted environmental impact (CO₂) rating was 75, compared with an actual rating of 78. Again, both were within the band C category on the energy performance certificate (69 to 80).
Property Details Robert:
Address: LOUGHBOROUGH, LE11
Located in: England
Region: Midlands
Date of assessment: 01 October 2013
Assessment type: Existing dwelling (SAP)
Tenure type: Owner
Thermal Mass Parameter for FSAP software: Indicative Value Medium
No information on thermal bridging

Table 22 Property Description Robert

<table>
<thead>
<tr>
<th>Property Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling type</td>
</tr>
<tr>
<td>Detachment</td>
</tr>
<tr>
<td>Year Built</td>
</tr>
<tr>
<td>Floor Location</td>
</tr>
<tr>
<td>Floor 0</td>
</tr>
<tr>
<td>Floor 1</td>
</tr>
<tr>
<td>Living area</td>
</tr>
<tr>
<td>Front of dwelling faces</td>
</tr>
</tbody>
</table>
### Table 23 Opening Types

<table>
<thead>
<tr>
<th>Name</th>
<th>Source</th>
<th>Type</th>
<th>Glazing</th>
<th>Argon</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>SAP 2009</td>
<td>Solid</td>
<td>-</td>
<td>-</td>
<td>PVC-U</td>
</tr>
<tr>
<td>Back Door</td>
<td>SAP 2009</td>
<td>Half glazed</td>
<td>double-glazed</td>
<td>Yes</td>
<td>PVC-U</td>
</tr>
<tr>
<td>Standard Window</td>
<td>SAP 2009</td>
<td>Windows</td>
<td>double-glazed</td>
<td>Yes</td>
<td>PVC-U</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>U-value</th>
<th>Area</th>
<th>No. of Openings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>3.0</td>
<td>1.85</td>
<td>1</td>
</tr>
<tr>
<td>Back Door</td>
<td>1.5</td>
<td>1.85</td>
<td>1</td>
</tr>
<tr>
<td>Standard Window</td>
<td>2.6</td>
<td>1.3</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>External Wall</td>
<td>North</td>
</tr>
<tr>
<td>Back Door</td>
<td>External Wall</td>
<td>South</td>
</tr>
<tr>
<td>Standard Window</td>
<td>External Wall</td>
<td>Unspecified</td>
</tr>
</tbody>
</table>

**Overshading**: Very Little

### Table 24 Opaque Elements

<table>
<thead>
<tr>
<th>Type</th>
<th>Gross Area</th>
<th>U-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External Elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cavity as built</td>
<td>45.668</td>
<td>0.3</td>
</tr>
<tr>
<td>Pitched Roof</td>
<td>40.51</td>
<td>0.3</td>
</tr>
<tr>
<td>Concrete Suspended Floor</td>
<td>40.51</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Internal Elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Party Wall Cavity Fill</td>
<td>40.169</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### Table 25 Ventilation

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ventilation</strong></td>
<td></td>
</tr>
<tr>
<td>Pressure Test</td>
<td>No</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Natural ventilation (extract fans)</td>
</tr>
<tr>
<td>Number of chimneys</td>
<td>0</td>
</tr>
<tr>
<td>Number of open flues</td>
<td>1 (main: 1, secondary: 0, other: 0)</td>
</tr>
<tr>
<td>Number of fans</td>
<td>1</td>
</tr>
<tr>
<td>Number of sides sheltered</td>
<td>2</td>
</tr>
</tbody>
</table>
### Table 26  Heating Robert

<table>
<thead>
<tr>
<th>Heating</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Heating System</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Main heating Control</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Secondary heating system</strong></td>
</tr>
<tr>
<td><strong>Water heating</strong></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

### Table 27  Other Robert

<table>
<thead>
<tr>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electricity tariff</strong></td>
</tr>
<tr>
<td><strong>Conservatory</strong></td>
</tr>
<tr>
<td><strong>Low energy lights</strong></td>
</tr>
<tr>
<td><strong>Water heating</strong></td>
</tr>
</tbody>
</table>
This is a Predicted Energy Assessment. It includes a predicted energy rating which might not represent the final energy rating of the property on completion. Once the property is completed, an Energy Performance Certificate is required providing information about the energy performance of the completed property.

Energy performance has been assessed using the SAP 2009 methodology and is rated in terms of the energy use per square metre of floor area, energy efficiency based on fuel costs and environmental impact based on carbon dioxide (CO2) emissions.

The energy efficiency rating is a measure of the overall efficiency of a home. The higher the rating the more energy efficient the home is and the lower the fuel bills are likely to be.

The environmental impact rating is a measure of a home’s impact on the environment in terms of carbon dioxide (CO2) emissions. The higher the rating the less impact it has on the environment.
Predicted Energy use summary UK Case Studies:

Table 28  Predicted Energy use using SAP (kWh/m²/year) – UK Case Studies

<table>
<thead>
<tr>
<th></th>
<th>Gas</th>
<th>Electricity</th>
<th>Total energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robert</td>
<td>149</td>
<td>28</td>
<td>177</td>
</tr>
<tr>
<td>Gwen</td>
<td>138</td>
<td>29</td>
<td>167</td>
</tr>
<tr>
<td>Jane</td>
<td>238</td>
<td>24</td>
<td>262</td>
</tr>
<tr>
<td>Juliette</td>
<td>172</td>
<td>27</td>
<td>199</td>
</tr>
<tr>
<td>Wendy</td>
<td>-</td>
<td>222</td>
<td>222</td>
</tr>
<tr>
<td>Anne</td>
<td>288</td>
<td>29</td>
<td>317</td>
</tr>
<tr>
<td>Arabella</td>
<td>254</td>
<td>34</td>
<td>288</td>
</tr>
</tbody>
</table>

Predicted energy use in SAP largely depends on the age and type of a property. This is because space heating is a major part of typical energy use in a dwelling. Predicted electricity use in all of the dwellings, apart from Wendy’s is reasonably similar (Wendy uses only electricity for all her energy requirements, while the others use gas for space heating). Robert’s predicted gas consumption is relatively low due to his terraced house being modern and energy efficient. Gwen lives in a modern flat and also has relatively low gas consumption. The other flat dweller is Wendy who lives in an older building, circa 1900. This combined with the assumed higher cost of providing electric space heating explains her predicted higher energy use.

Jane lives in an older terraced house (1900), while Juliette, Anne and Arabella live in 1930’s era semi detached houses. While Anne and Arabella have properties of solid brick construction, Juliette’s house is partly of cavity wall construction (this would explain the slightly lower predicted space heating cost). Appendix 4 gives much greater detail of the SAP analysis and differences in predicted costs between Jane, Anne and Arabella can be explained by details such as u-values of the construction elements, property orientation, shading, gas boiler types, etc.
6.2 Quantitative Empirical Data

Data was recorded from the seven case studies, including external temperature, using calibrated Hobo Pendant Temperature Data Loggers (UA-001-08). Four data loggers were calibrated in the Civil and Building Engineering laboratory in Loughborough, by placing them in a specially heated water tank which heated the water over a timing schedule to a set range of temperatures.

Figure 21 below shows that the loggers are accurate within acceptable levels (+ or - 2 °C) when compared with each other.

Once these four loggers were calibrated, the remaining 11 loggers required for the study were then calibrated against them to ensure the accuracy of all the temperature sensors in the study.

Because of the number of sensors, and the size of the available laboratory equipment, it was not possible to calibrate all the sensors together in a laboratory setting. Instead, the laboratory calibrated sensors were placed together with the remaining uncalibrated sensors, and moved from place to place internally and externally over a period of time.
The recorded temperatures of all sensors were then compared to ensure that their accuracy was within an acceptable range.

![Calibration All Loggers 08/08/2013](image)

**Figure 22 Calibration by comparison of all loggers**

As can be seen from the above figure 22, the accuracy of the temperature loggers is slightly less precise. Differences of up to 4°C emerged with this broader calibration. This is because the temperature loggers were loosely bagged and were placed externally in sunlight before being placed in the living room of a residential property. Despite the slight disparity in temperatures revealed in the graph, it can be seen that all the loggers responded to temperature changes in a similar fashion. As such, they were considered satisfactory to use for this research.
Again, Quantitative Empirical Data is summarised, with average lounge and bedroom temperatures represented in combined graphs. The following sections include an example of the detailed quantitative empirical data that is outlined in appendix 5.

6.2.1 Quantitative Results, Robert Lounge

Figure 23 below shows the temperature data monitored in the lounge area of Robert's house from midnight Wednesday 16 October 2013 until midnight Tuesday 11 February 2014. Temperatures were recorded half hourly over the period.

![Figure 23 Raw Temperature °C Robert Lounge](image)

In figure 24, average temperatures are displayed for the lounge area of Robert's house. While the daily average hovers around the 20° C mark, with a maximum daily average of 22.3° C and a minimum daily average of 17.7° C, it is evident from the raw data above, temperatures swing between a maximum of 33.6° C and the minimum of 16.6° C. The raw data gives a complete picture of temperatures recorded every half-hour during the 17 week monitoring period, and provides a context to the average temperatures that are assessed. Spikes over 30° C, as in the above graph, could be for a variety of reasons such as thermal gain from direct sunlight, impulse change in temperature by the participant to boost thermal
comfort, or other factors such as a party with a number of individuals adding internal heat gain to the premises.

![Figure 24 Daily Average Temperatures °C Robert Lounge](image)

There is surprisingly little difference between the daily average temperature in the living area, and the daily occupied average temperature in this part of the house. Total daily average temperatures are 20.2° C, while total daily average occupied temperatures are 20.3° C.

Maximum occupied and minimum occupied temperatures also only have minor variations from the overall daily averages, with a maximum daily occupied average temperature of 22.7° C and a minimum daily occupied average temperature of 17.5° C.

Occupied hours are calculated on the assumption that the property is occupied and using energy between 5 PM and 11 PM on weekdays, and between 7 AM and
11 PM on weekends (Saturday and Sunday). In order to maintain some consistency when making comparisons between the case study occupants, these hours have been investigated, irrespective of particular holiday periods during the time of the study. The purpose of examining these nominated occupied hours is to see how the energy use for each individual varies from the overall average energy use.

These occupied hours are assumed for all of the 7 UK participants. One might expect an individual's energy use to increase when they are assumed to be occupying the property, however, this may not be the case. In Robert's case, average temperatures do not vary to a great degree, whether the property is (assumed) occupied or not. There could be a number of explanations for this, and these could include Robert believing that it is in fact more efficient to maintain his property at a constant temperature, or that the energy efficiency of his relatively new house makes energy use sufficiently cheap, so that cost is not an issue.

**Bedroom**

Figure 25 shows the actual temperature data monitored in the main bedroom area of Robert's house from midnight Wednesday 16 October 2013 until midnight Tuesday 11 February 2014. Temperatures were recorded half hourly over the period.

![Figure 25 Raw Temperature °C Robert Bedroom](image)
In figure 26, average temperatures are displayed for the main bedroom area of Robert's house. While the daily average stays close to the 21° C mark, with a maximum daily average of 22.4° C and a minimum daily average of 18.5° C, it can be seen from the raw data above that temperatures swing between a maximum of 30.5° C and the minimum of 17.3° C.

![Figure 26 Daily Average Temperature °C Robert Bedroom](image)

Maximum occupied and minimum occupied temperatures are 22.3° C and 18.7 ° C, again very similar to daily average temperatures. Total daily average bedroom temperatures are 20.8° C, while total daily average occupied temperatures are 20.6° C.

**Actual Energy Use**

The energy use readings at each case study could not be taken concurrently, so actual energy readings are adjusted so that assumed energy use between 16 October 2013 and 11 February 2014 can be evaluated. This was done by dividing the readings by the number of days they represented, and then multiplying this by 119 days, which equates to the number of days in the formal monitoring period.
In Robert's case, actual readings were taken on 12 October 2013 with final readings being taken on 17 February 2014. This represented nine extra days over the monitoring period. So units were divided by 128 and then multiplied by 119 to give the assumed energy use over the period.

The energy from 293 m$^3$ of gas needs to be converted to kilowatt hours, as explained in section 5.2.1.2 Winter Energy Use. Using the link http://energylinx.co.uk/gas_meter_conversion.html, this gives 3,329 kWhs.

Total energy use is in Table 29 below.

**Table 29 Robert Total Energy Use**

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Start Reading 12/10/2013</th>
<th>End Reading 17/2/2014</th>
<th>Actual Total</th>
<th>Adjusted Total</th>
<th>Total kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas m$^3$</td>
<td>0845</td>
<td>1160</td>
<td>315</td>
<td>293</td>
<td>3,329</td>
</tr>
<tr>
<td>Electric kWh</td>
<td>01649</td>
<td>02033</td>
<td>384</td>
<td>357</td>
<td>357</td>
</tr>
<tr>
<td>Total Consumption</td>
<td></td>
<td></td>
<td>3,686</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Summary of UK case study participant's household temperature and energy data (predicted and extrapolated actual)**

The following composite figures 27 and 28 show average lounge and bedroom temperatures for each UK case study participant. Table 30 shows a composite of total predicted and actual energy use by participant. Further evaluation of differences in temperature and energy data is undertaken in section 6.4 (Reconciling differences in data inferences).
Figure 27 Average Lounge Temperatures across the UK householder cohort
Figure 28 Average Bedroom Temperatures across the UK householder cohort

Figure 28 Average Bedroom Temperatures across the UK householder cohort
Table 30 UK Case Study energy use

<table>
<thead>
<tr>
<th>Total Energy by Type</th>
<th>Predicted (SAP) kWh/m²/year</th>
<th>Actual kWh/m²/year</th>
<th>Predicted energy use difference from actual (%)</th>
<th>UK Case Study Participant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas &amp; Electricity</td>
<td>177</td>
<td>139</td>
<td>+27%</td>
<td>Robert</td>
</tr>
<tr>
<td>Gas &amp; Electricity</td>
<td>167</td>
<td>107</td>
<td>+56%</td>
<td>Gwen</td>
</tr>
<tr>
<td>Gas &amp; Electricity</td>
<td>262</td>
<td>205</td>
<td>+28%</td>
<td>Jane</td>
</tr>
<tr>
<td>Gas &amp; Electricity</td>
<td>199</td>
<td>220</td>
<td>-10%</td>
<td>Juliette</td>
</tr>
<tr>
<td>Electricity</td>
<td>222</td>
<td>98</td>
<td>+26%</td>
<td>Wendy</td>
</tr>
<tr>
<td>Gas &amp; Electricity</td>
<td>317</td>
<td>352</td>
<td>-10%</td>
<td>Anne</td>
</tr>
<tr>
<td>Gas &amp; Electricity</td>
<td>288</td>
<td>220</td>
<td>+31%</td>
<td>Arabella</td>
</tr>
</tbody>
</table>

The next section 6.3 examines the qualitative data collected for this study.
6.3 Qualitative Data

The qualitative data is considered in four main sections. A summary of the balance of views is set out at the end of each section.

1. The UK case study participants.
2. The UK landlords, the UK energy, environmental and government stakeholders
3. The Australian participants
4. The UK focus group

6.3.1 UK Case Studies

The following key questions were used to devise the interview questions:

1) How do domestic residents think about their energy use?

2) How does the form of energy residential consumers use appeal to their ideological, health or materialistic/economic consumer needs?

3) What impact has culture on energy use and can this be changed with education policy or through commercial/political marketing? (Remember the "Britain's Not Working" ad?)

4) How does more information on domestic energy consumption, such a smart meters which provide real-time information on energy use, automatically encourage greater energy efficiency or is it more complicated than this?

5) How important, or possible is it, for domestic consumers to measure their energy use in all energy related activity (so they can be aware of technology efficiency rebound effects)?

6) How responsible do domestic consumers feel for their efficient use of energy?

7) How could financial incentives be devised to make a difference?
Using the process described in Section 5.3.6, the interviews were analysed by coding the responses from the interview questions to inferential statements derived from those responses. Only inferred statements which linked to the key questions were used, as this was a necessary link to understand the participants viewpoints in terms of the aim and objectives of this study.

The actual interview questions were as follows:

1) How much difference will your energy use make to climate change?

2) How strongly do you feel about the energy you use, in the sense of where it comes from, what type of energy it is, how affordable it is, should you use less of it, etc?

3) What is the best kind of energy to use to heat your house?

4) How easily do you think you might be influenced by what other people do with regard to energy use?

5) How effective do you think education is, in the way people use energy when compared with say, regulation or financial incentives?

6) To what extent do you think our health could be affected by the way we use energy?

7) Would more information on your energy consumption really affect your energy use, or how much would it depend on a mixture of factors? (cost, what you feel you need, etc.)

8) If you knew you were saving energy on some things at home, should you get some kind of tangible reward for it (money, energy credits, etc.)?
9) Who should take most responsibility for saving energy domestically in our society (government, educated people, wealthy people, heavy energy users, etc)?

10) What kind of incentives would make you change your energy behaviour?

11) What will be the effect of technology on your energy use? (Use less, more or the same over time)

12) What is your attitude to nuclear power (and why)?

13) What is your attitude to the Green Deal? Would you use it to make energy improvements to your own house?

14) Would tax incentives make you more likely to try to save energy or pay for energy saving measures in your home? For example, could 10 years capital gains tax be waived in return for buy-to-let and commercial landlords upgrading their property to a certain level within a 2 year time frame? Could the inheritance tax threshold be increased for residents who upgrade their property? Could a large tax credit be given to working people who upgraded their property?

15) How important is saving energy compared with the other problems you have in your life?

16) Would you be prepared to pay a carbon tax and under what circumstances?

17) How would you feel about being given a personal carbon allowance?

18) The growth in the world's population has meant an increased demand for energy. What is you view on this? (Does it make it less worthwhile to worry about our energy use, as it dwarfs any impact we can make?)

The inferential statements derived from these questions result from indicative answers which are not necessarily from one interview question or participant, but
might have been a compilation of views or answers. Examples of how statements are inferred from descriptive statements can be seen in section 5.3.4.

The inferential statements are as follows, with an indication of their derivation.

Collective action is important to use energy sustainably
This statement is derived from answers to interview question 1 (Gwen, Jane, Anne) and question 9 (Arabella).

Differentials tariffs are a good idea (where charges vary according to the time of day)
Derivation from answers to interview question 7 (Wendy) and question 10 (Arabella)

Education is the most important thing in influencing energy use
Derivation from answers to question 17 (Arabella) and question 5 (Gwen, Jane)

Financial situation is the driver behind energy use (A participant's personal financial means)
Derivation from answers to question 1 (Robert, Gwen, Jane), question 9 (Gwen), question 12 (Jane) and question 13 (Anne)

Government regulation is important in residential energy use
Derivation from answers to question 2 (Anne), question 5 (Gwen), question 8 (Jane) and question 9 (Robert)

It would be useful if we could choose the sustainability of energy supply to our home
Derivation from answers to question 1 (Jane), question 2 (Arabella), question 3 (Gwen, Wendy) and question 7 (Anne)

People are influenced by the culture around them
Derivation from question 4 (Anne), question 5, 11 and 17 (Arabella)
People don't think rationally  
Derivation from question 13 (Wendy) 

People should take individual responsibility for energy use  
Derivation from question 1 (Arabella), question 9 (Gwen, Wendy, Anne) 

Saving energy results in it getting used elsewhere  
Derivation from question 8 and 14 (Jane) and question 11 (Arabella) 

The government should nudge us in the right direction  
Derivation from question 1 (Robert) 

Smart meters are useful (in providing the information to help people save energy)  
Derivation from question 7 (Robert, Jane, Wendy, Anne, Arabella) 

UK Case Study Participant Data can be found in table 17.

The interview results are organised by grouping inferential statements under relevant key questions, and detailing the interview responses. Not all respondents expressed views that led to each inferential statement, so where no opinion is provided it is not included in the analysis. Where participants had a positive view it meant they agreed with the inferred statement. A negative view indicated disagreement, while a mixed view reflected a mixed opinion. Inferential statements have (UK) after them in the table headings, to denote they are from the UK Case Study's. 

6.3.1.1 Key Question 1  
How do domestic residents think about their energy use?  

Collective action is important to use energy sustainably. 

The study found that the UK case study participants had disparate views on the effect of their energy use. However, nobody had a view indicating that the way they used energy would make no difference with regard to sustainability.
Table 31 Participants’ views on collective action (UK)

<table>
<thead>
<tr>
<th>Collective action is important</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
<td>4</td>
</tr>
<tr>
<td>2 : Negative View</td>
<td>0</td>
</tr>
<tr>
<td>3 : Positive View</td>
<td>2</td>
</tr>
</tbody>
</table>

One positive response suggests support for Kahneman’s line of argument that thinking heuristically is unhelpful with regard to energy use.

"I’d say I feel quite strongly. Well, I’d say I feel very strongly about everybody thinking carefully about where energy comes from" (Anne)

The mixed responses highlight the uncertainty that some people have with regard to the effect of their energy use.

"I don’t know. I suppose my individual energy use isn’t going to make much difference, to climate change. But, I do try and keep my energy use quite low, with climate change in mind. So yes, individually, not much difference, but probably if more people try to reduce it, then that would make a difference" (Jane)

"I think energy use can, but I also think that the fact that the climate is changing is a naturally occurring thing in the world as well" (Juliette)

6.3.1.2 Key Question 2

How does the form of energy residential consumers use appeal to their ideological, health or materialistic/economic consumer needs?

*It would be useful if we could choose the sustainability of energy supply to our home.*

Table 32 Participants’ views on choosing energy supplied to the home (UK)

<table>
<thead>
<tr>
<th>Useful if we could choose the energy we get supplied to our home</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
<td>1</td>
</tr>
<tr>
<td>2 : Negative View</td>
<td>0</td>
</tr>
<tr>
<td>3 : Positive View</td>
<td>3</td>
</tr>
</tbody>
</table>
One view on the ability to choose the type of energy we are supplied was mixed, again supporting Kahneman's view that many people think heuristically.

"I think for certain people it would be a better thing. But for people who are too busy and everything, or who feel so detached from that kind of information and knowledge. Also they don't see themselves getting to learn a few things, they're not interested, it would be a headache" (Arabella)

Other views were clearly positive towards the idea of being able to choose the form of energy we use, and lamented the fact that this is something that we cannot do at present.

"Well, because there are green tariffs, aren’t there? But as far as I can, as far as I know, if you pay for like a green tariff, you’re not getting lower, more, you’re not getting more electricity that’s powered by renewables, you’re just paying the company to invest in more renewables, aren’t you?" (Jane)

"Absolutely, but no-one actually ever told me where it comes from" (Wendy)

Waddams Price (2008) highlights the near impossibility of a consumer being able to choose power generated from a particular source, and have that power delivered to their home. This limits the range of incentives to use sustainable energy that can be offered to the residential sector.

6.3.1.3 Key Question 3
What impact has culture on energy use and can this be changed with education policy or through commercial/political marketing?

*Education is the most important thing in influencing energy use*

This research found that, although education is considered to have some value in terms of informing people of the consequences of using particular types of energy, this was not regarded as a motivating factor by all respondents in determining the impact on energy use.
A fairly jaundiced view was expressed by one respondent, who thought that changing residential energy behaviour was a difficult task.

"Possibly some adverts have some successful, I think in the past, at getting people to switch things off, and things like that. Kind of public education. I don’t know loads about that, to be honest. And in comparison to regulation and policy, well, what's the effect of regulation and policy?" (Jane)

Other views expressed were more positive.

"I think education has actually got a big part to play now" (Gwen)

"I think education has the power to transform cultures and lifestyles" (Arabella)

A mixed view made the point that the effect of education also depends on how long that effect lasts in terms of motivation.

"...I remember going around the house putting stickers up everywhere and doing it for a while and then, I don't know, you just get back into, like, the normal cycle again and it's so easy, isn't it, to not be careful of conserving energy?" (Anne)

**People are influenced by the culture around them**

It is almost axiomatic to assume that people are influenced by the culture around them, as culture is defined by the collective behaviour of a particular population. However, in this study, just over half the participants felt that they would not be affected by the behaviour of others.
Table 34 Participants’ views on cultural influence (UK)

<table>
<thead>
<tr>
<th>People are influenced by the culture around them</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
<td>1</td>
</tr>
<tr>
<td>2 : Negative View</td>
<td>3</td>
</tr>
<tr>
<td>3 : Positive View</td>
<td>3</td>
</tr>
</tbody>
</table>

There were positive views acknowledging the influence of culture on behaviour, once people are aware of what others around them are doing.

"...if somebody else has, like, done something successfully and it works, then you feel, you know, happier and more comfortable doing it yourself..." (Juliette)

Others did not believe they would be easily influenced by the behaviour of others with regard to energy use.

"I don't think I'm the kind of person that I can be influenced by others, like, I'm not, for example, recently one of my neighbours installed solar panels..." (Robert)

A mixed view made the point that with energy use the decision to follow what others do may be complex. For example, comparing your energy behaviour with that of others needs to take account of a lot of factors, not least the type of property one lives in.

"But I actually saw on TV, this advert from E.ON, where you can compare your energy use to your friends’, which I think is actually good, but then again, if you don’t live in the same type of property, it doesn’t really make sense to me" (Wendy)

**People’s attitude towards nuclear power**

The one negative opinion against using nuclear power derived from a cultural reluctance to use this kind of energy.

Table 35 Participants’ attitude to nuclear power (UK)

<table>
<thead>
<tr>
<th>What is your attitude to nuclear power</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
<td>3</td>
</tr>
<tr>
<td>2 : Negative View</td>
<td>1</td>
</tr>
<tr>
<td>3 : Positive View</td>
<td>3</td>
</tr>
</tbody>
</table>
"I'm against it........ Because it's fantastic all the nuclear power scientists and everything, yes, and how advanced we are now compared to the 80s. Well I remember Chernobyl very well. And then the other thing I have in my mind is a huge nuclear factory, yes, well, in the Philippines which never got to work because people... They did get together to say, no, to that. It did not work for a single day I think, yes" (Arabella)

Mixed views on nuclear power were unsure about safety, but generally accepted it as a necessary short term solution. There was an awareness that renewable energy cannot provide all our energy needs at present.

"I wouldn't be nervous about being near nuclear power, some people don't like the idea of it, but I don't necessarily see it as a hugely long term solution....." (Juliette)

"I'm not against nuclear power, I look at nuclear power as just an in-between solution, so you can't just say, like, switch to renewables overnight" (Wendy)

Positive views saw nuclear energy as a clean source of power with an acceptable level of risk.

"I think it's something that we need to accept as being one of the methods that we will be able to get energy and I think that's mainly down to the fact that so many people are against so many other methods, like coal powered stations due to the pollution element...." (Gwen)

"I think we need to invest in nuclear power, in the future, because we're not going to meet energy demand with renewables. But I don't think we should continue to invest in gas or fracking, so I support nuclear power, on the basis that, once built, it's low carbon, zero carbon" (Jane)

6.3.1.4 Key Question 4
How does more information on domestic energy consumption, such as smart meters which provide real-time information on energy use, automatically encourage greater energy efficiency or is it more complicated than this?

Differential Tariffs are a good Idea (where energy prices vary depending on time of day)

The idea of differential tariffs was mentioned, with positive support from a majority of respondents.
One mixed view was for the idea in principle, but envisaged some practical difficulties depending on the type of household.

"I think that's a good... it's a good scheme. And perhaps families cannot do that. I don't have a family but perhaps it's too difficult to change your schedule when you're in a house with a family, with many kids and all, and different schedules" (Arabella)

Positive views saw the benefits of differential tariffs for those who had the flexibility to make use of them.

"I think the most significant change that you could bring is, like, you know, the time-zoning tariffs, like when they make the consumers, like, I don't know, use the washing machine at certain times....." (Wendy)

"Oh yes, differential pricing. I think that's a good one. I think, yes, I think if, for example, I've got the luxury of having flexible working hours so I can do my washing in the day time and if I knew it might be cheaper..." (Anne)

The one negative view expressed emphasised thermal comfort and overall lifestyle satisfaction as more important than being influenced to change behaviour around energy use.

"The only way that I can change my behaviour is to reduce the temperature during the time that I'm home, but I really don't bother to do that because I feel like I'm only at home for a few hours, I'd like to be warm and feeling good because it gives me, I don't know, more satisfaction, maybe, with my life" (Robert)

**Smart meters are useful**

There was some agreement that smart meters were a useful device to provide more information on energy use, and nobody felt negative about them.
Table 37 Participants’ views on smart meters (UK)

<table>
<thead>
<tr>
<th></th>
<th>Smart meters are useful</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Mixed View</td>
<td>4</td>
</tr>
<tr>
<td>2: Negative View</td>
<td>0</td>
</tr>
<tr>
<td>3: Positive View</td>
<td>3</td>
</tr>
</tbody>
</table>

Mixed views were possibly more to do with the respondent's circumstances rather than the feeling that more information of itself was a major determinant of energy use.

"It could maybe influence it a bit. I couldn’t do that much to reduce my electricity use in the house, because I don’t have many electrical appliances" (Jane)

"I think 50% it can, for example, when I moved to the new house, before that I didn't have a smart meter in my previous house, and when I came to this house, so when I have different equipment or different types of lighting on, I can see that on the smart meter, and if I feel, well, now I know what sort of equipment uses a lot of energy" (Robert)

Positive views emphasised the value of awareness around energy use.

"I think if we had a smart meter that would really help just to see what's going on...." (Anne)

"I would be very interested to see how much I use, definitely, because I want to know how much I use" (Wendy)

6.3.1.5 Key Question 5
How important, or possible is it, for domestic consumers to measure their energy use in all energy related activity (so they can be aware of technology efficiency rebound effects)?

People don’t think rationally about their energy use

Rational thinking from the point of view of people like Thaler (1994) and Kahneman (2011) can be difficult from the point of view of using energy sustainability in the home. This is because energy is a derived demand, and not used for itself per se.

The probability of potential actions taken today having a detrimental impact on the future is hard to gauge, especially if one agrees with Kahneman and people look at
potential values of outcomes rather than probabilities, or as Thaler suggests, make heuristic decisions with short-term utility.

Although the UK case study participants were not asked directly how rational their thought process was with regard to sustainable energy use, responses to interview questions hinted at heuristic behaviour.

Table 38 Participants’ views on rational thinking (UK)

<table>
<thead>
<tr>
<th>People don’t think that rationally</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>2 : Negative View</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>3 : Positive View</td>
</tr>
</tbody>
</table>

One positive view in the table above tracks responses that indicate awareness of irrational behaviour around energy use.

"But people don't think that rationally, that's the problem as well. I mean, they don't think of... many of them don't think of long-term savings, so even if you give them something that they know they're going to make a return, like monetary return, in, I don't know, like a year or two years, some of the people, I don't know why, but they plan, like, short term, saying, okay, this is what I'm going to do now, this is what I'm going to do in one or two months – it's never, like, years" (Wendy)

Other views implied unconscious irrationality.

"I'd say I feel quite strongly. Well, I'd say I feel very strongly about everybody thinking carefully about where energy comes from but I haven't switched to a renewable energy company partly because I think we all have to do this together........." (Anne)

"It makes a difference when I think about the environment and how humanity has an impact on the environment. Like, yes, in sourcing the energy that we use and what implications it has in nature and things like that. So I would rather it came from a sustainable place... source, but it wouldn't change my energy use" (Arabella)

"I must admit when I switch the light switch on, I don’t think, oh, this is coming from the power station that’s X miles away. I just think I need the light on, it’s dark" (Gwen)

6.3.1.6 Key Question 6
How responsible do domestic consumers feel for their efficient use of energy?
The government should nudge us in the right direction

Table 39 Participants' views on the government's Nudge role (UK)

<table>
<thead>
<tr>
<th>The government should nudge us in the right direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>3 : Positive View</td>
</tr>
</tbody>
</table>

In discussing the work of Thaler in the literature review, routine biases in decision-making can be to some degree considered a function of local culture (and many other reasons as described in section 3.6.7). However, culture is a pattern of behaviour and a way of thinking that develops over time. There can be no doubt that government has an influence over culture. The "think before you drink before you drive" campaign in 1977 involving significant advertising, along with a lowering of the alcohol threshold at which one could legally drive, had a significant impact on behaviour.

However, while interview comments were generally positive as to the role the government could have in influencing energy use, one mixed view pointed out the complexities in this area.

"Yes, but like to me this is the thing. There's so many other factors that could influence how much people use. It depends what kind of job you're in. It depends if you've got any disabilities or health things that may actually contribute to you having to heat your home certain ways, or it might mean that you don't use... you can't drive, so you use public transport, all these kinds of things, and there's so many factors that will differ so much between everybody......" (Gwen)

Other views clearly welcomed government or large organisation involvement in influencing energy use.

"I think, the government should look after that and should, kind of, they should think of how they can prevent people to, you know, use a lot of energy" (Robert)

"If we don't start looking into efficient uses of energy production now it's going to get too late, the sooner you do it the more refined that technology can become and we're living in a society where we've got the capability of designers and engineers to be able to come up with alternative solutions nowadays" (Juliette)
**Government regulation is important in residential energy use**

Regulation was also considered by most respondents an important part of influencing energy use.

<table>
<thead>
<tr>
<th>Government regulation is important in residential energy use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
</tr>
<tr>
<td>2 : Negative View</td>
</tr>
<tr>
<td>3 : Positive View</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
<td>0</td>
</tr>
<tr>
<td>2 : Negative View</td>
<td>1</td>
</tr>
<tr>
<td>3 : Positive View</td>
<td>4</td>
</tr>
</tbody>
</table>

However, one negative view regarding regulation was targeted towards energy providers rather than the residential sector.

"I think to me anyway the regulation’s more focused towards actual energy providers, not the end consumer. I mean, I might be wrong in how I think about it in that way but to me it’s the regulations are more put on those providers, they’re meeting certain targets and everything like that. It’s not as if a householder is like you have this target of energy use or you have this target of kind of having a certain amount of energy efficiency in your house, so to me I don’t think that the regulations impact my own energy use in my house because to me it feels as if that’s more provider focused" (Gwen)

Positive views highlighted the importance of government regulation.

"I think there should be more government schemes to improve efficiency of homes, there should be more money put into that. So I think, government is partly responsible (Jane)

"I think if you are choosing someone it's government because they choose how they want society to be..........." (Juliette)

**Population and energy**

Only one person thought that the world’s forecast population peak of around 9 billion would not be a problem with regard to sustainable energy supply.
Table 41 Participants’ views on population and energy (UK)

<table>
<thead>
<tr>
<th>View</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Mixed View</td>
<td>2</td>
</tr>
<tr>
<td>2: Negative View</td>
<td>4</td>
</tr>
<tr>
<td>3: Positive View</td>
<td>1</td>
</tr>
</tbody>
</table>

"Generally I don't think of that as a problem, I don't know, China has billions and they still survive, you know. I don't think that will be a problem." (Robert)

Some views were uncertain as to the effect of population growth on our energy use.

"I don't know, it's a very difficult concept. I mean, in China, they had this birth control, and it's very interesting, because they limited the number of children, and it's like, only one" (Wendy)

However, the majority view was that population growth presented a major problem.

"If you look at what's happening we know that we are going to run out of coal and we know that that is causing pollution, just because other people do it doesn't make it sensible, and, you know, if we don't start looking into efficient uses of energy production now it's going to get too late" (Juliette)

"And you would think that these countries, when they get together, are getting to showcase the best practice examples of certain countries; what worked. And they would like to take it home, especially the ones that have the problem of booming populations. Take it home and, especially if they are newly developed countries, they still have a big chance to make an impact now at an early stage. Well if that does not happen... it does not, well, we don't really have a chance" (Arabella)

6.3.1.7 Key Question 7

How could financial incentives be devised to make a difference? Even without any special financial incentives cost is a major factor in determining energy use.

*Financial situation is the driver behind energy use*
Table 42 Participants’ views on finance as an imperative (UK)

<table>
<thead>
<tr>
<th>Financial situation is the driver behind energy use</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
<td>1</td>
</tr>
<tr>
<td>2 : Negative View</td>
<td>1</td>
</tr>
<tr>
<td>3 : Positive View</td>
<td>3</td>
</tr>
</tbody>
</table>

"...last year I moved to a house which I have to pay for the bills myself and since the first bill I received I felt that it's high, so now I'm thinking more about how to reduce energy in my house and, you know, not to heat my house all the time...." (Robert)

"Yes. It’s really to do with money. Money’s a lot more important than how much energy use I’m using" (Jane)

"Financial incentive is massive because a lot of education is often in terms of wastefulness, but it's also a wastefulness of money, so I'm more incentivised at the moment by me not having to pay big bills" (Juliette)

However, thermal comfort is also an important factor.

"I will put the heating up if need be, but I think I’d tend to kind of... it’s probably more money and comfort that’s the drivers to how I use it" (Gwen)

And some people feel energy should be used frugally regardless of cost.

"I don't pay the bills, it's included in the rent. So I could have it at 25 degrees all the time. But at night when I forget to turn off the boiler, ........., and it goes on running from, like, 12 until I wake up at seven or eight or nine, I feel bad in the morning. Going, like, damn it, that was, like, eight or nine hours of what? " (Arabella)

Attitudes to the Green Deal

Table 43 Participants’ attitude to the Green Deal (UK)

<table>
<thead>
<tr>
<th>What is your attitude to the Green Deal</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
<td>3</td>
</tr>
<tr>
<td>2 : Negative View</td>
<td>3</td>
</tr>
<tr>
<td>3 : Positive View</td>
<td>1</td>
</tr>
</tbody>
</table>
The green deal (see section 3.5.2), which is the government's flagship policy to encourage residential energy users to use more sustainable forms of energy and/or use energy more efficiently, was broadly not viewed as a positive measure by the UK interview respondents.

Even the positive view expressed depended on the assumption that predicted savings would be made.

"If I had an old house which was very leaky and I had to spend a lot of money, then I would definitely go for that, because I think that's a brilliant idea if it works, if the savings are as predicted" (Robert)

Mixed viewpoints thought the Green Deal was a good idea in principle, but that various parameters were unclear or posed a potential issue.

"I think, as an idea I think it's very good, in terms of, like, removing the upfront costs, and people not having to pay upfront for, like, energy-efficient measures, but then again, I think it comes with a lot of barriers. Like, I joined a Green Deal discussion group, and even the people who are supposed to be, like, the energy advisors, they are still not kind of clear about what they need to do......" (Wendy)

"I think it was a good idea and I can see why it seems like a good plan. I just think having the high interest rates has put people off entirely because the people I've spoken to have said it would be cheaper remortgage the house and that's actually what they're going to do or it would be cheaper to borrow from elsewhere" (Anne)

Negative viewpoints seemed to be motivated by the financial cost, even though the essence of the Green Deal as an idea is that the cost of energy improvements is less than the resultant net savings. This does not necessarily imply mistrust of Green Deal assessments, but signifies people's desire to get a competitive deal.

"No. The Green Deal, to me it was... I feel as if it was a good attempt by a government to actually finally realise that they need to actually invest a lot more in improving the UK building stock but it's completely structured wrong in my eyes. I mean the fact that it's cheaper for someone to re-mortgage their house to get these improvements than using a Green Deal finance deal just to me is ridiculous" (Gwen)

"If I had my own house, probably not.......I don’t have any savings, and at the moment, I don’t know what the rate of the loan is, but it’s not that low is it? If I get a loan........ I would be better, probably, borrowing money, either from family or... yes. Or I could maybe get a low interest loan" (Jane)
"I don't know enough about it....... there's a loan but if there's lots of interest, well, you know, people haven't got money to be paying all of that" (Juliette)

An interesting point is that people are equally (quite rationally) positively motivated by a financially good deal. The researcher advised Juliette of a temporary cash back scheme run by the government, where there was a subsidy of around £6000 on a £9000 solid wall installation. Juliette took up this offer, which made strong financial sense with a significantly positive net present value over the projected lifetime of the installation. The scheme, designed to encourage take up of the Green Deal, was clearly popular as it was discontinued after a few months when allocated funding was depleted.

Some of the negative points associated with the Green Deal, such as long term debt attached to a Green Deal property (Juliette felt she could easily pay off her £2000 Green Deal debt in the event she wished to sell her house) and the concern that projected savings would not materialise, were not barriers in Juliette's case.

A personal carbon allowance

Table 44 Participants' views on a personal carbon allowance (UK)

<table>
<thead>
<tr>
<th>How would you feel about being given a personal carbon allowance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
</tr>
<tr>
<td>2 : Negative View</td>
</tr>
<tr>
<td>3 : Positive View</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>3</td>
</tr>
</tbody>
</table>

Positive perspectives on a personal carbon allowance liked the fact that such a scheme would raise personal awareness with regard to fossil fuel use.

"Yes, I think it's a great idea actually and I think, say, for example, you had so many carbon credits and after you'd use those carbon became more expensive, I think that would be great" (Anne)

Mixed viewpoints could perceive the potential benefits of carbon credits, but worried about the fairness in which such a scheme might be implemented.
"It might be the way forward, but it's a bit like, who is the person who's going to tell me how much I can have, you know? It's a bit like a restriction" (Wendy)

A negative view felt strongly that it was too like a tax, and that people should be encouraged in a more positive way to use energy sustainably.

"No, because I don't think that that'll solve it, I just, I feel very strongly that it's like tax, that is not the way to do it, there's ways of getting things done and one is carrot and one is stick, and people do not respond well to the stick approach of you can only have so much and if not you're penalised, you have to pay lots, I don't think that that's the way to get people to do it" (Juliette)

A tax on carbon emissions

Views were quite evenly spread on the pros and cons of a carbon tax.

Table 45 Participants’ views on a carbon tax (UK)

<table>
<thead>
<tr>
<th>Would you be prepared to pay a carbon tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>2 : Negative View</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3 : Positive View</td>
</tr>
<tr>
<td>2</td>
</tr>
</tbody>
</table>

One mixed view felt that such a tax would have to be clearly justified.

"I don't know. I think it would need to be... I think the Government would need to justify it really clearly to everybody" (Gwen)

The potential amount of such a tax was also an issue.

"It depends on how... if it's 10%, I think that's a lot" (Wendy)

Negative views were basically resistant to any extra taxes.

"I hate any kind of tax so I really don't want to have that, why should I have that?" (Robert)

Positive views were happy with a carbon tax, provided it was fair.

"Yes. I guess, however much money you have that's going to be spent on energy-consuming ways in one way or another because everything pretty much consumes energy somehow so, yes, I do think that's quite a good idea if it's fair" (Anne)
There will be further discussion of financial incentives in the discussion section 6.5.1. A summary in table 46 of UK Case Study participant responses is shown below.

Table 46 UK Case Studies*

<table>
<thead>
<tr>
<th>Inferred Statement</th>
<th>Mixed View</th>
<th>Negative view</th>
<th>Positive View</th>
<th>Balance of view</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collective action is important</td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>Uncertain</td>
</tr>
<tr>
<td>Useful if we could choose the energy we get supplied to our home</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>Positive</td>
</tr>
<tr>
<td>Education is the most important thing</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>Uncertain</td>
</tr>
<tr>
<td>People are influenced by the culture around them</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>Uncertain</td>
</tr>
<tr>
<td>What is your attitude to nuclear power</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>Uncertain</td>
</tr>
<tr>
<td>Differential tariffs are a good idea</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>Uncertain</td>
</tr>
<tr>
<td>Smart meters are useful</td>
<td>4</td>
<td>0</td>
<td>3</td>
<td>Uncertain</td>
</tr>
<tr>
<td>People don’t think that rationally</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>Positive</td>
</tr>
<tr>
<td>The government should nudge us in the right direction</td>
<td>1</td>
<td>0</td>
<td>4</td>
<td>Positive</td>
</tr>
<tr>
<td>Government regulation is important in residential energy use</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>Positive</td>
</tr>
<tr>
<td>What is your view on population and energy (bad effects)</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>Negative</td>
</tr>
<tr>
<td>Financial situation is the driver behind energy use</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>Positive</td>
</tr>
<tr>
<td>What is your attitude to the Green Deal</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>Uncertain</td>
</tr>
<tr>
<td>How would you feel about being given a personal carbon allowance</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>Uncertain</td>
</tr>
<tr>
<td>Would you be prepared to pay a carbon tax</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>Uncertain</td>
</tr>
</tbody>
</table>
* Positive views agreed with the inferred statement, Negative views disagreed with the inferred statement, Uncertain views were mixed. This applies to all other groups in the study.

Participants all generally agreed that people don't necessarily think rationally, government regulation was important, finance was a key driver to energy use and that attitudes to the Green Deal were negative or mixed.

### 6.3.2 Other UK Stakeholders

Other UK stakeholder observations comprise UK Landlord, Environmental Group, Government and Energy Company views. A summary of the other UK stakeholders is set out in tables 18 and 19.

For the other UK stakeholders the key questions still formed the basis behind the actual interview questions. To that extent most of the questions were the same, but with one or two variations.

The environmental group representative was asked about the rebound effect and its potential influence on policy.

In addition to the other questions, the energy company representatives were asked about their longer term plans to produce more renewable energy and what effect this might have on their profits.

The government representative was the only person who was too busy to do a face-to-face interview, so she asked the researcher to submit the four most important questions he had to her in writing. She was also asked about the rebound effect and its influence on policy.

Landlords were effectively asked the same questions as the UK case studies, but from the landlord's point of view.

All the groups in section 6.3.2 were asked what were the key things they could to in their own particular role to influence domestic energy use.
Again the interview results are organised by grouping inferential statements under relevant key questions, and detailing the interview responses. Inferential statements have (OUK) after them in the table headings, to denote they are from the Other UK Stakeholders.

6.3.2.1 Key Question 1
How do domestic residents think about their energy use?

Collective action is important to use energy sustainably

Respondents thought that collective action was important in changing energy behaviour and that this was driven by individual responsibility.

Table 47 Participants’ views on collective action (OUK)

<table>
<thead>
<tr>
<th>Collective action is important</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
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<tr>
<td>2 : Negative view</td>
</tr>
<tr>
<td>3 : Positive view</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>0</td>
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<tr>
<td>6</td>
</tr>
</tbody>
</table>

A mixed view was positive but with some reservation about how long it would take to effect change.

"So you have to lead by example. And what we do will eventually make an impact in two years’, five years’, ten years’, 20, 30 years’ time, but change has to start somewhere, however small" (Mike)

Positive views were less concerned about length of time and focussed on individual motivation.

"It is small, but if everybody has that attitude, then, you know, we're not going to improve on that, are we? So everybody's got to do their bit, yes" (Ava)

"I firmly believe, that as a collective, individuals can make a big difference to climate change in actions that they take every day" (Pauline)
"I've replaced LEDs and stuff but the amount of energy I've saved for me is quite a lot but in terms of contribution to climate change, nothing. But it's a bit like -- I was listening in the car this morning to a radio program about voting and the debate was what difference does your individual vote make? And individually, it probably doesn't make a lot of difference but it doesn't mean you shouldn't vote because collectively, it makes a huge difference and that was kind of the fundamental problem with solving climate change is that on an individual basis, it's quite hard to see the difference that you make. But when there's however many billion individuals, it makes all the difference" (James)

Daryl agreed with his colleague, and focused on the effect of combined collective action in making a difference in climate change. He also pointed out the effective leadership in influencing cultural change.

"Clearly the UK as an island has a very limited impact really on climate change, but UK is part of the European Union and the European Union as a whole is a much bigger block, and therefore there is greater potential if it can actually get its act together and take steps to reduce its carbon emissions, then one, it's going to make a bigger difference in world terms firstly but secondly, it's showing leadership to the rest of the world ......" (Daryl)

6.3.2.2 Key Question 2
How does the form of energy residential consumers use appeal to their ideological, health or materialistic/economic consumer needs?

It would be useful if we could choose the sustainability of energy supply to our home

Two of the UK Landlords interviewed felt some choice over type of energy supply was important. However, at least part of the reason behind this view was cost.

| Table 48 Participants’ views on choosing energy supplied to the home (OUK) |
|-----------------------------------------------|--------|
| Useful if we could choose the energy we get supplied to our home | 3 |
| 1 : Mixed view | 0 |
| 2 : Negative view | 0 |
| 3 : Positive view | 3 |

"I've had a few tenants complain ..... where the energy prices have been high ..... Most apartments are electric. You do get ones that are both but these are just electric and the heating is from storage heaters and conventional electric heaters, so obviously they are generally a bit more costly to run than the gas equivalent" (Patrick)
The respondent from the environmental group was more interested in being aware of the sustainability of energy supply.

"The problem is there’s a big disconnect between you switching the lights on and you understanding that somewhere, maybe 60 miles away, it’s, like, you know, churning out loads of smoke" (Pauline)

6.3.2.3 Key Question 3
What impact has culture on energy use and can this be changed with education policy or through commercial/political marketing?

*Education is the most important thing in influencing energy use*

The role of education was not regarded as predominantly important by a majority of respondents, partly because it was viewed as less effective than other motivating factors.

<table>
<thead>
<tr>
<th></th>
<th>Education is the most important thing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
<td>5</td>
</tr>
<tr>
<td>2 : Negative view</td>
<td>0</td>
</tr>
<tr>
<td>3 : Positive view</td>
<td>2</td>
</tr>
</tbody>
</table>

Mixed views didn't see education as a big enough driver to make many people care enough about energy.

"Tenants are concentrated on the cost of the rent, but if they realised that their energy bills were considerably lower then, you know... most tenants have a choice over property, so you’d pick the cheapest, wouldn’t you, one, on top of their green credentials" (Mike)

"Unfortunately I think education doesn’t rank as high as regulation or financial incentives, because where we are at the moment energy isn’t something people care about and talk a lot. We see a lot about energy bills, but then again people don’t really understand how energy use and energy bills tally up and how they can take control of that" (Pauline)

"So, providing information to customers is very important, so at least they have an opportunity to make an informed decision. It doesn't mean to say they’re actually act on it but nevertheless, that education is a first step I think on the way" (Daryl)
Positive views regard education as having a measured influence over culture.

"If you go back, sort of, ten or fifteen years ago when I was a kid, with energy-saving and all that, all right, yes, it was good to do it, it’s always been good to save, but you never used to talk about it. You used to get a lot more rubbish dumped everywhere back then and I think the whole world is shifting, or the whole country is sort of shifting" (Patrick)

**People are influenced by the culture around them**

The influence of culture is less straightforward around energy than perhaps it may be around other societal elements.

<table>
<thead>
<tr>
<th>People are influenced by the culture around them</th>
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</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
<td>2</td>
</tr>
<tr>
<td>2 : Negative view</td>
<td>1</td>
</tr>
<tr>
<td>3 : Positive view</td>
<td>4</td>
</tr>
</tbody>
</table>

A mixed view pointed out that it may not be obvious what people are actually doing regarding their energy use. Within the household sustainability may be hard to see.

"Well, most... a lot of research points to the fact that people do learn... are very influenced by social learning and what their neighbours might do or what people might do in the near vicinity. With energy it’s quite difficult, because actually how do you know what your neighbours are doing, unless you physically see them putting solar panels on a roof or having some kind of insulation put in and you all happen to be there and you get talking" (Pauline)

Daryl felt that energy companies incentives to influence culture needed to go further.

"So the whole intention, as you're fully aware of then is to say, am I doing better or worse than my peers? And to try and provide you with some tips to help save energy. So, I think that has some potential, if I'm being honest I think more -- we need much more than that" (Daryl)

Interestingly, a negative view held that energy delivery could affect the environmental social climate. In essence the complaint is similar to why many people are against wind farms, as they impact on the contended natural beauty of a precinct.
"For me, I’m a very aesthetic person. I like things to look nice, and it’s always bothered me how houses look really ugly when their roof is covered in solar panels. So if I was living in the street and someone had solar panels, I’d really be praying they’d put them on the back of the house instead of the front of the house" (Mike)

One positive view felt ideological drivers played a part.

"I mean, you shouldn’t base it all on the money; it’s nice to think that you’re being green. I suppose as time moves on and more and more of these get made, hopefully the price will come down on these alternative things and people will start adopting more of them" (Patrick)

A politicians view valued a positive culture around energy, but regarded it as more achievable through positive incentives (subsidies rather than taxes).

"If we are looking at a carrot and stick approach then, as a rule, I prefer the carrot ie. to incentivise better behaviour rather than to penalise people. Over time I think that is likely to change behaviour in a more sustainable way" (Alice)

Another energy company viewpoint was positive as to the effect of education on changing culture over time.

"Yeah. And that's why I do think you have to dangle some strong carrots to really get people to change their behaviours. Now overtime -- and that's where I think education has a key role to play, the future generation will see things differently" (James)

**People’s attitude towards nuclear power**

The political respondent was only able to take a limited number of questions so her complete views on all questions could not be established, however as she is a member of government it can be assumed she is not against nuclear power.

<table>
<thead>
<tr>
<th>Attitude to nuclear power</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
<td>3</td>
</tr>
<tr>
<td>2 : Negative view</td>
<td>1</td>
</tr>
<tr>
<td>3 : Positive view</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 51 Participants' attitude on nuclear power (OUK)

Of the remaining respondents, views were varied.
Two mixed views (both landlords) had concerns because they felt insufficiently informed.

"I don't know that much about it. All I've ever discussed, ....... there is still an amount of usability left in the old blocks of power they get rid of. If you could find a way of utilising that, I think, yes, I'm all for it - if they could find an efficient, safe way of dealing with it" (Patrick)

"I don't know enough about it really, but I just think, you know, you hear nuclear power, and you quite often want to steer clear of it" (Ava)

Another mixed view from an energy company executive, felt there were dangers around using nuclear power, but they were probably less harmful than the effect of fossil fuels on climate change.

"I think I describe myself as kind of agnostic. So I kind of think with nuclear there is a big unknown risk. It's not -- this is not a known that there's a -- you know, you've got the waste, how long do you have to keep it for? What problem is that going to cause in the future? There is a potential environmental risk which could be significant. Yet, with fossil fuels, there is known environmental risk which is also significant. So I guess that kind of pushes me slightly in favour of nuclear because I know there is a problem with fossil. And it's probably worse than the problem with nuclear, but there is -- nuclear is still -- I watched a program once which talked about the construction of the waste site in Finland and they were talking about how they were having to construct this sort of cavern so that it could hold the waste for thousands of years. And they were talking about putting signs up in case civilisation was wiped out so the next (inaudible 01:05:19) should realise there was something there. You just think, that inherently cuts out like a bad thing to do, but the alternative -- if the alternative is fossil fuels then that's probably worse" (James)

A negative view (perhaps unsurprisingly) came from the environmental group participant. Her objections were on both safety and cost grounds.

"Well, I'm not... on a personal level I'm not an absolute fan of nuclear power, mainly because we just end up with a whole bunch of waste that we still, you know... gosh, how long has nuclear power been around, a long time and we still haven't figured out what to do with it. ....... I think one of the things about nuclear power that really offends me is that it's so expensive and, you know, the powers that be just don't want to acknowledge how expensive it is. And it offends me on a social level when I think about people struggling to pay their energy bills" (Pauline)
A positive view felt radiation risk could be dealt with, and used the analogy of a plethora of other potentially harmful sources of radiation.

"Well, no, I mean, when you talk about natural radiation and you think about the amount... how often people fly. And you think about how many X-Ray machines we've got worldwide, you know, we're never ever a few miles away from an X-Ray machine or... so that would be my only caution, but you've got cautions and negatives with everything. So nuclear is the way forward, isn't it, really?" (Mike)

Another positive view was realistic about the limitation of renewable energy to provide the U.K.'s total energy requirements.

"It's all part of the way to address climate change. I think there's a range of technologies and solutions required to get us on the path to 80 percent decarbonisation by 2050. So nuclear has a role to play, renewables has a role to play, demand reduction has a role to play" (Daryl)

6.3.2.4 Key Question 4
How does more information on domestic energy consumption, such as smart meters which provide real-time information on energy use, automatically encourage greater energy efficiency or is it more complicated than this?

**Difference Tariffs are a good Idea**

There were diverging views on differential tariffs.

Table 52 Participants' views on differential tariffs (OUK)

<table>
<thead>
<tr>
<th>Differential tariffs are a good idea</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
<td>1</td>
</tr>
<tr>
<td>2 : Negative view</td>
<td>1</td>
</tr>
<tr>
<td>3 : Positive view</td>
<td>3</td>
</tr>
</tbody>
</table>

A mixed view saw them as useful when allied with smart meters.
"I think smart meters are interesting. I think they have the potential to make a big difference, but that is only if they’re really linked to things like maybe time of use tariffs and having, you know, have lots of different kit in your house like smart controls - that’s the word I’m looking for – you know, especially when we move to a grid that’s maybe more reliable on... reliant on variability in systems, like wind, all that" (Pauline)

A negative view felt that in practice, for a variety of reasons people would find it hard to change their routine.

"I’m not that comfortable, actually. I don’t know why. I’m like... every... that surge is part of human life. How do you stop that surge? And how... yes, you can charge people more, but are they going to stop heating at that time, putting the telly on at that time, having a shower at that time?" (Mike)

One positive view was a result of already using a dual rate tariff.

"IV Yes and I suppose electric heating that’s not storage would be way too expensive, wouldn’t it, because you’re using peak rates. So I suppose there’s dual rate electricity in your properties?

Yes, there is, it's more economical" (Patrick)

Another positive view looked at the advantage of using new technologies to combine with differential tariffs.

"That's only the start of the journey that should lead to the harnessing of smart technologies, including appliances, including other things. So you could see, hypothetically in years to come an energy supplier providing you with -- well, to take advantage of tariff, we're going to give you for free this kind of product, like a dishwasher and then we're going to use that to manage how much we need to purchase energy from the marketplace" (Daryl)

**Smart meters are useful**

The information provided by smart meters was seen as attractive by most respondents.
Table 53 Participants’ views on smart meters (OUK)

<table>
<thead>
<tr>
<th>View</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed view</td>
<td>1</td>
</tr>
<tr>
<td>Negative view</td>
<td>0</td>
</tr>
<tr>
<td>Positive view</td>
<td>6</td>
</tr>
</tbody>
</table>

Again, one respondent strongly linked their usefulness to differential tariffs.

"Actually if you had smart meters, really properly smart meters, with smart controls in the house you could set it all up whereby someone would say, okay, when the price of energy drops to this level, yes, I want you to turn the washing machine on. You know, you could really have some great stuff going on there" (Pauline)

Others valued how awareness of energy use confers an element of control.

"It is to be hoped that new technology will mean we use less energy and lower our carbon emissions. The rollout of smart meters, for example, will help people control their energy use" (Alice)

"I think it does train you. We did try one of those energy monitors. I can’t remember if it came from one of the energy providers or is it one we bought from Argos or somewhere and basically, you plug it in and you just key in the details of your tariff and your provider and it shows how much per hour you’re using the meter or something on and yes, when I think you actually see it in black and white in front of you, it does make you more aware. It almost becomes like a game, you want to keep that figure down as low as you can, within reason, I mean, obviously you’ve got to keep your lights on and things" (Patrick)

"And my personal view is the role of smart metering and having real-time data in a very user-friendly format which could also be on your tablet or mobile phone, app type stuff. Having that information I think and that prompt may help certain customers that want to be engaged in this market to make those key decisions. And without that information, they're kind of powerless, so it's quite hard to say, "Well, why isn't the customer making the decisions?" They need the information in the first place to be able for them to decide, "What do I want to do? How can I save energy? What are my options? Is it hardware? Is it software? What is it?" (Daryl)

A mixed view saw the scale of savings as important.
"So, I think the comparison is a good thing to have but ultimately the motivation is to save cost. And if a customer saw that they were using more energy but then if that only cost them an extra 10 quid a year, they might not care" (James)

6.3.2.5 Key Question 5
How important, or possible is it, for domestic consumers to measure their energy use in all energy related activity (so they can be aware of technology efficiency rebound effects)?

The rebound effect is important

It was interesting, to assess views on the rebound effect by the energy company, environmental group and the politician, all of which were mixed.

Table 54 Participants’ views on the rebound effect (OUK)

<table>
<thead>
<tr>
<th>1 : Mixed view</th>
<th>2 : Negative view</th>
<th>3 : Positive view</th>
</tr>
</thead>
<tbody>
<tr>
<td>The rebound effect is important with regard to policy.</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

One mixed view accepted the rebound effect, but thought that efficiency measures should still be done in tandem.

"I think so the rebound effect is almost -- there's almost two elements of it. There's the -- if I fit LED lightbulbs, my electricity use at home on average is going to be lower. I don't think I'm going to rebound in my electricity use, but the extra money that I save I might go on a holiday. Or I might buy something that comes from a factory which has lots of gasses or something. So I think you kind of have to unpick those two elements of the rebound effect and as I say, that to me is just - I don’t think doing green deal now you undermine the benefits necessarily. It just means you have to do the two in tandem" (James)

Another mixed view felt that the rebound effect was complex and could not straightforwardly be correlated with energy efficiency.

"With regards to the rebound effect there’s still loads to be understood about it. So, for example, I could change jobs and I could buy a new more efficient car. And my new job could be further away than here, so therefore I would be driving more. But actually I’d only be
driving more, because actually I could afford to go and do that new job, because my car was more efficient. So I’m not driving more because of my more efficient car, I’m driving more because I need to go to that job. Does that make sense? So it’s what bits are genuinely a rebound based on a saving made or actually you were going to do it anyway" (Pauline)

Other mixed views looked at the economic effects of the rebound effect, and felt that it should be a consideration with regard to policy.

"So a crude way of putting that is if you cut people's energy bills, you make them richer. If you make them richer, that's economic growth which could lead to more carbon emissions which kind of is logical and you can't really argue with it, but then if you rephrase that as you make people richer, surely that's not a bad thing" (Daryl)

The political response ignored the possibility that an individual might shift energy demand from one part of their life to another, given the possibility to do so.

"It is not necessarily clear that energy efficiency leads to increased growth, and the ‘rebound effect’ is a widely recognised effect. For instance, if a person in fuel poverty has a more efficient boiler fitted, the person may then turn up the heating. But improving energy efficiency does deliver more outputs for the same carbon emissions, or the same outputs for lower carbon emissions" (Alice)

**People don't think rationally about their energy use**

Again, to assess heuristic behaviour (fast thinking Kahneman style or cognitive bias Thaler style) responses were considered for their implications in this respect.

**Table 55 Participants’ views on rational thinking (OUK)**

<table>
<thead>
<tr>
<th>People don't think that rationally</th>
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</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
</tr>
<tr>
<td>2 : Negative view</td>
</tr>
<tr>
<td>3 : Positive view</td>
</tr>
</tbody>
</table>

Careful thought does not seem to be given to energy use by either landlords or their tenants.
"I would have thought the tenants would be the same however every time I’ve shown a tenant around and I’ve given them the EPC Certificate, and then there are lots of people who have looked at it and gone out and thought, well, whatever. I don’t think it registers with a lot of people what it is yet but I suppose we’re still in the early days yet" (Patrick)

"I suppose the priority is convenience, second is cost, third is green. Having said that, in terms of cost .....I would pay a little bit more if it was greener, but not a lot more, and over convenience I’d do my best to use a supplier, provider, that was greener, but I wouldn’t inconvenience myself, for example moving into a new house, waiting an extra week or two weeks for a green supplier to connect heat. I’d go non-green just for selfishness" (Mike)

A more rational political way to think about the Green Deal would to admit that it is not working very well.

"Working to change the way we think and use energy is critical and Green Deal and other schemes play an important part in that" (Alice)

An environmental group perspective admitted that motivating people to think more carefully around energy was difficult.

"If you’re just someone who’s just plodding along and you just pay a direct debit every month and you don’t really think about it, it’s probably... Well, it’s not; we know it’s not making a big difference, it might... Every 10% rise in energy costs you might get a 1% improvement in energy efficiency or something like that. It’s really... you’d have to see energy prices soar before, you know, the middle England bit and all others change their ways with the cost of energy" (Pauline)

An energy company point of view felt that their customers were not particularly rational when it came to using energy.

"Personally, they're pretty irrational really. All they think about I think is they'd say, "I just want my engine when I want it to power whatever or heat whatever I want." And they come back to -- it's very pricing elastic really. There's no correlation between what I'm paying and what I'm demanding. And that's the problem and I think that's where again, things like smart meters and the catalyst that it can provide can only be a good thing and hopefully over time, it's a slow burn but over time, we'd start to change that. But at the moment, many, many, many customers are very irrational I think" (Daryl)
6.3.2.6 Key Question 6
How responsible do domestic consumers feel about their efficient use of energy?

The government should nudge us in the right direction

There were a multiple viewpoints around this inferred statement. However, most viewpoints felt that government had a role to play in influencing positive behaviour.

Table 56 Participants’ views on the government’s Nudge role (OUG)

<table>
<thead>
<tr>
<th>The government should nudge us in the right direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
</tr>
<tr>
<td>2 : Negative view</td>
</tr>
<tr>
<td>3 : Positive view</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

A political view naturally considered the role of government and quasi government bodies important.

"Working with bodies such as the Energy Savings Trust, DECC, local authorities, Citizens Advice Bureau and, if appropriate, energy companies to get energy saving and new technology messages to my constituents – and relaying their comments about energy policy back to these organisations" (Alice)

An eco group view was that government entities could encourage efficient energy use, particularly with community based schemes.

"Usually local authorities are the best place to manage area based schemes .... And it could be that you letter drop. I used to work for a local authority and that's what we did, we letter dropped and it was incredibly successful" (Pauline)

An energy company viewpoint clearly agreed on the importance of government to influence people's behaviour in a positive manner.

"I think what I'd probably say is government has responsibility to set the kind of framework that everyone is hopefully trying to get -- that framework should be designed to getting people to do the right thing but ultimately, individuals have their own role to play and you've
got to, through those policies, try and get them to do the right thing. But you clearly can't mandate them because we don't live in a society that does that" (Daryl)

One landlord had a negative view.

"I suppose saving energy is not that important, no. It’s not one of my main priorities, no. Which is very naughty, but..." (Ava)

A summary table of Other UK Stakeholders responses (Landlords, Environmental group, Energy company, Politician) is shown in table 57.

Table 57 Other UK Stakeholders

<table>
<thead>
<tr>
<th>Inferred Statement</th>
<th>Mixed View</th>
<th>Negative view</th>
<th>Positive View</th>
<th>Balance of view</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collective action is important</td>
<td>1</td>
<td>0</td>
<td>6</td>
<td>Positive</td>
</tr>
<tr>
<td>Useful if we could choose the energy we get supplied to our home</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>Positive</td>
</tr>
<tr>
<td>Education is the most important thing</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>Uncertain</td>
</tr>
<tr>
<td>People are influenced by the culture around them</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>Uncertain</td>
</tr>
<tr>
<td>Attitude to nuclear power</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>Uncertain</td>
</tr>
<tr>
<td>Differential tariffs are a good idea</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>Positive</td>
</tr>
<tr>
<td>Smart meters are useful</td>
<td>1</td>
<td>0</td>
<td>6</td>
<td>Positive</td>
</tr>
<tr>
<td>The rebound effect is important</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>Uncertain</td>
</tr>
<tr>
<td>People don't think that rationally</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>Positive</td>
</tr>
<tr>
<td>The government should nudge us in the right direction</td>
<td>1</td>
<td>0</td>
<td>6</td>
<td>Positive</td>
</tr>
</tbody>
</table>

The UK stakeholders questioned in this research agreed with UK case study participants in that they thought people can think irrationally and that government was important in influencing people. Views were mixed as to the importance of the
Rebound Effect, especially from energy company, environmental group and government representatives. This is not surprising as these groups all supported the Green Deal. All of these groups also encourage collective action in using energy efficiently, and thus energy choice and enabling technology such as smart meters.

### 6.3.3 Australian Qualitative Data

A summary of the Australian Case Study Participants is outlined in table 21.

The same key questions underlie the analysis of the Australian qualitative data, and by and large the inferred statements are similar to those derived from the UK analysis, but there are some changes. Also, some of the interview questions vary slightly and are set out below. Inferential statements have (AUS) after them in the table headings, to denote they are from the Australian participants.

*How much difference can an individual residential user make to climate change?*

*How strongly do you feel about your domestic energy use, in the sense of where it comes from, what type of energy it is, how affordable it is, should you use less of it, etc?*

*Do you use more energy heating or cooling your house? How much does this depend on where you live in Australia?*

*How easily do you think a domestic energy user might be influenced by what other people do with regard to energy use?*

*How effective do you think education is, in the way people use energy when compared with say, regulation or financial incentives?*

*To what extent do you think people’s health could be affected by the type of energy we use?*
Would more information on a householder’s energy consumption really affect how much energy they use, or how much would it depend on a mixture of factors? (cost, what they feel they need, etc.) For example, the UK is introducing Smart Meters.

Australia has a large take up of solar panels in the domestic sector (one in eight households). To what extent do you think solar panels could provide your domestic energy needs?

Who should take most responsibility for saving energy domestically in our society (government, educated people, wealthy people, heavy energy users, etc)?

What kind of incentives do you think would make people change their energy behaviour?

What will be the effect of technology on domestic energy use? (Use less, more or the same over time)

Should Australia switch to using more renewable energy in the domestic sector?

What is your attitude to nuclear power (and why)?

How important is saving energy compared with the other problems people have in their lives?

What are your views on a carbon tax?

How would you feel about being given a personal carbon allowance?

Are you concerned that one of Australia’s biggest exports is coal, which contributes to CO₂ emissions?

The growth in the world’s population has meant an increased demand for energy. What is your view on this? (Does it make it less worthwhile to worry about our energy use, as it dwarfs any impact we can make?)
What are the key things you can do to influence domestic energy use generally (not necessarily just thinking about your own use)?

6.3.3.1 Key Question 1

How do domestic residents think about their energy use?

Collective action is important to use energy sustainably

While nobody was against collective action in terms of using energy sustainably, Australians were more positive than UK case study respondents that their individual energy use would as a group make a difference.

Table 58 Participants’ views on collective action (AUS)

<table>
<thead>
<tr>
<th>Collective action is important</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
<td>1</td>
</tr>
<tr>
<td>2 : Negative view</td>
<td>0</td>
</tr>
<tr>
<td>3 : Positive view</td>
<td>5</td>
</tr>
</tbody>
</table>

One positive view outlined how as a collective sustainable energy use was significant.

"Well, I think that’s an interesting question, because on their own, none at all. As part of a group, a huge amount" (Angela)

Another positive view agreed that individual responsibility was the first step in group action.

"I guess very little for the whole world, but I think it has to be individual... you know, a whole bunch of individuals would make a heap of difference if everybody made a decision" (Ellie)

A mixed response pointed out that people don’t always have the discretion to use the amount of energy they would like.

"So, for example, I might have some discretionary and also, well, in terms of the heating, if you've got a sick person at home, well then, you know, you have to keep a fairly constant temperature versus if you're all young and healthy then... or if you have children" (Tilly)
6.3.3.2 Key Question 2
How does the form of energy residential consumers use appeal to their ideological, health or materialistic/economic consumer needs?

*It would be useful if we could choose the sustainability of energy supply to our home*

There is a much greater opportunity in Australia to build your own house, and therefore decide on not only the energy supplier, but also the type of energy is delivered to the property. So the majority of respondents wanted to be aware of the type of energy they were receiving.

<table>
<thead>
<tr>
<th>Table 59 Participants’ views on choosing energy supplied to the home (AUS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Useful if we could choose the energy we get supplied to our home</td>
</tr>
<tr>
<td>1 : Mixed view</td>
</tr>
<tr>
<td>2 : Negative view</td>
</tr>
<tr>
<td>3 : Positive view</td>
</tr>
</tbody>
</table>

One respondent was in the process of building her own house, and thus deciding exactly in what form her energy needs would be supplied.

"*I feel strongly enough about it to be building entirely off grid; there is power available in my area but it's very expensive to connect, so I'm doing solar, and there is no town water or sewerage so I'm doing rainwater and septic treatment on site*" (Sue)

Another respondent agreed that would be useful to choose the energy supplied to her home. However, as in the UK, there was frustration that paying a "green" energy company gave little information on what type of energy was actually being delivered.

"*...paying for extra energy when I couldn’t get out of the companies any straight answer as to exactly, you know, what that meant – you know, did it mean... they kind of gave you these strange answers of, oh, it means we’re going to invest. Well, you’re investing in what? *" (Angela)

A mixed view allowed this frustration to result in no longer caring whether the energy delivered to their house was sustainable not.
"Well, you know, there is an option you can, sort of, tick on your energy if you want the green energy and then you pay 10% more. I did it first when it came out and then I was thinking, well, you know, I don't really know if it's truly these things. Then I, sort of, thought, no, why should I? Let the government regulate to say, it shouldn't be up to me, I'm not a, sort of, welfare agency. It's the government's responsibility" (Tilly)

6.3.3.3 Key Question 3
What impact has culture on energy use and can this be changed with education policy or through commercial/political marketing?

*Education is the most important thing in influencing energy use*

Although there were mixed views on the importance of education in influencing energy use in Australia, there were no negative views that indicated that it wasn't important.

<table>
<thead>
<tr>
<th>Table 60 Participants' views on energy education (AUS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education is the most important thing</td>
</tr>
<tr>
<td>1: Mixed view</td>
</tr>
<tr>
<td>2: Negative view</td>
</tr>
<tr>
<td>3: Positive view</td>
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<tr>
<td>3</td>
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<tr>
<td>0</td>
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<td>2</td>
</tr>
</tbody>
</table>

Mixed views felt that despite the fact that education could deliver important information, some people were in a position to ignore this information if they wished.

"I think it depends on the demographic. I think it also depends on... because they showed...they did some research here about rich families, and they really don't care a crap because, you know, they just pay the bill! (Angela)

A positive view indicated that education needed to be robust.

"So, unless there's a very strong education campaign of explaining that things do not change linearly, just like the global financial crisis came about, not in a linear sense. So, people have to, sort of, get to realise that the same is going to happen with climate change! (Tilly)
**People are influenced by the culture around them**

The majority of Australian respondents felt they would be influenced by cultural factors with regard to energy use.

<table>
<thead>
<tr>
<th>People are influenced by the culture around them</th>
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</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
<td>1</td>
</tr>
<tr>
<td>2 : Negative view</td>
<td>1</td>
</tr>
<tr>
<td>3 : Positive view</td>
<td>4</td>
</tr>
</tbody>
</table>

One positive view emphasised the importance of a peer group.

"Oh, I think it’s very important. I think peer effects are hugely important" (Angela)

A mixed view was concerned about the lasting effect of cultural exposure.

"It would to a certain extent, but I suppose it’s how much knowledge comes with that. It’s all right saying you’ve seen a 30-second ad on TV, but that kind of only has a lasting effect" (Mandy)

One negative view felt that many people won't influenced by what others did.

"I think the majority of people don't think about it very much at all other than how much is my next bill going to cost me, I really don't think people think about it too much at all" (Sue)

**People’s attitude towards nuclear power**

Interestingly, in contrast to the UK and despite Australia's enormous uranium resources, nobody had a positive view of nuclear power.
Mixed viewpoints seem to balance the positives and negatives of nuclear power, but tended to lean against using it in Australia. This was possibly because it is not needed as a source of power due to the abundance of other energy choices.

"And then we haven’t resolved storing of the wastes; nuclear waste. So, that’s still an unresolved issue. That’s on the one hand. Now, on the other hand is all the carbon footprint from the, you know, from the coal powered stations, it’s, yes... I’m not a fundamentalist one way or the other. I prefer not to have to make the choice" (Tilly)

Negative viewpoints encapsulated the almost cultural dislike there is to using nuclear power in Australia.

"But one thing in the Australian psyche that’s really interesting is uranium is... people are paranoid about uranium even though we sell it to everyone overseas. People do not like energy that comes from uranium" (Angela)

"Oh, I wouldn’t want to have nuclear power" (Ellie)

"I don’t have a good attitude to nuclear power" (Sue)

**Renewable energy could power Australia**

Respondents answered this question from the point of an individual property being self sufficient in energy.

**Table 63 Participants’ views on whether renewable energy could power Australia (AUS)**

<table>
<thead>
<tr>
<th>Renewable energy could power Australia</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
<td>2</td>
</tr>
<tr>
<td>2 : Negative view</td>
<td>1</td>
</tr>
<tr>
<td>3 : Positive view</td>
<td>3</td>
</tr>
</tbody>
</table>

**Table 62 Participants’ attitude to nuclear power (AUS)**

<table>
<thead>
<tr>
<th>Attitude to nuclear power</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
<td>3</td>
</tr>
<tr>
<td>2 : Negative view</td>
<td>3</td>
</tr>
<tr>
<td>3 : Positive view</td>
<td>0</td>
</tr>
</tbody>
</table>
Mixed views were uncertain about the degree to which renewables could provide power. They implicitly considered solar power as a main source, as it has been heavily promoted. Heat pumps, both ground or air source, seem to be uncommon in Australia.

"I know they don't provide a lot as in, like, I don't think you could run your house off it but I think it's a start. I definitely think it's a start. I think you could develop the technologies that could, you know, get more, like, more from less sort of thing" (Bruce)

A negative view disagreed that household renewable power could be cost effective.

"I don't believe it could provide all of them. I looked into it and the problem for me was and the reason why I didn't get them is the problem for me is that you use a lot of your energy at night and there's no way to store it. And if you set up a system that stores it with batteries then it costs you a lot of money" (Ellie)

However, half of the respondents thought household renewable energy could meet most of their energy needs.

"Oh, I know that they can provide 100% if you're willing to work with them, so you do your high power consumption activities in the middle of a hot sunny day and you charge the laptop and you charge the phone, you do the laundry, because often during the middle of the day the batteries are fully charged and they're often just releasing, they can't take any more power, so you're just letting all this power go, so you'd use it all in the middle of the day and then come about four o'clock you wind it down and don't use too much" (Sue)

6.3.3.4 Key Question 4

How does more information on domestic energy consumption, such a smart meters which provide real-time information on energy use, automatically encourage greater energy efficiency or is it more complicated than this?

Differential Tariffs are a good Idea

There were no negative views against differential tariffs.
Table 64 Participants’ views on differential tariffs (AUS)

<table>
<thead>
<tr>
<th>Differential tariffs are a good idea</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
<td>3</td>
</tr>
<tr>
<td>2 : Negative view</td>
<td>0</td>
</tr>
<tr>
<td>3 : Positive view</td>
<td>3</td>
</tr>
</tbody>
</table>

Mixed views were largely because it was felt that these type of tariffs were not available. However, one mixed view felt that was important to understand the pros and cons of signing up with particular tariff providers. She was annoyed when her husband changed provider without consulting her.

"You know, they're tempting. My husband’s done it twice; killed him when I got home then, why you change... Because every time he changes, you know, you also lose some things, you know, that he might not have been familiar with" (Ellie)

Positive views were interested in the obvious potential to save money.

"You can do your best to not put the dishwasher on till later at night when it’s going to cost less to use" (Mandy)

**Smart meters are useful**

As in the UK, people felt that smart meters were a positive source of information, and there were no negative viewpoints.

Table 65 Participants’ views on smart meters (AUS)

<table>
<thead>
<tr>
<th>Smart meters are useful</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
<td>3</td>
</tr>
<tr>
<td>2 : Negative view</td>
<td>0</td>
</tr>
<tr>
<td>3 : Positive view</td>
<td>3</td>
</tr>
</tbody>
</table>

Positive viewpoints like the idea of having a smart meter, but respondents indicated that they weren’t generally available as yet.

"I think it would definitely affect people. A lot of people don't even know where their meters are in their house sort of thing. We don't, like... I was saying, like, so if we turn something on, you know, it works. We turn something off it stops. Then people come around that check our meters for us. A lot of people wouldn't even know where their meters are" (Bruce)
"Yes, and especially how much you’re told as well; like that meter you (the interviewer) have has a massive effect" (Mandy)

Mixed views liked the idea but were not particularly proactive.

"Well, I wouldn’t mind having one, but I haven’t... it hasn’t come my way easily and I haven’t gone out to find it" (Sue)

"Look, I think in terms of homes, I know some people who’ve got those energy meters. They’re putting smart meters all the way through Australia at the moment and at great cost to the customer. And I think people who are interested use those things, and certainly when I worked at EnviroGroup we had a lot of homeowners coming and buying those monitors so they could see where their energy use was and what was going on. But you’ve got to want to do it. And you have to have time" (Angela)

6.3.3.5 Key Question 5
How important, or possible is it, for domestic consumers to measure their energy use in all energy related activity (so they can be aware of technology efficiency rebound effects)?

**People don't think rationally about their energy use**

Again, although respondents didn’t specifically refer to rationality around energy behaviour, the responses inferred that people make heuristic decisions with short-term utility.

*Table 66 Participants' views on rational thinking (AUS)*

<table>
<thead>
<tr>
<th>People don't think that rationally</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
<td>1</td>
</tr>
<tr>
<td>2 : Negative view</td>
<td>0</td>
</tr>
<tr>
<td>3 : Positive view</td>
<td>4</td>
</tr>
</tbody>
</table>

One positive view that inferred that people do not think all that rationally emphasises people's tendency to engage in heuristic behaviour.
"There's not a lot of people doing it, you know, like, being quite energy conscious and that sort of thing. Everyone's quite happy just to, well, things work for us, like, you know, things actually work so why go and change that?" (Bruce)

Another interesting positive example of irrational thinking came from a respondent whose husband bought a new showerhead designed to save water (and presumably the energy required to heat it).

"Like a guy stopped by and sold my husband these... a water saving shower...

IV Oh yes. That’s electric.

No, the showerhead.

IV Oh, I see, yes.

You know, it’s a different sort of showerhead. And I had a shower, it was that big and, you know, that much water came out with big holes. Now we’ve got this thing like this and it’s, like, little needles coming down.

IV And you don’t get enough water.

Well, yes. So I think you probably do save water, but I think you have a longer shower; I do anyway, to wash my hair.

IV And it’s not as much fun.

And I said to him one of the few pleasures in my life is having a shower and I work hard and I’ve got a stressful life, you just took that away from me" (Ellie)

The husband's decision in this case not only resulted in disapproval from his wife, but his showerhead purchase was probably made as a result of Kahneman's (2011) System1 thinking, which is fast and instinctive. The decision may also have been irrational as the reduced flow of water simply meant a longer shower was necessary.

The inferred mixed view on rational thinking indicated that people should behave responsibly regarding energy use, but often don't.

"The average person in terms of managing their own energy just because they're not educated as a classification doesn't give them the right to not be informed and be responsible" (Sue)
6.3.3.6 Key Question 6
How responsible do domestic consumers feel for their efficient use of energy?

The government should nudge us in the right direction

As has been mentioned, some people consider the government has a role to play in influencing how people behave.

Table 67 Participants' views on the government's Nudge role (AUS)

<table>
<thead>
<tr>
<th>The government should nudge us in the right direction</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
<td>0</td>
</tr>
<tr>
<td>2 : Negative view</td>
<td>1</td>
</tr>
<tr>
<td>3 : Positive view</td>
<td>5</td>
</tr>
</tbody>
</table>

One negative viewpoint believed that government would not try to influence people's behaviour in ways that they didn't want, presumably on the basis that it would be politically untenable.

"Oh, I don't think our government would regulate things that people really wouldn't want" (Ellie)

However, most viewpoints were positive, indicating that governments were well-placed to influence behaviour.

"So in Western Australia, like, they had these like little egg timers so we had a massive drought. We were many million litres of water short of what we needed for the amount of people that we had and the farms sort of thing so the government genius or ingenious, I don't know which, you know, which way it will go but they had this little egg timer that you'd put into the shower and then when you started to shower you turned it and it would go for three minutes. I was just like an hourglass, three minutes" (Bruce)

This simple initiative by the Western Australian government resulted in significant water saving during drought conditions.

The success of solar panel take up throughout Australia was also attributed to government support and significant advertising.

"One of the reasons why we've had so many solar panels is because we've had big government support programs that have allowed people to uptake on it" (Angela)
Another example of the government nudging people to save energy was in the provision of standby plugs.

"Yes, we’ve even a little... plug on our TV back home, where if it’s on for a certain time and someone doesn’t change the channel it’ll just knock itself off; it’ll give you a warning, but it’ll knock itself off. So there’s... yes, there’s little things like that, but they’re just provided by the government" (Mandy)

One respondent pointed out the limits of the individual.

"An individual has got limited choices, I think. That's why you need government policies" (Tilly)

Government regulation is important in residential energy use

Most respondents recognise the importance of government regulation in energy use.

**Table 68 Participants’ views on government regulation role (AUS)**

<table>
<thead>
<tr>
<th>Government regulation is important in residential energy use</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
<td>1</td>
</tr>
<tr>
<td>2 : Negative view</td>
<td>0</td>
</tr>
<tr>
<td>3 : Positive view</td>
<td>5</td>
</tr>
</tbody>
</table>

A mixed view from a respondent lamented the fact that government regulation is concerned with property were almost exclusively for new buildings.

"But at the same time if you move into an old house, I’ve found that most people move into old houses, they don’t do anything to them, it costs you money ...." (Ellie)

A positive (and coercive) view of government regulation cited the example of China.

"But how do you keep people mindful of what they’re doing is the question. You know, how do you keep them mindful without... Because if you have to dictate that, then it becomes... it’s really... in our society, you can’t do that. If you’re in China, you can, say, like they did, you’ve got this amount. They literally gave them, you’ve got this amount of energy and people were... if you don’t meet that target... and I said to somebody, one of the policymakers, what happens if they don’t meet their targets? And they said, they end up cleaning toilets. You know, so there was great incentive. So you’ve got to have an incentive – not necessarily that one" (Angela)
Another view shared the responsibility between the government and energy providers.

"I think the providers have a big responsibility and the government, I guess, through regulation to regulate the companies and, you know, across the board" (Ellie)

**Population and energy**

Unlike UK respondents where there were mixed views on the effect of a growing population on energy supplies, Australian respondents were broadly positive the future population growth would impact negatively on energy supply.

<table>
<thead>
<tr>
<th>Population and energy is a problem</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
<td>0</td>
</tr>
<tr>
<td>2 : Negative view</td>
<td>1</td>
</tr>
<tr>
<td>3 : Positive view</td>
<td>5</td>
</tr>
</tbody>
</table>

There was, however, one view of the future interaction of population and energy supplies would be solved through human ingenuity.

"Yes. And I think that, you know, with so many people now craving a newer, cleaner, better way of using energy, because we don't want to change our lifestyles so much that we revert to the dark ages and don't use any power, that so many people want it so badly and there's so many brilliant minds on earth, the scientists and, you know, the people that invent these things, that it's going to happen, I think it's going to happen soon, it's going to be new, it's going to have nothing to do with nuclear, nothing to do with burning fossil fuels, it's just going to rock our world, I think" (Sue)

A number of positive views were expressed indicating that the demands of a large population would make sustainable energy supply more difficult.

"And I think maybe one, like, one thing that was more powerful than money and that was life or death, pretty much. It was just like we're going to come to a point where we're going to have so many people and old Mother Earth, kind of, you know..." (Bruce)

"I think it's very worrying" (Angela)
"Yes, the extent they’re proclaiming that it’s going to increase over the next, you know, ten, 100 years, is double, treble what we ever had, and that’s, that’s crazy; that’s what you just look at it and go, you know, oh, no" (Mandy)

6.3.3.7 Key Question 7
How could financial incentives be devised to make a difference? Even without any special financial incentives cost is a major factor in determining energy use.

Financial situation is the driver behind energy use

For Australians, cost is also a major factor in determining energy use.

Table 70 Participants’ views on finance as an imperative (AUS)

<table>
<thead>
<tr>
<th>Financial situation is the driver behind energy use</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
<td>0</td>
</tr>
<tr>
<td>2 : Negative view</td>
<td>0</td>
</tr>
<tr>
<td>3 : Positive view</td>
<td>6</td>
</tr>
</tbody>
</table>

Every respondent agreed to this was a key driver behind their energy consumption.

"Like, there's obviously the money aspect. You know, like, that's the, like, immediate thing" (Bruce)

"Look, I did a lot of research into green energy and things like that, on what it meant for me, because I'm a single parent. There are financial restrictions, quite severe financial restrictions, on what I can do" (Angela)

".... the cost of it (energy) would probably be the first thing that would turn my head" (Mandy)

"I mean, some people have got enormous problems and, you know, they've got no food for the day and, well, they don't even have money for, to pay for any energy" (Tilly)

"And I think the, you know, the financial incentive of course is the biggest" (Ellie)
A personal carbon allowance

No respondents had a negative view of personal carbon credits, but nevertheless there were some reservations.

Table 71 Participants’ views on a personal carbon allowance (AUS)

<table>
<thead>
<tr>
<th>How would you feel about being given a personal carbon allowance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed view</td>
</tr>
<tr>
<td>2 : Negative view</td>
</tr>
<tr>
<td>3 : Positive view</td>
</tr>
</tbody>
</table>

One mixed view made a good point about equality.

"Yes. Like a ration card, isn't it, in a way? Which is, well, I suppose it has some sort of, it's the same issues, the same with water, I mean, it has... it's, sort of, like, it gives a freedom for the rich to pollute at the expense of the other ones."

IV The poor.

The poor. Exactly. So, it's not equitable from that perspective. You could argue that the carbon tax, you know, is the same but then because the carbon tax brings in money that then will be used to do other... and then subsidised the low income earners some way or another, I know it's difficult to do exactly. So, in a way that becomes more equitable from that perspective than the allowance. But giving them an allowance actually is probably more efficient in managing your own, sort of, usage" (Tilly)

Another uncertain view thought that it would be an unpopular policy.

"That's quite interesting. I'm not too sure how I would feel about, you know, to have such a direct impact on me personally but the fact is, like, people, you know, people wouldn't like it" (Bruce)

Positive views liked the incentive to save, and possibly sell unused credits.

"I think that's a good idea, yes. I'd go for that. You try and save, that would be a huge incentive to save. You'll try and save if you can sell it" (Ellie)

"I wouldn't mind at all because I know that I'd probably use less energy than the average person. For example, I don't really watch TV and I go to bed pretty early so I turn the lights off early, don't watch TV, you know, I'm already using far less power than most people" (Sue)
A tax on carbon emissions

Views on paying a carbon tax were diverse, and it did not seem to be well understood or even a major issue. This was somewhat surprising, given its existence at the time of the respondent interviews, although it was due to be scrapped in the forthcoming summer (it was removed by legislation in July 2014).

The tax was only levied on the largest industrial energy users (emitting over 25,000 tonnes per year of CO2-e), with some of the revenue raised used to subsidise low and middle income consumers through changes in income tax. The tax free threshold increased from $6,000 to $18,200 on 1 July 2012. So domestic consumers were only indirectly exposed to this tax, and some received compensation.

<table>
<thead>
<tr>
<th>Table 72 Participants’ views on a carbon tax (AUS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>paying a carbon tax</td>
</tr>
<tr>
<td>1 : Mixed view 2</td>
</tr>
<tr>
<td>2 : Negative view 1</td>
</tr>
<tr>
<td>3 : Positive view 3</td>
</tr>
</tbody>
</table>

One mixed view exemplified the lack of understanding.

"And, for example, it's probably one of the problems with the carbon tax that, you know, people don't understand it" (Tilly)

A negative viewpoint was against a household tax.

"Yes. I don’t know a lot of the details of the carbon tax. I think there should be costs and I think companies should be paying not... but I don’t think individuals should pay" (Ellie)

A positive view supported a carbon tax with the right structure.

"Oh, I'm all for the right sort of carbon tax. I think the one we have in place at the moment where they give it back into innovation is really important" (Angela)

Another positive view thought it would be more acceptable if it was not labelled as a tax.
"I think if they didn’t call it a tax that might be... that’s... if they called it something else, just like a levy or... it softens that little three-letter word, I think it probably might have a different effect" (Mandy)

A summary table of Australian participant responses is shown in table 73.
Australian participants clearly thought collective action was important. They also had a negative attitude to nuclear power, which is not surprising, as they are so blessed with so many other sources of energy. Like UK participants, they agreed that people
did not always think rationally, and the government was important both for regulation and to nudge people in positive ways. They also agreed that finance is a key driver behind energy use. Australians also saw growth in world population as an energy problem.

6.3.4 Focus Group Qualitative Data

Focus Group Questions - July 21st 2014

The focus group questions were a distillation of what were considered the most productive questions that had previously been asked, on the basis that the answers elicited interesting ideas or were particularly insightful. Analysis was done using inferred responses from these focus group questions. The nature of a group discussion means that individual questions often lead to a broad debate. So there was overlap in the answers from the group (which is why inferential responses can be greater than the number of group members), with responses to one question often being pertinent to a number of key questions in this study. Further analysis of these responses is done in the next section 6.5.

In a focus group the number of questions have to be limited to fit in a reasonable time period. The focus group consisted of all the original UK Case Study respondents. The questions were as follows:

1) Is the energy you use at home too expensive?

2) If you saved money on your energy bill, what would do with that money?

3) If a carbon tax was called something else, like say a cleaner energy contribution, would it make it more acceptable?

4) What is your attitude to the Green Deal? If you were a home owner, would you use it to make energy improvements to your house?
5) If you were the Prime Minister, what would you do to encourage people to save energy or use more renewable energy at home?

UK Focus Group Participants are shown in table 74 (and are composed of all the UK Case Study participants).

Table 74 UK Focus Group participants

<table>
<thead>
<tr>
<th>Participant</th>
<th>Gender</th>
<th>Age Range</th>
<th>Occupation</th>
<th>Property Type</th>
<th>Property Age</th>
<th>Tenure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robert</td>
<td>Male</td>
<td>18 to 29</td>
<td>Research student</td>
<td>Terraced House</td>
<td>2012</td>
<td>Owner</td>
</tr>
<tr>
<td>Gwen</td>
<td>Female</td>
<td>18 to 29</td>
<td>Research student</td>
<td>Flat</td>
<td>2000</td>
<td>Tenant</td>
</tr>
<tr>
<td>Jane</td>
<td>Female</td>
<td>30 to 40</td>
<td>Research student</td>
<td>Terraced house</td>
<td>1890</td>
<td>Tenant</td>
</tr>
<tr>
<td>Wendy</td>
<td>Female</td>
<td>30 to 40</td>
<td>Research student</td>
<td>Flat</td>
<td>1880</td>
<td>Tenant</td>
</tr>
<tr>
<td>Anne</td>
<td>Female</td>
<td>18 to 29</td>
<td>Research student</td>
<td>Semi-detached house</td>
<td>1930</td>
<td>Tenant</td>
</tr>
<tr>
<td>Arabella</td>
<td>Female</td>
<td>30 to 40</td>
<td>Research student</td>
<td>Semi-detached house</td>
<td>1935</td>
<td>Tenant</td>
</tr>
<tr>
<td>Juliette</td>
<td>Female</td>
<td>30 to 40</td>
<td>Teacher</td>
<td>Semi-detached house</td>
<td>1931</td>
<td>Owner</td>
</tr>
</tbody>
</table>

In the focus group session, there was a broad discussion of the Green Deal which covered a number of key questions in this study. As such, attitudes to the Green Deal revealed how the group thought about their energy use (Key Question 1), how it appealed to their ideological, health, and economic needs (Key Question 2), the importance of measuring overall energy use (Key Question 5), how responsible they felt for their energy use (Key Question 6), and the importance of finance in relation to energy use (Key Question 7). Inferential statements have (FG) after them in the table headings, to denote they are from the Focus Group participants.
**Attitude to the Green Deal**

Table 75 UK Focus Group Participants’ attitude to the Green Deal (FG)

<table>
<thead>
<tr>
<th>Attitude to the Green Deal</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
<td>8</td>
</tr>
<tr>
<td>2 : Negative View</td>
<td>0</td>
</tr>
<tr>
<td>3 : Positive View</td>
<td>1</td>
</tr>
</tbody>
</table>

A positive response to the Green Deal was from Juliette, who used it when she needed a new boiler. She also received a cash-back incentive.

"I like the Green Deal, because they gave me a leaflet when my boiler died! .... It's really good, because it links in with what you're saying about savings. I've now got a brand new boiler, because my other one was making very scary noises and kept cutting out. It was over twenty years old. ......So to have a new one, it wasn't a case of just having a normal boiler, I had to have a new one in a different place with all new pipework to a different route, so it was going to cost, like, three grand, and I didn't have three grand to say, here you are Mr. Plumber. So it's great, because it’s an incentive, and it gave me £300 cashback, and the amount that I now save by having a more efficient boiler, because it's not twenty years old, that difference between my energy bill and my saving, that little margin is what pays for it. So I don't notice that I had to pay out for like, a really expensive boiler, and I get a guarantee on it, and I got a nice cheque for £300" (Juliette)

Clearly the incentive for Juliette to take up the Green Deal was the availability of finance, augmented by the £300 cashback, which represented an effective discount of approximately 10% (Key Question 7) . Even so, Juliette would not have used the Green Deal if her old boiler had not reached the end of its useful life. There is the financial rationale for this, as explained by Hassett & Metcalf (1993) . This is an important point, as without the Green Deal most people will still replace energy using capital at the end of its usable life.

"I have a question. If you still had that old boiler, and it wasn't broken down, and someone told you about the Green Deal, would you still go for it? (Robert)

"I was thinking about it, because it was a bit like - I called it Bertha, the boiler. It was like, a Goliath one. It was very good when it worked, but because I didn't have any thermostat or any timer or anything like that, I'd just have to press it on when I was in, but once it was on, it stayed on. I thought about getting a plumber in to put a thermostat on it, and if I thought it
was going to last, I would have got a thermostat fitted, because it just belted out the heat until you were too hot and then you had to turn it off. So I had thought about making it more efficient that way, but in terms of buying a new boiler, I would have kept eking it on" (Juliette)

Juliette also opted to get external solid wall insulation under the Green Deal. However, this was because she was offered a large financial incentive representing around two thirds of the cost of the work (£6,000). This incentive scheme was so popular that the government had to close it within a few months, and it is now no longer available. Clearly, large financial incentives will induce people to take up the Green Deal, but this is not sustainable in policy terms, due to limited funding allocation.

"Yes, and I mean, I'll be paying it off through my energy bill that I won't notice, but then when that's paid off there's going to be all these houses round the country that are more efficient, and there's no way I would have spent nine grand out of my own pocket, because I didn't have it. Most people wouldn't have that money. Yes, I think it's a very good scheme" (Juliette)

Juliette's projected energy saving from her solid wall insulation is around £450 a year. Interestingly, the terms of the deal she was offered only include around £385 as actual green deal finance, the cost of which is spread over 25 years, at an interest rate of just below 7%. The rest of the money, around £2500, is payable on completion of the work. Juliette plans to finance this with a 0% credit card deal, which she will pay off over two years. Apart from finance as an incentive, it's clear that Juliette likes the idea of being more energy efficient (Key Question 2).

Other responses to the Green Deal were mixed. The eight responses in the table above represent eight comments from a variety of the focus group participants.

"I think I'm really positive about the Green Deal and I think it's a good thing, but for me I think I would go for it only if I had a problem, like a broken boiler. If everything was working alright, and I knew already that I'm not paying a lot for energy, I would still keep it, because I don't know, I think... I feel it's a bit, I don't know, that's very clear for me, how much I have to pay for the heating and things like that. So I wouldn't bother, really, going for the Green Deal" (Robert)

This response from Robert indicates his uncertainty around the cost of his energy use over time (Key Question1, Key Question 5).
"If I owned this old house where I am now... I would think about it (the Green Deal), because somebody else pays most of it and then I would have to pay much less, but I think going through the... you know, who pays, how does it get paid, ....... Where does my paying start, where they'll ask me to pay if something happens and the assessment changes, or the prices change and all? And the interest rates, I would go through, and I hate going through that kind of thing. I would have to find somebody who understands it to explain it to me. A headache, that's all I can think of!" (Arabella)

Here, Arabella's response also highlights the uncertainty around the green deal in terms of future savings. She is also concerned about the complexity of the process. Gwen's view on the Green Deal was also mixed:

"I think if I was owning my own house, then it'd definitely come down to what the circumstances were at the time, whether or not I knew I was going to be in that property for a while, or just how unstable my life was, or whatever. But I think I've always been brought up to be the type to shop around to see what is the best deal. So I think I would consider it, but I wouldn't necessarily just be like straight, right, I'm going for the Green Deal. I would look at all my other options, whether that be taking out a loan, whether that be remortgaging if I hadn't paid off the house, that kind of thing. So I'd definitely weigh up the pros and cons" (Gwen)

Apart from the cost, the fact that the green deal is also paid off over a reasonably long period which could be inefficient, is clearly an issue for Gwen (Key Question 6, Key Question 7).

Jane's view was similarly concerned with finance.

"Naturally, I'd look into it. I could only see me using it for like, a big job, where we needed to borrow a substantial amount of money, and then I'd only be doing it if it was the best deal financially" (Jane)

**Financial situation is the driver behind energy use**

Table 76 UK Focus Group Participants' views on finance as an imperative (FG)

<table>
<thead>
<tr>
<th>Financial situation is the driver behind energy use</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
<td>6</td>
</tr>
<tr>
<td>2 : Negative View</td>
<td>0</td>
</tr>
<tr>
<td>3 : Positive View</td>
<td>7</td>
</tr>
</tbody>
</table>

235
Among views expressed in the focus group, finance is clearly an important issue. Even so, other factors have an influence. Some mixed views show this clearly:

"I think my experience has been completely opposite to many of you, because I grew up somewhere where the energy was really cheap, so we were not aware of it at all, really. Are we using energy? We didn't care. The air conditioner was always on, and heating in the winter, everything. So when I came here at the beginning, I was living with other people and the landlord was paying the bills, so I still didn't care! I had the heating on with the window open. But now I'm living on my own, in my own house, I think it's pretty expensive. Now I notice that yes, energy is expensive and I have to pay for my own, so I do care now, how I use energy" (Robert)

While the cost of energy is clearly important to Robert, it is not necessarily predominant. The way he thinks about his energy use, and how responsible he feels for it, is interwoven with his cultural background. (Key Questions 1,3, 6 and 7)

For Jane, while finance is significant, how energy is used is also important and people should use it responsibly (Key Questions 1 and 6).

"I kind of accept that energy... I kind of think energy should be expensive, otherwise people think they can just use as much as they like" (Jane)

Gwen clearly thinks about her energy use from the point of view of cost, but also from the perspective of not being wasteful (Key Questions 1, 2 and 6).

"I'm kind of aware of what I'm using, and obviously the bills come in and stuff, and whenever my mum's asked how much it is, she's always like, that's really cheap. But I think that's more just to be myself and kind of aware of how much energy I'm using, not being very wasteful" (Gwen)

She also recognises that some people will prefer to be thermally more comfortable, even if it's more expensive (Key Questions 1, 6 and 7).
"...then there probably are other people who maybe prioritise their comfort over cost, if they have that flexibility to be able to do it and afford it" (Gwen)

Arabella is also aware of her energy use and thinks it should be used responsibly (Key Questions 1, 2 and 6).

"I don't like waste. When I'm alone at home I'm aware of which light I should keep lit the whole night to show that there's somebody living there. It's like, the smallest light" (Arabella)

There were also some positive statements, some highlighting unexpected views of finance as a driver behind energy use:

Would you not want (the Green Deal) in your rented place, though? Because my brother got it in his rented place, but he thought it was great, because he's paying less on his bills now" (Juliette)

"I'm not sure, because the rented place I'm in is quite energy-efficient anyway, and I think, I don't know, I think I would have the fear that if the energy efficiency had been improved in my rented place, then it'd be more likely that at the end of that year, right, your rent's increasing. So I think I would have that kind of fear, almost, that if you improved energy efficiency the landlord might be like, well, you're living in a more energy-efficient house, you're saving money on your energy bills, I'm putting the rent up" (Gwen)

Gwen's view is interesting, as it shows that landlords and tenants motivations to use energy efficiently are not always in alignment. To some amusement from the group, Arabella supported this view.

"I will definitely have that fear" (Arabella)

However, a serious point from these comments is the apparent acceptance that energy improvement measures can add value to a property, either in terms of rent or sale price (Key Questions 1, 2, 6 and 7).
The extent to which finances are a driver behind energy use also depends on the context.

"I'm comparing it to at home in Greece, where it is very expensive, painfully, and there you're aware of how long you have the power on, because you're counting the minutes and the hours. It's 30 euro per hour" (Arabella)

Government regulation is important in residential energy use
Comments from the focus group were all positive when it came to the influence of government regulation in energy use (Key Questions 1 and 4).

<table>
<thead>
<tr>
<th>View</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
<td>0</td>
</tr>
<tr>
<td>2 : Negative View</td>
<td>0</td>
</tr>
<tr>
<td>3 : Positive View</td>
<td>5</td>
</tr>
</tbody>
</table>

"They could cut the VAT on all the products that you need to refurbish a house, as well" (Anne)

The government should nudge us in the right direction

Equally, the group felt that the government had a role to play in nudging us to be more energy-efficient (Key Questions 3 and 6).

---

9 This verbatim statement is incorrect as power costs would be much less, perhaps a maximum of 30 cents per hour (see http://www.bbc.co.uk/news/business-25200808). However it expresses how expensive power is in Greece relative to their economic situation.
Table 78 UK Focus Group Participants' views on the government's Nudge role (FG)

<table>
<thead>
<tr>
<th>View</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
<td>0</td>
</tr>
<tr>
<td>2 : Negative View</td>
<td>0</td>
</tr>
<tr>
<td>3 : Positive View</td>
<td>11</td>
</tr>
</tbody>
</table>

Jane had an ideological view.

"Double the price of energy for rich people, then have support for poor people to improve their houses" (Jane)

Juliette felt that the government had to make choices that would benefit the people. The implication is that people need to be convinced that these are the right choices (Key Questions 1 and 2).

"I think part of your job running the country is to make the country more efficient and think, well, I have this amount of money to spend on infrastructure and I will spend it this way, not, aha, I'll get more money from everybody! It's about the choices that you make with that money you've already got as well, as Prime Minister" (Juliette)

Anne felt that the government could influence people through the public sector (Key Questions 3, 4 and 5).

"I think they could lead by example, and say, for example, the government buildings, they could make those as energy-efficient as possible. They could look up what you can do and start showing examples and have live energy readings from their building .............. Like, this is how much energy we use, and this is where it's coming from, this is what we're trying to get towards and get everybody on board, and then I think there should be more information about the problems and challenges at the moment with energy generation and supply, where it's coming from" (Anne)

Gwen advocated that the government could make relatively small changes which the people could get used to. She felt this tactic would help to change the culture around energy use (Key Questions 1,2,3,6 and 7).

"I think that's the thing, if you want anything like that to happen, it is changing the public perception of stuff. So like, trying to get the public behind certain changes, so whether it's like, stop using plastic bags by charging 2p or 5p or whatever, those kind of changes are what's getting the public to actually change their opinion and change what they do" (Gwen)
**Paying a carbon emissions tax**

Table 79 UK Focus Group Participants' views on a carbon tax (FG)

<table>
<thead>
<tr>
<th>paying a carbon tax</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
<td>6</td>
</tr>
<tr>
<td>2 : Negative View</td>
<td>0</td>
</tr>
<tr>
<td>3 : Positive View</td>
<td>0</td>
</tr>
</tbody>
</table>

The group's view on paying a carbon tax was not particularly negative. However, people felt that they would want to know exactly what the tax was being used for (Key Questions 1 and 2).

"I'd still basically want to know what it's for, and if you realise that everyone's contributing towards it, then I wouldn't really be that bothered" (Gwen)

"I don't have a big issue with carbon taxes or clean energy taxes, but yes, I'd want to know where the money was going" (Jane)

"I would be looking at exactly what it is and why I'm paying for it" (Arabella)

**The rebound effect is important with regard to policy**

This implied statement is in response to the question "If you saved money on your energy bill, what would you do with that money?" (Key Question 5)

Table 80 UK Focus Group Participants’ views on the rebound effect (FG)

<table>
<thead>
<tr>
<th>The rebound effect is important with regard to policy.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : Mixed View</td>
<td>2</td>
</tr>
<tr>
<td>2 : Negative View</td>
<td>0</td>
</tr>
<tr>
<td>3 : Positive View</td>
<td>5</td>
</tr>
</tbody>
</table>

There were some mixed views with regard to the rebound effect on stimulating energy consumption.
"The thing is, I like knowing that I've got money aside if something unexpected happens, or anything like that. Like, just moving flat, having the savings helped me furnish it and everything, so having done that I'm now aware that it's actually quite good to have that money aside, so that it's there if you ever do need it. I think if I was saving anything from energy bills or whatever, I'd just build it up again" (Gwen)

Other views agreed with the implication that residential energy savings would likely transfer into energy consumption elsewhere.

"Okay, thank you. Next question is, if you saved money on your energy bill, what would you do with that money?" (Moderator)

"Go on holiday" (Robert)

"I would spend it on the house, probably, doing all the things that I want to do. There's always projects, like oh, when I have money, I'll buy new carpets, do that. I'd spend it, I don't think I'd put it on one side" (Juliette)

"ISA. No matter how small the amount, it goes to the ISA, and that's where I draw my once or twice a year good holiday, I take a plane, it's expensive, but I get it out of there, this amount, or I get something to contribute to the money that I've put aside for that trip. But yes, every little thing that I don't buy or I don't have to do, money gets saved and it goes there" (Arabella)

"I'm terrible with money, to be honest, and if I save money on my energy bill it'll just go on another bill somewhere" (Jane)

It can be seen that in the focus group there were a complexity of views, most of which were mixed with different motivations. The two areas of reasonable clarity, were that the government has a role to play in encouraging energy efficiency and that the rebound effect was the likely result of saving energy in the residential sector.

Table 81 summarises the Focus Group participants responses.
Table 81 UK Focus Group responses

<table>
<thead>
<tr>
<th>Inferred Statement</th>
<th>Mixed View</th>
<th>Negative view</th>
<th>Positive View</th>
<th>Balance of view</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attitude to the Green Deal</td>
<td>8</td>
<td>0</td>
<td>1</td>
<td>Uncertain</td>
</tr>
<tr>
<td>Financial situation is the driver behind energy use</td>
<td>6</td>
<td>0</td>
<td>7</td>
<td>Uncertain</td>
</tr>
<tr>
<td>Government regulation is important in residential energy use</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>Positive</td>
</tr>
<tr>
<td>The government should nudge us in the right direction</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>Positive</td>
</tr>
<tr>
<td>paying a carbon tax</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>Uncertain</td>
</tr>
<tr>
<td>The rebound effect is important with regard to policy.</td>
<td>2</td>
<td>0</td>
<td>5</td>
<td>Positive</td>
</tr>
</tbody>
</table>

A key message from the focus group was the mixed attitude towards the Green Deal. There was also strong support for the role of government in influencing energy use, as well as agreement that the rebound effect should be considered when developing energy policy.

The next section looks at a summary of the quantitative, predictive, and qualitative results and seeks to reconcile inferred differences in the data.
6.4 Reconciling differences in data inferences

6.4.1 Predictive Data vs. Actual Data

Energy Use:
The following section includes a summary of the UK participants’ predicted energy use, compared with their actual energy use. The comparison is made on the basis of kWh/m²/year, which is used by SAP to compare energy use. An example plan of one of the properties is included (Robert’s dwelling).

Full details of all the UK Case Study Participant’s floor plans and how their energy use was converted to kWh/m²/year is included in Appendix 6.

Robert: Floor area 81.02 m²   Mid-terrace house, 2012

Figure 29 Downstairs Floor Plan Robert
In order to convert Robert's actual energy use to kWh/m²/year, total kWh for the monitoring period should be divided by 119 and multiplied by 365. This figure is then divided by the floor area of the property. Although this "actual" figure is extrapolated, monitoring of energy use and temperature was done over the winter period. For a calendar year it is likely to be slightly overstated. However, this is not particularly important, as the overstatement will apply to all the participants in this study. In addition, of more interest than average temperatures are the actual temperatures recorded, particularly when participants occupied their property, as it provides a measure of the thermal comfort level at which the participant existed.

Gas: \(3,329 \div 119 \times 365 = 10,211 \div 81.02 = 126\)

Electric: \(357 \div 119 \times 365 = 1,095 \div 81.02 = 13\)
Table 82 Predicted and Actual Energy Use Robert

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Predicted (SAP) kWh/m²/year</th>
<th>Actual kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>149</td>
<td>126</td>
</tr>
<tr>
<td>Electricity</td>
<td>28</td>
<td>13</td>
</tr>
<tr>
<td>Total Energy</td>
<td>177</td>
<td>139</td>
</tr>
</tbody>
</table>

Table 83 outlines a summary of the UK participants' predicted energy use by type, compared with their actual energy use.

Table 83 Predicted and Actual Energy Use by Type UK Case Studies

<table>
<thead>
<tr>
<th>Energy Use by Type</th>
<th>Predicted (SAP) kWh/m²/year</th>
<th>Actual kWh/m²/year</th>
<th>UK Case Study Participant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>149</td>
<td>126</td>
<td>Robert</td>
</tr>
<tr>
<td>Electricity</td>
<td>28</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>138</td>
<td>85</td>
<td>Gwen</td>
</tr>
<tr>
<td>Electricity</td>
<td>29</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>238</td>
<td>192</td>
<td>Jane</td>
</tr>
<tr>
<td>Electricity</td>
<td>24</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>172</td>
<td>192</td>
<td>Juliette</td>
</tr>
<tr>
<td>Electricity</td>
<td>27</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>222</td>
<td>98</td>
<td>Wendy</td>
</tr>
<tr>
<td>Gas</td>
<td>288</td>
<td>305</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>29</td>
<td>47</td>
<td>Anne</td>
</tr>
<tr>
<td>Gas</td>
<td>254</td>
<td>184</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>34</td>
<td>36</td>
<td>Arabella</td>
</tr>
</tbody>
</table>

Like Robert, Gwen uses significantly less gas and electricity than predicted. In part this can be explained by SAP assuming higher occupancy than is the case in both of these properties. However Gwen’s use of gas which provides her space heating is more than 50% lower than predicted, and this may be a result of her more frugal attitude towards energy use than Robert’s.
Jane also uses less energy than predicted and again this can be partly explained by her single occupancy of a two bedroomed terraced house (SAP will assume an occupancy of two). However her electricity use is around half of that predicted, unlike the predicted use for Gwen who lives in a two bedroomed apartment (Robert’s electricity use is also low, but he lives in a new three bedroomed terraced house, with assumed occupancy of three). One explanation for Jane’s low use of electricity is her avowed dislike of non-essential electrical gadgets.

Juliette’s gas and electricity use is slightly higher than predicted, even though a SAP assessment would have assumed more than single occupancy, as she has a 3 bedroomed semi-detached house. This might be partly explained by her house lacking a central thermostat and the age of her boiler, which is of a design that was first produced in the 1950’s. Although the actual age of the boiler is unknown, Juliette believes it is over 20 years old.

Wendy, who uses only electricity, has much lower actual use than predicted. This can in part be explained by her frequent absence from her one bedroomed apartment.

Anne’s is fully occupied, as she shares with two other people. A SAP assessment would not take account of electricity used in cooking, or to power gadgets such as televisions and laptops. As such, it might predict more savings that might actually result in practice. She uses 60% more electricity than predicted, and only 6% more gas.

Arabella uses less gas than predicted but slightly more electricity. Her two bedroomed house is shared with one other person. Although her attitude to energy use is quite frugal, she has thermal comfort needs that necessitate having an electric heater in her bedroom to boost temperature when necessary.

Table 84 outlines a summary of the UK participants’ total predicted energy, compared with their actual energy use.
Table 84 Total Predicted and Actual Energy Use UK Case Studies

<table>
<thead>
<tr>
<th>Total Energy</th>
<th>Predicted (SAP) kWh/m²/year</th>
<th>Actual kWh/m²/year</th>
<th>UK Case Study Participant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas &amp; Electricity</td>
<td>177</td>
<td>139</td>
<td>Robert</td>
</tr>
<tr>
<td>Gas &amp; Electricity</td>
<td>167</td>
<td>107</td>
<td>Gwen</td>
</tr>
<tr>
<td>Gas &amp; Electricity</td>
<td>262</td>
<td>205</td>
<td>Jane</td>
</tr>
<tr>
<td>Gas &amp; Electricity</td>
<td>199</td>
<td>220</td>
<td>Juliette</td>
</tr>
<tr>
<td>Electricity</td>
<td>222</td>
<td>98</td>
<td>Wendy</td>
</tr>
<tr>
<td>Gas &amp; Electricity</td>
<td>317</td>
<td>352</td>
<td>Anne</td>
</tr>
<tr>
<td>Gas &amp; Electricity</td>
<td>288</td>
<td>220</td>
<td>Arabella</td>
</tr>
</tbody>
</table>

Arabella’s house has adequate loft insulation (250 mm) but is constructed of solid brick. Her front door is made of wood and part single glazed, with double glazing in all the remaining windows. So one of the main likely Green Deal assessment recommendations would be to install solid wall insulation. This would result in significant energy saving, but it is very costly measure. As Arabella’s house is a similar age and construction to Juliette’s, but completely solid wall rather than part cavity, the installation cost would likely be in a similar range i.e. £9000.

As can be seen, apart from Juliette, and Anne, predicted annual energy use is higher than actual energy use, in some cases significantly. As has been discussed, one reason for the lack of correlation with actual energy use is because the SAP predictive analysis uses “standard occupancy” assumptions that do not always reflect actual occupancy patterns or behaviour.
The concept of standard occupancy is important in rating energy use in properties, as it provides a means by which people can use an Energy Performance Certificate (EPC) to compare one property with another (see section 6.2 Predictive Data). So although the Green Deal allows some consideration of occupancy, as it classifies energy use in properties as light, medium or heavy, the SAP assessment concentrates on the fabric of the building and the means of energy delivery.

SAP works by measuring the annual cost of maintaining an acceptable temperature regime in a property. The assumption is that an acceptable regime would be attained by heating the property to 21 degrees centigrade in the lounge and 18 degrees centigrade in other habitable rooms for 9 hours per week day and 16 hours at weekends. The calculation uses the size of the property to estimate a suitable average number of occupants and hence the hot water requirements for that number of occupants.

SAP estimates a thermal mass parameter based on the noted construction elements, such as walls, floors, doors, etc. and the total floor area. The heat loss associated with thermal bridges is the linear thermal transmittance. If this data is unknown (which was the case for the UK case study properties) the transmission heat transfer coefficient is calculated by reference to Appendix K in the SAP manual.

The predictive analysis of energy use will not take account of a four-bedroom property which has only one occupant rather than a family of four. Equally, a small flat might actually be occupied by a large family using considerable amounts of heat and hot water.

Thus the standard predictive analysis can have a wide variation when compared with actual energy use in a property. Nevertheless, recommended energy efficiency measures do make sense if they have an impact on cost and individual thermal comfort.
However, even allowing for this latitude in the SAP projection as compared with actual energy use, in many of the UK case studies the discrepancy is very large. In the case of Robert he actually uses less than half the amount of electricity predicted, even though SAP ignores any energy requirements for cooking or the use of other electrical items, such as computers and televisions, etc.

Gwen lives alone in a two-bedroom flat, yet her actual space heating cost is almost 40% less than predicted, even though whatever heat she used would permeate most areas of her flat.

Jane lives alone in a two bedroomed mid-terraced house, and uses around half of the electricity predicted by SAP.

Juliette lives alone in a three bedroomed semi-detached house. Her energy use is actually slightly more than that predicted by SAP.

Wendy lives alone in a one bedroomed mid floor flat. All her energy needs are supplied by electricity. She uses around 44% of the energy predicted.

Anne shares a three bedroomed semi-detached house with two other people. Her space heating usage is slightly more than predicted, and her electricity use is considerably more, no doubt reflecting on energy use by electrical items such as computers amongst members of the household.

Arabella shares the two bedroomed semi-detached house with one other person. Her space heating use (gas) is only about 70% of that predicted, yet electricity use is marginally higher. However, she has an electric heater in her bedroom, which she tends to use to ensure her thermal comfort.

**Temperature:**
SAP assumes people live at a temperature of 21° C in the main living area of the property, and 18° C in other areas. In Robert's case, there is little variation in the temperature of his house, whether there is an assumed occupancy are not (see section 6.2.1 Quantitative Results). His maximum daily occupied average lounge
temperature of 22.7° C, slightly exceeds that as assumed by SAP. However, his bedroom temperature averages over 20°C whether during occupied hours are not, and so is higher than the 18°C assumed in the predictive analysis.

As is the case with Robert, Gwen's temperatures show little variance between overall average temperatures and assumed occupied average temperatures. Although her heating is obviously turned off for around nine days of the monitoring period (see appendix 5) it is clear from the measurement of her daily average temperatures that are average lounge temperature is below the 21°C assumed by SAP (19° C) and average bedroom temperature is around 18° C (as assumed by SAP).

Jane's temperature analysis is also affected by periods when she was away with the heating turned off (approximately 16 days). This is around 13% of the monitoring period. Again, there is little difference between overall average temperatures and average temperatures during assumed occupancy. Despite the low daily average temperatures, which are affected by the lack of heating when Jane was away, it can be seen from the graphs that even when she was occupying the house, her maximum daily average temperatures only reach about 18°C in the lounge and slightly over 19°C in the bedroom. This explains to some extent why her energy use is so much less than predicted. Further explanation may be due to factors such as financial constraints, a lower personal thermal comfort threshold, wearing warmer clothes while at home, or a philosophical reluctance to waste energy (for which there is some evidence from the interviews).

Juliette was away for about five days towards the end of the monitoring period. Again, there is very little difference between daily average temperatures and daily occupied average temperatures, both in the lounge (nearly 20° C) and the bedroom (nearly 19° C). These temperatures are not wildly different than those assumed by SAP. Despite living on her own in the property, Juliet used more energy than was predicted. The reason for the difference between actual and predictive energy use could be due to multiple factors, which could include modelling inaccuracy, a particularly inefficient boiler and variation in occupancy times.
Wendy was away for about 46 days of the monitoring period, a significant amount of time during which her one bedroomed flat was left unheated. This represents about 39% of the monitoring period. Once again, there is little difference between overall average daily temperatures and average daily temperatures during assumed occupied times. In addition, there is not much difference between temperatures in Wendy's Lounge and her bedroom, which is not surprising, as it is a small flat with both rooms adjacent to each other. Looking at the graphs, and ignoring away periods, Wendy's approximate average temperature for both the lounge and her bedroom is around 18° C. So while this temperature is slightly lower than that predicted by SAP, much of her lower actual energy use can be reasonably attributed to the fact that she was away from the property for a significant amount of time, and consequently her heating was switched off.

Anne's house was unoccupied for about 14 days of the monitoring period, when she and her fellow occupants vacated the property over the Christmas holiday. Although this would affect overall average temperatures recorded, there was again little difference between overall daily average temperatures and overall daily average occupied temperatures. These were nearly 18° C for both the lounge and the bedroom. Looking at the recorded temperature graphs, the average would more likely be around 19° C if the unoccupied period was ignored. While the temperatures are slightly different than those assumed by SAP, what is interesting is the lack of variation between different rooms in the house. Despite these overall lower than predicted temperatures, the higher actual energy use in Anne's house is probably attributable to factors such as three adult occupants cooking independently and using a variety of personal electrical appliances.

Arabella's house was unoccupied for about 15 days over the monitoring period, as she and her fellow sharer were away over Christmas. Once again, there was little difference between overall daily average temperatures and overall daily average occupied temperatures, both in the lounge and the bedroom. However, there is a distinct difference between temperatures in these two areas. Average lounge temperatures are only about 15.5° C, while average bedroom temperatures are around 18° C. Allowing for the away period over Christmas, this would push the
average temperature of Arabella’s bedroom to around 20° C. The fact that Arabella has an electric heater in her bedroom explains the higher average temperature, and possibly also explains the higher than predicted electricity use for the property. The lower temperature in the lounge area could also be attributed to the fact that both Arabella and her fellow sharer are both postgraduate students, and have heated research areas available for their use on a 24-hour basis. Space heating from gas is significantly lower than that predicted by SAP.

Overall, Robert and Juliette (who are the two homeowners) live in properties with the highest average temperatures. Jane’s property records the lowest temperatures. Yet, because Robert lives in a newly built house, his energy bills are much lower than Jane’s. Wendy’s energy use is very low, but this is at least in part because she is absent from her flat on a number of occasions during the monitoring period. Gwen’s relatively modern flat also means that energy bills are low even though the data indicates that she lives in relative thermal comfort. Her energy bill is half that of Jane’s. Arabella’s bedroom temperature is consistently higher than the temperature in her lounge, indicating that she uses her electric bedroom heater frequently.

6.5 Discussion of Results

6.5.1 UK Case Studies
The UK case studies were chosen in order to try to gain deeper understanding of what factors would be important in motivating the participants to use energy more efficiently and/or more sustainably. The responses were related to some key strands in the literature covering occupant behaviour and energy use. The participants’ views can be considered in relation to these key areas.

The Green Deal is the UK government’s flagship policy intended to improve energy efficiency in existing residential buildings.
"The Green Deal will deliver energy saving packages to millions of homes .....across the country" (DECC, 2010)

However, the government's own statistics revealed that the policy is not so far having much effect, with 97% of installed efficiency measures done through the Energy Company Obligation. The ECO generally replaces two previous schemes (Carbon Emissions Reduction Target - CERT - and Community Energy Saving Programme - CESP) and concentrates on providing energy efficiency measures to low income and vulnerable consumers and those living in 'hard-to-treat' properties.

The number of households in Britain is approximately 26 million. Of this number around 8 million has solid walls. Of the remaining 18 million, nearly 14 million have cavity wall insulation. The total number of properties with satisfactory loft insulation is just over 16 million. Details of cavity wall and loft insulation are shown in figure 31 (DECC, 2014).

Homes in Great Britain with cavity wall insulation and loft insulation: March 2008 to September 2014 (Thousands)

- The number of properties with cavity wall insulation increased by three per cent (380,000) between the end of September 2013 and September 2014.
- The number of properties with loft insulation with a depth of at least 125mm increased by one per cent (220,000) between the end of September 2013 and September 2014.

Figure 31 UK cavity wall & loft insulation 2008 - 2014 (DECC, 2014).
Of the approximately 8 million solid wall household properties, very few are insulated with internal/external wall insulation, particularly since the start of the green deal. See figure 32 below (DECC, 2014).

Figures 31 and 32 clearly show that progress in installation of insulation measures in domestic properties was comparatively more successful prior to the onset of the Green Deal in January 2013.

Relative to the number required, Green Deal assessments have been relatively few at less than 360,000 since the scheme began (DECC, 2014) as is evident in figure 33. There are approximately 10 million households with inadequate loft insulation.
More importantly, however, the number of installations using Green Deal finance has been far less than the assessments, with the number totalling 7,939 to the end of November 2014. A breakdown of the types of measures installed is given in table 85 (DECC,2014).

Table 85 Green Deal measures installed to end November 2014 (DECC, 2014)

<table>
<thead>
<tr>
<th>Type of Measure</th>
<th>Number installed with GD finance</th>
<th>Percentage of measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boilers</td>
<td>1,881</td>
<td>24%</td>
</tr>
<tr>
<td>Cavity Wall Insulation</td>
<td>298</td>
<td>4%</td>
</tr>
<tr>
<td>Loft</td>
<td>Insulation</td>
<td>771</td>
</tr>
<tr>
<td>Photovoltaic Solar Panels</td>
<td>2,279</td>
<td>29%</td>
</tr>
<tr>
<td>Heating Controls</td>
<td>587</td>
<td>7%</td>
</tr>
<tr>
<td>External Wall Insulation</td>
<td>1,254</td>
<td>16%</td>
</tr>
<tr>
<td>Other Insulation</td>
<td>741</td>
<td>9%</td>
</tr>
<tr>
<td>Other Measures</td>
<td>128</td>
<td>1%</td>
</tr>
</tbody>
</table>

Figure 33 Monthly assessments since the start of Domestic Green Deal to end Nov 2014 (DECC, 2014)
In March 2013, Greg Barker, then Minister for Energy and Climate Change, said he'd have sleepless nights if less than 10,000 people had signed up for a Green Deal by the end of that year (Paxman, 2013). Barely more than 1,000 people had gone ahead with the scheme by the end of November 2013. Although that target was not reached even after two years, as we have seen from this research what counts as a "Green Deal" can be questionable, as in the case of Juliette.

Some of the reasons that the Green Deal is not being effective include:

- The Green Deal's Golden Rule does not take into account the true (social) cost of carbon emissions. If the cost of externalities was included as advocated by Tol (2007) and Stern (2009) there would be a big incentive to use more sustainable energy. This could increase the demand for domestic ground and air source heat pumps and for solar panels, which currently require subsidy to be competitive with fossil fuel energy.
- The savings calculated to obtain Green Deal finance are not determined on a net present value basis. Nominal savings over the life of the energy efficient measure are estimated and only savings made in the first year after installation have to be guaranteed.
- The structure of the green deal is convoluted, with assessors originally intended to be independent from installers and providers (as is confirmed by Juliet's experience, this is not always the case). This means transaction costs are increased for all the actors involved with energy saving installations.
- Evidence from this research points to knowledge of the Green Deal being limited amongst UK participants who were not already involved in the energy efficiency sector. For example, the landlords interviewed and Juliette, who is a teacher, had little knowledge of this policy before it was explained to them during the research.
- Very few energy improvement measures are likely to be cost-effective (Bowen and Rydge, 2011) and a real example of this is shown in appendix 2.
- Because of the relatively long payback period from many energy improvements, risk and uncertainty over future energy costs represent a real barrier to uptake. The empirical results from this research support this view.
This research clearly showed that the UK case study participants did not find the Green Deal an attractive proposition. This was largely because of the uncertainty in financial savings that will apply, as well as the reluctance to potentially take on long-term debt against a property. Some participants felt that this would be a negative if they wished to sell the property before the Green Deal finance was paid off.

While participants liked the idea of the policy, they were only likely to take it up if it was clearly financially competitive or unless they had no other option (Section 6.3.1.7 Key Question 7, Attitudes to the Green Deal). Currently the green deal interest rate is 6.8%, a good deal higher than the market rate for credit worthy borrowers. Following the initial research involving Juliette, as has been mentioned, she installed solid wall insulation after being offered a very generous subsidy. One interesting point was that £385 was the finance provided under the Green Deal at 6.8% interest over 25 years. This was only 4.8% of the total installation cost. The balance after the subsidy of approximately £2600 was payable on completion of the installation.

Interestingly, the experience of Juliette seems to make the recommendation by James (2012) to allow residents to make up the difference between the cost of an energy efficiency measure and the amount of finance available for it under the Green Deal golden rule redundant. In Juliette's case, the provider simply reduced the amount nominated as green deal finance to easily meet the necessary requirements, and simply charge the rest as a direct installation cost. Despite the tiny percentage (4.3%) of the cost of the work being provided by Green Deal finance, this was enough to allow the work to be classified as a green deal installation. If many other of the recorded Green Deal's have such a small finance element, then it could mean that the policy is even less successful than it appears statistically.

The Rebound Effect is another reason the Green Deal is an ineffective policy. Saunders (1992), Sorrell (2007) and many others, including a pending paper by Adetutu, Glass and Weyman-Jones (2015), confirm through their research that
energy savings from improved energy efficiency measures result in a less than proportionate reduction in energy consumption resulting from improved efficiency gains. In fact, research shows that on aggregate increased energy efficiency can lead to increased economic growth (Thomas & Azevedo, 2013). If this growth depends on energy from fossil fuels, then CO₂ emissions are likely to increase, at least partially offsetting residential efficiency savings.

Although the Green Deal is a clever idea in so far as savings made from installing energy saving measures must be greater than the cost of those measures, thus making their implementation financially worthwhile, it is reasonable to wonder what will happen to those savings. At least initially the policy is well conceived in that it does not allow the homeowner to gain the benefit of those energy savings, or at least not to any great degree. The money saved usually goes to pay off the energy saving measure over a period of time. This is likely to mute the strength of the rebound effect.

However, at some point energy saving measures are likely to result in a real reduction in energy costs to the householder. In these circumstances, it is not hard to imagine for example, an energy saving of say £400 a year being used for:

- a household in fuel poverty, using the money to gain greater thermal comfort, thus using extra energy that way.
- Middle-class households using the money to go abroad for a holiday, creating extra energy demand that way.
- A frugal household, putting the money in the bank, thus allowing the bank manager to loan the money to an entrepreneur wishing to expand his or her business, creating extra energy demand that way.

Even before any energy savings are available to the household as a result of a Green Deal installation, the fees paid to the assessors, installers and providers is likely to result in extra energy use.
With regard to this research, in the case of Juliette, her green deal was a tiny proportion of the cost of the actual installation, most of which was paid for via a subsidy. Her predicted saving is over 40% of her as assessed energy use, which is approximately a saving of £450 per annum. As her actual energy use is 10% higher than predicted, her actual monetary saving could be in the region of £468 per annum. Because of the subsidy (and she was given a free Green Deal assessment) she is likely to start reaping the benefits of cheaper energy costs within four years. The solid wall insulation which she has had installed is guaranteed for at least 25 years. During a discussion in the focus group, she indicated that she would spend any savings made on activities which use energy (as did many of the other participants).

Provided it is accepted that the rebound effect (Saunders, 1992. Sorrell, 2007) exists (and this seemed to be accepted more clearly by the UK Case Study participants than the Other UK Stakeholder policy makers), then savings from residential energy efficiency measures effectively displace a potentially significant level of demand for energy in the home to elsewhere in the economy.

So if the Green Deal was massively effective, and the entire existing housing stock of the UK was refurbedished over the next six months, hypothetically the net effect could be an increase in energy demand. As long as this demand is being met predominantly through the use of fossil fuels, then the "success" of this policy, could lead to an increase in carbon dioxide emissions.

It can therefore be argued that instead of the Green Deal, it would be more sensible to have a policy that directly targets the use of fossil fuels.

**Human irrationality and Nudge theory** (Thaler 1994) were confirmed in this research as factors influencing residential energy use. The research participants generally concurred that their thinking was not always highly rational, and as Kahneman (2011) suggests, they often adopted the System1 mode of thinking (see section 6.3.1.5 and 6.3.1.6). Government in particular, as a large organisation, was viewed by most participants as having the capability to influence behaviour around energy use in the residential sector. It has the potential to alter
heuristic behaviour to achieve more favourable outcomes using marketing and advertising measures to influence opinion. Importantly, it can also use regulation to impact on energy use, and does so with increasingly rigorous building regulations. It could, for example, require existing buildings to reach a minimum energy efficiency standard before they could be sold.

During a focus group discussion (see section 6.3.4) the participants overwhelmingly agreed that governments had a role in nudging people in the right direction, and also that governments have a responsibility to regulate in order to influence energy use.

When it came to a person's social identity, determining their choices around energy use (Ackerlof & Kranton 2000, Vale & Vale 2010), participants felt that the actions of government or other large organisations could have an influence on changing culture, and thus an individual's social identity. However, it was felt that this sort of change would be slow, perhaps taking years to change behaviour. It was felt that small steps could be effective, and an analogy was made to the example of stopping people using plastic bags by charging 5p for their use.

Existing cultural influences coloured the participants' views which were mixed regarding the effects of education, and the desirability of nuclear power. Views were also mixed on whether more information on energy use, including smart meters or differential tariffs, would be significant in changing energy use behaviour. As has been pointed out not everyone would be able to take advantage of differential tariffs or alter their energy needs.

The majority of participants had some concern about the effect of world population growth (although this was more accentuated in Australia), as the related growth in world energy demand could overshadow any efforts the UK made to reduce CO$_2$ emissions. This could be another reason why participants wanted government to act on their behalf.

The response of the participants to the idea of energy prices reflecting their real costs (Tol, 2007, Stern 2009), including externalities, was mixed. This is partly
because people felt they wanted to clearly understand how this real cost was calculated (and, in truth, it is almost impossible to cost externalities such as security of supply, the effects of pollution, and climate change - see section 3.4.3, which demonstrates a wide range of estimates). It was also because finance was generally a major factor in the participants lives, so when it came to energy use, if they had to pay an effective tax on their energy supply, they were very concerned on how this extra money would be spent. This highlighted an interesting tension on how participants viewed government. On the one hand, they expected government to influence their energy use (perhaps through education, marketing, advertising, etc.) as well as regulate standards around that use. On the other hand, perhaps unsurprisingly, they were resistant to paying more tax.

**Financial incentives** (or disincentives) were clearly a major factor in influencing the participants’ energy use at home. However, their importance was relative to the participants income (see Jane, section 6.3.1.7). A participant's reduction in energy use was also limited by their desire for thermal comfort and their ideology. An indication of this is provided by assessing the actual temperature and measured energy data for each case study. For example, on average Robert prefers to live at a higher thermal comfort level than Gwen, and Gwen prefers a higher thermal comfort level than Jane. It is important to note, however, that the fabric of each participant's dwelling plays a significant role in actual energy use. Despite Jane's frugal use of energy, it still costs her more than Robert, who lives in a modern, well insulated house.

While the importance of financial incentives was acknowledged by the participants, the nature of those incentives needed to be aligned to the participants' needs. Hence the general reluctance to regard the Green Deal as a positive measure. Attitudes were also mixed with regard to the idea of a carbon allowance or a carbon tax.
6.5.2 UK Participants - A synthesis of Quantitative and Qualitative Research

Findings

It is informative to compare the actual energy use of the UK case study participants with their attitude to energy use. In this study, the average temperatures, which in many cases include periods when participants are absent from their dwelling, are less important than noting the temperatures at which they live when their premises are occupied. Despite the fact that there are differences in attitude to energy use, there is generally not a great difference in bedroom temperatures between the participants when they are in occupation of their dwellings. This could indicate that in many cases good intentions with regard to energy saving are overridden by the participant's requirement for thermal comfort (see figure 28). A good example of this can be explained by reviewing the behaviour of Arabella. There were a number of occasions when her bedroom temperature reached nearly 30°C. When the researcher asked her about this, she explained that for medical reasons each month, she commonly increased her bedroom temperature during the evening for a number of days. This alleviated any actual or psychological pain she felt at this time. This kind of finding offers an explanation as to why it is important to record predictive, actual, and intended behaviour with regard to energy use, as well as understand the reasons behind these behaviours (i.e. there can be a disconnect between intention and behaviour).

Robert: Robert keeps his average bedroom temperature, which is nearly 21°C, at a higher level than his lounge (see figure 24). Yet he claims that he would prefer his house to be warmer, if his finances would allow it (see comments after table 42). Despite this, his energy bill is lower per square meter than most of the other participants. His house is only three years old, so this highlights the positive effect of building regulations on newly built properties. His attitude also confirms the importance of thermal comfort in overriding other attitudes around energy use. Living at a bedroom temperature of 21°C is 3°C higher than that assumed by the government's Standard Assessment Procedure (SAP), so under the government's assumption, Robert could reduce his bedroom temperature by 3°C and still live within the SAP implied definition of ‘comfortable’, thereby improving his finances, which he claims are of importance to him. However, he does not choose to do this, and it is interesting to note that there are degrees of needs and wants, some of
which are driven by emotional desires and others by the necessity to survive. In Robert's case, his need for thermal comfort overrides his need to save money.

**Gwen:** Gwen has the second lowest energy use of all the UK study participants corrected for property size, and the biggest difference in predicted energy use from actual. Despite this, she recognises that there are enormous complexities behind the reasons people use various levels of domestic energy (see comments after Table 39). Her average bedroom temperature is just over 18°C, less than 1°C lower than the average in her lounge. Probably because of the size of her dwelling, which is a relatively small two-bedroom flat, temperature variance is relatively low. Despite her low energy use, she said she ranks thermal comfort as important a driver as finance in determining how much energy she uses. However, she may not have the same thermal comfort needs as Robert,(or she may wear warmer clothes, although the researcher has no evidence of this) which could contribute to her low energy use in her well insulated, modern, top floor flat.

**Jane:** Jane uses nearly twice as much energy as Gwen and regards money as a key driver behind her energy use (see comments after table 42). Even so, her predicted energy use is 28% greater than her actual. This is because the predictive analysis provides results heavily weighted depending on the age of the property and the number of assumed occupants. However her thermal comfort needs seem to be lower than normal, averaging just over 16°C. This could be explained by her wearing warmer clothing, which would have a money-saving benefit. However, the researcher did not see any evidence of this on visits to the property. Nevertheless, her greater energy use highlights the difference between living in her older circa 1900 terraced house, which is likely to be less well insulated and airtight, and a modern property.

**Juliette:** Juliette uses slightly more energy than Jane. Her property was built in the 1930s, and is semi-detached, so there may be more heat loss through the walls, compared to Jane's mid-terrace property. Juliette's predicted energy use is 10% less than her actual energy use. It is not clear why this is the case, as she lives in the property on her own, and predictive modelling would assume an occupancy of 3 people However, her average bedroom temperatures are nearly
19°C, less than 1°C lower than average temperatures in her lounge. Her heating control is poor, as the property has no wall thermostat, and neither do the radiators have thermostatic controls. So it is likely that heat defuses fairly evenly throughout the property. Like most of the UK case study participants, Juliette’s attitude toward energy use is motivated by cost (see comments after table 46). However, she does not seem to directly associate this with the lack of control she has over domestic energy use. This supports Guy & Shove's (2000) analysis that a lack of knowledge and information are barriers to the adoption of energy efficiency measures.

**Wendy:** Wendy lives in a small, one bedroomed flat and has the lowest energy use of all the UK case study participants. Because her energy use is quite low, she is not very aware of it, but would like to know more (see comments after table 37). During the period of research Wendy was absent for a significant periods of time, and this lowered average temperature measurements. Because of the size of her flat, there was little difference between her lounge temperature and her bedroom temperature, and as can be seen from figure 60 when Wendy was present, her flat was often at a thermally comfortable 20+ degrees centigrade. Because of her extended periods of absence, it is not easy to assess her typical thermal comfort levels.

**Anne:** Anne shares a 1930s, three-bedroom (the downstairs living room is used as a bedroom) semi-detached house with two other people. Because of this her energy use is the largest recorded amongst all the UK case study participants. However, divided by three it equates well with Arabella, who shares with one other person. It also means that her individual energy costs are the third lowest in the group of UK participants. This highlights the benefits of sharing, although no doubt a certain amount of privacy is foregone. Her attitude towards conserving energy is very positive, but she concedes that she doesn't always put her intentions into practice (see comments after table 33). Because of absence from her house for about 20% of the monitoring period, the averages recorded are affected. Looking at actual measured temperatures when Anne was in residence, it can be seen that average bedroom temperatures were approximately 19°C. This sort of thermal comfort level is similar to most of the other UK case study participants.
Arabella: Arabella lives in a semi-detached, two bedroomed house which she shares with one other person. As the house was built circa 1935 it is not particularly energy efficient. Arabella regards frugal use of energy as important in itself, regardless of the financial cost (see table 42). That is not to say that, to her, finance is not also an important factor. Her energy use is the same as Juliette's, but because she shares her house, individually, it is much less per person. However her electricity use is slightly higher than that of the other participants, because of the electric heater she has in her bedroom (explained above). As can be seen from figure 70, Arabella's thermal comfort levels in her bedroom could be estimated at 21°C. This is significantly warmer than the temperature is in her lounge, so it could be surmised that the lounge area is not used particularly frequently.

In general, then, it can be seen that attitudes and behaviour don't always match perfectly and thermal comfort requirements vary from individual to individual. The combined evidence from this research seems to point to the fact that many people will put their thermal comfort needs ahead of conceptual viewpoints that they may wish to follow in principle. This makes influencing individual behaviour more difficult as those offerings which people say are attractive may not be sufficient to override what people regard as necessary thermal comfort needs. Gyberg & Palm, (2009) do not take account of this in their analysis of behavioural incentives. To make things even more complicated, thermal comfort forms part of adaptive behaviour. In equatorial climates, people become used to the warmer temperatures and feel thermally comfortable at temperatures that are significantly higher than those prevalent in temperate zones. Equally, in colder climates, many people get used to wearing far warmer clothing, and thus require less energy to maintain a comfortable body temperature (Parsons, 2003).

So an interesting aspect revealed from this research is that the intention to save energy does not always lead to energy-saving activity. This can be seen when comparing some interview comments from UK case study participants with their actual energy use (e.g. Arabella). As such, it is worth considering thermal comfort in more detail so that its constraints on behaviour can be more clearly understood.
As we have seen, UK case study participants in this research have the capacity to adjust their thermal comfort, through wearing warmer clothing, increasing their space heating temperature or adapting physiologically to preserve deep body temperature so that it is well within the necessary requirements for survival. However, while thermal comfort may be a constraint on influencing behaviour through energy policy, UK case study participants do conform to regulation and state their willingness for the government to take a lead on influencing their energy behaviour. There may, for example, be a case for launching energy policies at particular times of year. Would a push to adopt better insulation have more take up in the autumn, with winter approaching (especially if supported by a nudge campaign)? Should the installation of solar panels be more aggressively marketed in the spring (perhaps with some time limited financial incentives)?

6.5.3 Australian Case Studies
The Australian case studies were chosen in order to compare attitudes towards residential energy efficiency between two very different energy environments. In Australia, there are abundant potential energy sources, and the vast size of the country means that pollution is a minor factor, and energy consumed within Australia is not a large contributor to climate change on a global scale. In practical terms, no one is worried about energy supplies running out or energy security becoming an issue.

Unlike the UK, there is no overarching national strategy such as the Green Deal to encourage residential energy users to use energy more sustainably. Perhaps because of the lack of a cohesive national government led plan to encourage sustainable energy use, Australian participants felt more strongly about the importance of collective action.

Like the UK, Australian participants generally would have liked to have had more control over the sustainability of the energy they were supplied. They were sceptical, however, as to whether green tariffs actually meant the energy they used was more sustainable.
Despite the plentiful availability of uranium, the Australian participants did not favour using nuclear energy. This is unsurprising given the negative connotations many people have in relation to nuclear power, and the many alternative sources of energy available. Also, respondents didn't feel at least without special effort, that renewable energy would be sufficient to provide all their energy needs.

Interestingly, while views on the importance of education were somewhat mixed, culture was seen as an important driver in influencing energy behaviour. It could be argued that there is some contradiction here, as education is one factor influencing culture in the long run.

Australian views were mixed on with regard to more information on energy use, including smart meters or differential tariffs. In large measure, this was due to limited availability of these technologies.

In general, participants viewed the projected increase in world population growth as a worrying development with regard to climate change.

In Australia human irrationality (see section 6.3.3.5) and the role of government to both legislate and influence energy demand behaviour by nudging people in the right direction (see section 6.3.3.6 and 6.3.3.2) were also confirmed as factors in determining residential energy use.

As in the UK, financial incentives (or disincentives) were confirmed as a key driver behind energy consumption in the residential sector (see section 6.3.3.7). However, there seems to be fewer caveats to the importance of energy costs compared to respondents in the UK. This may well be because of the more amenable Australian climate (although this research was limited to Melbourne weather conditions) and the lower pressure for participants to think ideologically. Because of the small population individual energy use can be less attributed to causing climate change, energy security and supply is not an issue because of the availability of energy sources within the country, and pollution does not pose a problem.
Attitudes were also mixed with regard to the idea of carbon allowance or a carbon tax (even though a carbon tax was in place at the time of the research).

### 6.5.4 A comparison of UK and Australian Case Studies

As has been discussed in section 3.5 (see table 9), there have been a series of initiatives in the UK since 1989, which has consistently increased the pressure to use energy more sustainably and efficiently throughout all sectors of the economy. All the main political parties have broadly supported this development in energy policy. In the domestic sector, the Green Deal policy has not faced any significant political opposition, despite its lack of momentum to date. In contrast, Australian energy policy is both fragmented and in a state of flux (see section 5.4.1). Victoria State does not, so far, implement residential energy regulation as part of a national structure, and with the scrapping of the National Carbon Tax replacement policies have not yet been implemented and are still under discussion by the Federal Government.

The Australian Department of Climate Change and Energy Efficiency (DCCEE, 2012) still confirm Australia as one of the top carbon dioxide emitters per capita. However, if the Australian carbon tax had remained in place, emissions were projected to drop by nearly half between 2012 and 2030. It is a matter of speculation as to what the effect of any eventual sustainable energy policy may be. Figure 34 shows the breakdown in domestic energy use by energy type in Petajoules (PJ). A petajoule is a large unit of energy equivalent to one thousand million million joules of energy, or nearly 288 million kilowatt hours (KWh). 1 Megawatt hour (MWh) = 1000 Kilowatt Hours (Kwh). 1 tonne of oil equivalent (Mtoe) = 11.63 MWh. So in figure 35 then 288 million KWh is approximately 24,763 toe (or 1 PJ). 225 PJ is around 5.5 Million tonnes of oil equivalent (Mtoe), the Australian electricity use and 150 PJ is around 3.7 Mtoe, the Australian natural gas use. Total energy consumption is in the order of 10 Mtoe (in 2011).
The UK domestic sector breakdown is represented in Figure 35 below.

**Domestic consumption by fuel (Mtoe), UK (2014)**

![Pie chart showing energy consumption by fuel type]

- Natural gas, 23.9
- Petroleum, 1.6
- Solid fuels and heat sold, 0.6
- Bioenergy and waste, 1.7
- Electricity (including renewable electricity), 6.4

Figure 35 UK Household Energy Consumption by fuel 2014 (DECC, 2015)

In 2014, energy consumption from the UK domestic sector (excluding transport use) was 38.2 million tonnes of oil equivalent (Mtoe).
While exactly comparable figures were unavailable for this research, it would not be unreasonable to estimate total Australian domestic energy use in 2014 as approximately 11 Mtoe. This is for a population of approximately 22 million (WPR, 2015) and equates to 0.5 toe per capita. With UK domestic energy use at 38 Mtoe and a population estimate of 63 million (WPR, 2015), this equates to 0.6 toe per capita approximately. So, Australian domestic energy use could be said to be slightly less than in the UK. Electricity is however a far greater component of Australian domestic energy use (see figure 34 and 35), and a large proportion of this, around 90%, is generated using fossil fuels, of which coal represents around 68% (Byrnes et al, 2013). This way of generating electricity is far less efficient than doing so using renewable energy or nuclear power, because much of the fossil fuel energy source gets wasted as heat in the generating process. In the UK, most domestic space heating relies on gas being pumped directly into the home before it is combusted to produce energy for heat. This is more efficient than a large power station burning gas to generate steam required by a turbine to produce electricity.

Table 86 shows a comparison of per capita energy consumption between the UK and Australia.

Table 86 Comparison of UK/AUS per capita energy consumption

| Per capita UK/Australia Household Energy Consumption in Million tonnes of oil equivalent (Mtoe) |
|--------------------------------------------------|--------------------------------------------------|
| UK                                               | 0.6 Mtoe                                         |
| Australia                                        | 0.5 Mtoe                                         |

6.5.4.1 Individual viewpoints

In both the UK and Australia, there was overlap between individual viewpoints. Jane (UK) (see comments after table 35) has a strong ideological belief that energy should be used sustainably and efficiently. Sue (Aus) (see comments after table 63) also has a strong ideological belief that she should control how she uses
her energy, to the point where she is building her own house which is off grid i.e. generating her own power requirements from solar panels.

The impact of culture on energy use (see sections 6.3.1.3 and 6.3.3.3) was more positive in Australia than in the UK. One could argue that this may be because there is a stronger status quo bias in the UK due to its rich and ancient history. Australia in contrast is a younger country subjected to cultural influences from antipodean countries in Europe and North America as well as South East Asia. This positive outlook did not go as far as endorsing very far reaching cultural change. There was no suggestion by either participants in the UK or Australia that they would be predisposed to adopt a living systems based approach, where people live in as self sufficient a way as possible, growing part of their food and disposing of much of their own waste as postulated by Reed (2007) and Vale & Vale (2010). Even Sue (Aus), who was building her own off grid dwelling, was still planning to spend a number of months of each year living in a normal house in the USA (her husband was American). Nevertheless, in both the UK and Australia there were mixed views on how education could influence culture. Some participants felt that education designed to affect energy behaviour had differential effects amongst different groups. For example, wealthy people might be more inclined to satisfy their energy needs because they could easily afford to, as there were few obvious negative effects in the short term. Other participants believed that education had a role to play in influencing culture, but that it would a very slow acting remedy.

Again in both countries there were mixed views on the value of more information regarding domestic energy use. Both smart meters and differential tariffs were seen as useful, but not necessarily very effective. Isacsson et al. (2006) argue that total knowledge of all energy related activity is necessary to encourage more efficient energy use, but for those participants such as Arabella (UK) and Angela (AUS) that were sceptical (see sections 6.3.1.4 and 6.3.3.4), a similar argument was put forward, which was that some people don't have a choice as to when their energy demands need to be met.
As has been pointed out earlier in this research, participants in the UK and Australia were strongly of the opinion that people did not always behave rationally with regard to their energy use. They were also strongly of the opinion that government was the best agency to both regulators energy use and influence energy use behaviour.

The effects of a vast world population in the future was considered by Australian participants to be more likely to have a negative impact on energy use (i.e. increase the use of fossil fuels, thus affecting climate change) than research participants in the UK.

When it came to the effect of finance on energy use, most participants in both countries were clear that it was an important driver behind their energy use. However, participants in both countries had mixed views on a carbon allowance or a carbon tax. This reflected a general distaste for taxation amongst most of the participants. When they stated that they might accept some form of taxation, it was contingent on them being very clear as to how the tax might be used. The implication was that hypothecated taxation would be more acceptable.

6.5.4.2 How does the Australian research inform UK energy policy

A point worth noting is that domestic energy in Australia is required for both heating and cooling, whereas in the UK the requirement is largely for space heating. However, in Victoria state (particularly in Melbourne, where most of the research was carried out) most of the domestic energy requirement is for heating. This was confirmed by Bruce during his interview. "Yes, so I'd say 90% heating. So we've got an in-duct heating system so when it heats up, it heats up all the house".

Nevertheless, Australian energy policy can be said to be a huge success in terms of encouraging sustainable energy use. Mountain & Szuster (2014). explain that Australia has the highest market penetration for domestic solar panels of any country in the world and that this was achieved by offering significant subsidies. This compares well with the UK Green Deal, which has unsuccessfully targeted energy efficiency, as distinct from energy sustainability.
While the climate in Australia may favour solar power, the climate in the UK lends itself quite well towards the development of wind power. Given the similarity in attitudes between UK and Australian research participants, it may be that significant subsidies to encourage community wind farms on the outskirts of towns and villages, could form the basis of a successful UK domestic energy strategy.

6.5.5 Other UK stakeholders
The other UK stakeholders were included in the research to offer a different perspective on the motivations behind residential energy use.

Collective action driven by an individual sense of responsibility was generally considered important by this group of stakeholders (see section 6.3.2.1). However, it was recognised that in practice householders had little choice in choosing the sustainability of the energy they received.

This group also had mixed views on the effect of education on energy use. This is perhaps because energy is a derived demand, and people are more concerned about the cost of energy using capital equipment than the cost of the energy itself. When it came to the influence of culture, views on energy sustainability were mixed. Unsurprisingly, a political view was that it was better to incentivise people than to penalise them when it came to encouraging responsible energy use.

Views on nuclear power were also varied. The landlords tended to be insufficiently informed, environmental group participant had a negative view, and the energy group participants had positive views.

Views were overwhelmingly positive around having more information on residential energy use, such as the use of smart meters. Opinions on the use of differential tariffs are more mixed. Views on the rebound effect accepted its existence but seemed to weigh the economic gain from increased energy efficiency above the impact on climate change.
Human irrationality and Nudge theory were both considered important factors in determining energy use in the residential sector. It was generally agreed that most people did not think very rationally when it came to energy use (see section 6.3.2.5), but that it was desirable to change this behaviour. Also the role of government and other large organisations was considered important in nudging people to behave more sustainably around energy use.

There were mixed views on the importance of Financial Incentives. This is not to say that energy costs were not important, but this group by its very nature (a professional income group) were likely to find energy use more affordable in general. The environmental group participant made the point that to change energy behaviour in "Middle England" it would require a huge increase in energy costs.
CHAPTER 7. Analytical and policy conclusions, including research limitations and further work recommendations

This research undertook a study to assess how financial and non-financial incentives influence energy demand in residential property. This was done by evaluating previous research in this area, and choosing a case study approach to investigate people's motivations to use energy more efficiently and/or sustainably in the residential sector. Section 7.1 reviews the analytical conclusions of the research that was undertaken. Section 7.2 considers the policy conclusions that can be drawn from the study. Section 7.3 evaluates the research limitations that need to be considered. Section 7.4 outlines further work recommendations that are suggested as a result of the information gathered in this thesis.

7.1 Analytical Conclusions

The case study approach was deemed to be appropriate, as it allowed a deeper understanding of why people were motivated around energy use, than a larger scale statistical analysis would have yielded. More rich data was obtained than would have been likely if a large scale questionnaire survey was undertaken. For example, the actual proportion of Juliette's Green Deal as a percentage of her efficiency measures would not have come to light. In Australia, Ellie's response to her husband purchasing an energy saving showerhead would not have registered on a Likert scale questionnaire. Her response reveals that some energy-saving equipment has unintended consequences, such as being used for a longer period, thus saving no energy, but increasing consumer dissatisfaction.

The study found that there was a regular interaction between governments, environmental groups and energy suppliers, and that this assisted in the exchange of ideas and planning to influence consumer behaviour so that energy was used more sustainably. As expected, lobbying, also took place amongst these groups and there was an acceptance by the environment group participant that "behind closed doors" large energy companies might well have discussions that would
influence energy policy. Their huge scale and ability to invest (or disinvest) in critically important infrastructure clearly gives them some influence on policy to protect key areas of their business. The energy company executives felt that it was clear that in the future more and more energy would be provided by decentralised renewable power, which would replace large fossil fuel power stations. Within the constraints of having to make a profit for their shareholders, they were working to adapt their business model to profitably provide renewable power.

In addition to a quantitative and qualitative analysis of seven case study participants in the UK, comparison was made with six case study participants in Australia. To give the study a broader scope, interviews in the UK with three residential landlords, one senior local politician, one senior specialist, an environmental organisation, and two senior executives in an energy company were also incorporated.

7.1.1 Contribution to Original Knowledge
This research clarified several aspects concerning the motivations behind domestic energy use.

a) The Green Deal is bound to fail as a domestic energy policy. This is for a number of reasons:

- It does not include the true cost of carbon emissions, and if it did so, this would make installing energy efficiency measures far more attractive for domestic consumers of energy.
- Its structure is unnecessarily convoluted, and this increases transaction costs between parties leading to an interest rate charge that is uncompetitive.
- Energy savings are not calculated on a net present value basis and in any case are uncertain for most efficiency measures, leading consumers to be wary of engaging with this policy.
• Even if the Green Deal was incredibly successful, it takes no account of the Rebound Effect. Most domestic participants taking part in this research agreed that they would be likely to spend energy efficiency savings made in their homes on other energy using capital elsewhere in the economy.

So, the Green Deal should be scrapped as a domestic policy, and replaced with a policy that concentrates on encouraging the use of sustainable energy rather than solely improving energy efficiency.

b) Nudging people to change their behaviour was seen by most domestic participants as an effective means of changing behaviour. Participants did not see it as a fast acting remedy, and often as more effective if used in tandem with government regulation. An example of this is attitudes towards drinking and driving. Prior to government campaigns to change behaviour, it was illegal to drink alcohol and drive. However, 30 years ago many people ignored the drink - drive law, and there was a general culture that breaking it was acceptable. Today, most people would take a pejorative view of anyone caught driving while over the alcohol limit.

c) The comparison between UK and Australian domestic energy policy. It was interesting to note that despite very different energy regimes, common ground was found across most domestic research participants in factors that they thought would motivate them to alter their energy demand behaviour. These included financial incentives, government "nudge" to alter heuristic behaviour, government regulation, and policies that would mitigate the Rebound Effect. Where financial incentives could be effective in encouraging the development of sustainable solar power in Australia, this common ground could mean that along with other strategies, significant levels of financial subsidy could be effective in developing sustainable community wind power in the UK.

d) The disconnect between intention and behaviour with regard to domestic energy use. The research reveals examples where domestic participants in the UK did not always align their intended energy use behaviour with their actual energy use behaviour. For example, Robert, Gwen, and Arabella all allow thermal comfort to take precedence over their avowed intention to use energy more efficiently.
7.1.2 A Reflective Assessment of the Meaning of this Research
This thesis set out to develop a greater understanding of residential energy use, and residential users’ motivations to use particular types of energy. It reflects a need to understand what drives the preponderance of fossil fuel use in the residential sector. The importance of this understanding is clear. Fossil fuels are causing climate change, a development that could eventually have devastating consequences for the world as a whole, as well as local effects that could be unwelcome and unpredictable.

In addition, fossil fuels are a limited resource. Despite continued discoveries of new sources of hydrocarbons, it is clear that these sources of supply will eventually run out or become so expensive to access that they will effectively be unobtainable. Mankind is using, in a few hundred years, energy resources that have taken billions of years to accumulate. Energy use in this way is clearly not sustainable, and so we need to develop sufficient alternative sources of energy to sustain future generations.

Another reason fossil fuel use is undesirable in the UK (but not in Australia) is strategic. As section 1.2 explains, the UK is not energy independent. As a net importer of approximately 28% of its energy use, and with energy demand increasing, dependency on imports leaves the country vulnerable to potential energy shortages in the event of political disagreements with supplier countries. Security of energy supply necessitates, at least in part, a move away from dependence on fossil fuels.

A final reason for avoiding the use of fossil fuels, which is somewhat less important nowadays, is the tendency of these fuel types to create pollution. This particularly applies to coal and oil. However, coal is slowly being phased out and being replaced by gas and renewable sources of energy, and oil is mainly used in the transport sector.

So, this research wanted to understand more clearly what would motivate residential energy users to use more sustainable forms of energy. This is against a background of a lack of clarity around occupancy behaviour with regard to energy
use. Previous research tended to concentrate on one aspect that could influence residential energy behaviour. Attribution ranged from financial incentives (such as the Green Deal), poor cognitive choices (Thaler, 1994), sub optimal decision-making (Kahneman, 2011), lifestyle choice (Vale & Vale, 2010), and the failure to include the cost of externalities in the fuel source (Stern, 2009. & Tol, 2011).

The research has provided the insight that attitude does not always correlate with behaviour. There can be many reasons for this, as has been explained in section 6.5. One of the most interesting is the effect of thermal comfort on behaviour. While this was more clearly demonstrated in the UK research, Australian participants also agreed that people do not always behave rationally (it is a reasonable, rational assumption to expect that people's attitudes influence their behaviour). This insight is important as it makes energy policy more complex.

Another important piece of knowledge with regard to both countries is that financial incentives can be very important. While this may seem obvious, what has transpired from this research is that financial incentives need to be quite large to be effective. They also need to be tailored to the individual, or at least to a group of individuals. Disparities in wealth will lead to some extent to disparities in motivation.

Despite the very different energy regimes in the UK and Australia, it was interesting to note that energy consumption per capita was similar in both countries. There were also similarities in mixed viewpoints. Participants were uncertain as to the value of better information with regard to their domestic energy use (i.e. the availability of smart meters and differential tariffs).

With regard to policy, both respondents in Australia and the UK were generally unwilling to undergo any far reaching cultural change, such as adopting a living systems based approach. Indeed, the idea of government taking responsibility for more efficient energy use rather than the individual resonated well with both sets of participants. This included accepting government regulation as well as being "nudged" in the right direction.
The researcher was particularly enlightened by the UK element of the study, because of his detailed assessment of the Green Deal. This highlighted the impact of the Rebound Effect. While Australia had great success with their policy to encourage take-up of renewable energy in the form of solar panels, the UK residential policy encouraging greater energy efficiency (if it had worked well) was always likely to encourage increased demand for fossil fuels elsewhere in the economy.

One of the reasons that the Green Deal is unlikely to succeed from its inception, was that its attempts to address market failure in the Golden Rule do not take into account the true (social) cost of carbon emissions. If the cost of externalities was included, it could provide a big financial incentive for households to install efficiency measures and/or non-emission producing energy sources, such as heat pumps or solar panels. This of course would require significant government subsidy.

Also, as has been pointed out in section 6.5, there are many other reasons why the Green Deal is an ineffective policy. One reason is its poor design. The convoluted structure adds unnecessary cost to the whole policy, and this contributes to the necessity to charge uncompetitive interest rates on the loans provided for Green Deal installations. The policy also does not take into account the more manageable elements of human behaviour, as revealed in this study. For example, there is insufficient financial incentive incorporated in the Green Deal. Indeed, on a net present value basis many energy saving installations would make a loss. Even those that confer some profit to the customer, only provide very modest savings over many years. This has to be weighed against the potential disadvantages of an energy saving installation under the Green Deal policy. These disadvantages include long-term debt tied to the customer's property, which could affect future demand for the property in the event of a sale. There is also the uncertainty of future energy prices, which could mean that customers predicted energy savings might not materialise. The disparity between predicted and actual energy use, revealed in this research with regard to the UK case study participants, reinforces this point. Another flaw in the Green Deal policy is its emphasis on
energy-saving (which is likely to cause a rebound effect) rather than encouraging the development of renewable energy.

Would the Green Deal policy work any better in Australia? The answer is likely to be no, as this research confirms it would run into the same problems as in the UK. Participants in both countries require significant financial incentives to motivate them to respond adequately. The same poor design in policy structure would create inefficiencies and increased costs so that it would be uncompetitive. And despite the fact that future energy prices might be less uncertain due to the abundance of energy sources in Australia, this is counterbalanced by the fact that it is more expensive to provide grid capacity throughout the country due to its vast size. In general, the similarity of viewpoints between UK and Australian participants mean that the same policy flaws would likely apply in both countries. In this research the answers and comments of the respondents proved to be very useful. They allowed the researcher to test the conclusions available from previous research, and see to what extent these previous research strands were applicable. For example, more information on energy use, did not appear to be a critical factor in motivating the participants in this study. There were also differences in opinion as to the efficacy of education and culture.

There was, however, a large measure of agreement among participants in both the UK and Australia with regard to human rationality. Most participants thought that there were many instances in which people do not behave in a particularly rational manner. Economists and policymakers tend to model consumer behaviour as generally rational in an ideal sense (the Green Deal where saving tiny amounts of money is considered rational behaviour is a good example of this). Heuristical behaviour, often irrational, is something that needs to be incorporated in future energy policies.

Additionally, it became clear from this research that energy policies which save people money do not necessarily result in an overall energy-saving. Most participants agreed that their demand for energy using capital would be displaced to elsewhere in the economy.
Another important contribution from the participants in this study was that there was significant tolerance, indeed, preference, to adhere to government regulation and government encouragement to behave positively with regard to energy use.

The choice of methodology in this research was considered important. The research is a mixture of Positivist and Realist (Neo-empiricist), and uses both quantitative and qualitative methods. It seeks to both explain and understand. Much of the explanation is quantitative. For example, the energy use of the seven UK case studies is measured numerically. Also, the temperatures at which the participants live in their dwellings is factually recorded in degrees centigrade. The type of energy they use is also uncovered by the research.

The qualitative element of the research is used to develop an understanding of why the participants use their residential energy in the way in which they do. Qualitative research is difficult and demanding but can yield valuable insights about individual behaviour. Part of the difficulty with qualitative research is the fact that it relies on subjective opinion. The researcher has to assess this opinion carefully and honestly in order to understand its meaning. Before people who favour quantitative research regard this as a qualitative weakness, they should bear in mind that there are many instances where quantitative research depends on subjective opinion. For example, monitoring equipment in offices that is unwittingly unplugged occasionally by office cleaners results in data which can be treated in various ways by a researcher. The researcher has to decide whether to "clean" such data, by ignoring unrecorded time periods, or include these unrecorded periods, as they are in fact part of the reality of the research. Ultimately the opinion of the researcher must be considered credible, and this has to be justified by the way in which the research is conducted.

Using both quantitative and qualitative methods can help clarify research results. In this study, for example, it helped elucidate why some people do not always behave in the way in which they intend to. The approach used in this research, which was a mixed method approach, was adopted to assess human motivation and in particular to compare participants views with the flagship residential energy saving policy in the UK. As has been discussed, it reveals useful information on
people's motivations and attitudes. Would this approach be useful to adopt in evaluating other policy issues related to consumer behaviour? After carrying out the research over a three-year period, the researcher believes it was a useful methodology when trying to assess opinion related to consumer actions. The approach worked for a number of reasons. One was that the participants were chosen carefully (see section 4.3.1), which allowed the researcher to obtain constructive and thoughtful opinions. Another was the adoption of both quantitative and qualitative data collection in the research. This allowed some triangulation of results, which helped provide an internal validation of the research process. Finally, the semi-structured interview process was invaluable. It was carefully managed so that participants were comfortable and in a positive frame of mind. This allowed the researcher to carry out relatively long interviews during which the participants were happy to reveal their thoughts in a relaxed and truthful manner. This resulted in a considerable amount of raw data, which could be analysed at length.

Naturally there were aspects of the study that the researcher would change, were he to do it again. Clearly, a larger sample would be preferable, as it would provide a wider range of results, and possibly improve validation of the opinions derived from this study. This, however, would mean that the study would require a longer time period to be completed. Another area that the researcher feels it would be important to improve is obtaining more data with regard to the Rebound Effect. This is a critical area with regard to policy, as it informs policymakers of the extent to which they can or should incorporate energy efficiency measures in the residential sector, as opposed to the encouragement of the adoption of renewable energy systems. Another way in which this research could possibly be enhanced is the inclusion of a questionnaire sent to a large random sample of the population. This questionnaire would have to include some general explanation as to the aims of energy policy. It would require very careful consideration to eliminate bias, and encourage a reasonable response rate. Likert scale questions could be used to allow statistical analysis. Certainly, the results would be interesting to compare with the conclusions of this study as it stands.
7.2 Policy Conclusions

A change in residential energy policy could involve a change in emphasis away from energy efficiency to energy sustainability. The results of this study indicate that current policy concentrating on energy efficiency does not result in substantially reduced carbon dioxide emissions in the residential sector. This is because of the ineffectiveness of the Green Deal and the existence of the rebound effect.

One possibility might be to tax fossil fuels (effectively a carbon tax), so that the price of alternative energy from renewables and nuclear power became competitive (Chen et al, 2014). As some people are wary of tax increases, as revealed by responses in this study, the money raised from the new tax could be rebated, so that the net effect was no increase in energy cost to the consumer. However, it would make renewable energy more attractive as a form of energy supply. A policy such as this might shift demand significantly away from fossil fuels and towards renewables. As the policy progressed, the tax levy from fossil fuels would be reduced and some subsidy would be required from the government to mitigate the impact of the higher price of renewable energy. However, people might accept a gentle increase in energy prices and in any case, this might be compensated by a reduction in renewable energy prices due to an increase in efficiency.

Another possibility could be to levy an environmental tax on existing residential property that did not meet a certain standard of sustainability. This could be linked as a progressive surcharge on the council tax rate, and thus property values. It could be made clear that the surcharge would increase by a fixed percentage each year, thus incentivising residential consumers to act immediately to improve the sustainability of their energy use.

A reversion to a system where large energy companies were mandated to improve energy efficiency/sustainability in the residential sector would be wise, as this study has shown that take-up of energy efficiency measures is unsatisfactory. This would be straightforward and could be more cost-effective than the Green Deal, as
transactional costs would be lower. This could form part of a framework that encouraged householders to choose heat pumps over gas boilers.

PostScript: The Department of Energy and Climate Change announced it was ending funding for the Green Deal scheme on the 23rd July 2015, after the submission of this thesis. This was due to the low take-up and costly nature of the policy. The research reported here confirms the reasons for the failure of the Green Deal and, as is explained in section 7.2, a replacement policy should focus more on energy sustainability rather than energy efficiency.

7.3 Research Limitations
This research is qualified by a number of limitations. A case study format naturally limits the breath of data available, if not the depth. The gathered quantitative data in the UK case studies was limited to an approximately four month autumn/winter period. While this was considered satisfactory as it covered a time of year when the was significant energy use, a longer period of data gathering might have meant a greater degree of accuracy as to actual energy use and thermal comfort preferences. The case study participants, both in the UK. Australia were not chosen as random samples. Purposive samples were chosen as it was felt that the complexity of the subject matter generally required some prior understanding by participants of the issues around energy use in the domestic sector. The sample size reflected the time it would take the researcher to gather rich data from each participant.

7.4 Further Work Recommendations
Further research exploring the feasibility of policies that directly address the reduction of fossil fuel consumption in the residential sector is recommended. A specific study linking the rebound effect to residential energy use would also be of value. Development of studies such as Bristow et al (2010) which assessed the acceptability of a carbon tax would usefully inform policymakers on the design of such a tax and its feasibility. Further research on the financial potential of reducing
carbon dioxide emissions, as carried out by Kesicki(2012), is necessary due to the rapidly changing costs of renewable energy production.
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Appendix 1 Qualifying energy improvements

The following is a list of qualifying energy improvements under the green deal (Department of Energy and Climate Change, 2011).

a. air source heat pumps,
b. biomass boilers,
c. biomass room heaters with radiators,
d. cavity wall insulation,
e. high efficiency gas-fired condensing boilers,
f. oil-fired condensing boilers,
g. cylinder thermostats,
h. draught proofing,
i. energy efficient glazing,
j. external wall insulation,
k. fan-assisted replacement storage heaters,
l. flue gas heat recovery devices,
m. ground source heat pumps,
n. heating controls (for wet central heating systems and warm air systems),
o. high efficiency replacement warm-air units,
p. high thermal performance external doors,
q. hot water cylinder insulation,
r. internal wall insulation,
Appendix 2 Example: Cost of a new gas-fired condensing boiler in 2011

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Details</th>
<th>Unit Price</th>
<th>Net Amount</th>
<th>VAT Rate</th>
<th>VAT</th>
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<tbody>
<tr>
<td>1.00</td>
<td>Install new Worcester Bosch Greenstar 15i all as quotation</td>
<td>3,125.00</td>
<td>3,125.00</td>
<td>20.00</td>
<td>625.00</td>
</tr>
<tr>
<td>1.00</td>
<td>Supply and fix 3 No. Thermostatic radiator vales (NO CHARGE)</td>
<td>0.00</td>
<td>0.00</td>
<td>20.00</td>
<td>0.00</td>
</tr>
<tr>
<td>1.00</td>
<td>Supply and fix new ball valve to toilet remove kitchen mixer, overhaul &amp; refit</td>
<td>128.00</td>
<td>128.00</td>
<td>20.00</td>
<td>25.60</td>
</tr>
<tr>
<td>1.00</td>
<td>Emergency call out, cut out section of kitchen waste, clear blockage reflex, test sink and washing machine</td>
<td>145.00</td>
<td>145.00</td>
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<th>Total Net Amount</th>
<th>Carriage Net</th>
<th>Total VAT Amount</th>
<th>Invoice Total</th>
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VAT Reg. No: 222 8638 78
Appendix 3: NPV calculation of boiler replacement

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<th>Period (Year)</th>
<th>New Boiler Cost</th>
<th>New Boiler Energy Saving</th>
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<tbody>
<tr>
<td>2012</td>
<td>-£3,800</td>
<td>£224</td>
</tr>
<tr>
<td>2013</td>
<td></td>
<td>£224</td>
</tr>
<tr>
<td>2014</td>
<td></td>
<td>£224</td>
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<tr>
<td>2015</td>
<td></td>
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<tr>
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<tr>
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<tr>
<td>2026</td>
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</table>

Discount Factor
- 5.00% Discount Factor
- 1.0000 0.9524 0.9070 0.8638 0.8227 0.7835 0.7462 0.7107 0.6768 0.6446 0.6139 0.5847 0.5568 0.5303 0.5051

Discounted Cash Flow
-£3,576 £213 £203 £193 £184 £176 £167 £159 £152 £144 £138 £131 £125 £119 £113

Net Present Value
-£1,359

IRR
-1.70%

Net Present Value
-£1,359
Appendix 4: SAP Input for Predictive Data

Property Details Robert:
Address: LOUGHBOROUGH, LE11
Located in: England
Region: Midlands
Date of assessment: 01 October 2013
Assessment type: Existing dwelling (SAP)
Tenure type: Owner
Thermal Mass Parameter for FSAP software: Indicative Value Medium
No information on thermal bridging

Table 87 Property Description Robert

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<th>Property Description</th>
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</tr>
<tr>
<td><strong>Year Built</strong></td>
</tr>
<tr>
<td><strong>Floor Location</strong></td>
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</tr>
<tr>
<td>Floor 1</td>
</tr>
<tr>
<td>Living area</td>
</tr>
<tr>
<td>Front of dwelling faces</td>
</tr>
</tbody>
</table>
### Table 88 Opening Types

<table>
<thead>
<tr>
<th>Name</th>
<th>Source</th>
<th>Type</th>
<th>Glazing</th>
<th>Argon</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>SAP 2009</td>
<td>Solid</td>
<td>-</td>
<td>-</td>
<td>PVC-U</td>
</tr>
<tr>
<td>Back Door</td>
<td>SAP 2009</td>
<td>Half glazed</td>
<td>double-glazed</td>
<td>Yes</td>
<td>PVC-U</td>
</tr>
<tr>
<td>Standard Window</td>
<td>SAP 2009</td>
<td>Windows</td>
<td>double-glazed</td>
<td>Yes</td>
<td>PVC-U</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>U-value</th>
<th>Area</th>
<th>No. of Openings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>3.0</td>
<td>1.85</td>
<td>1</td>
</tr>
<tr>
<td>Back Door</td>
<td>1.5</td>
<td>1.85</td>
<td>1</td>
</tr>
<tr>
<td>Standard Window</td>
<td>2.6</td>
<td>1.3</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>External Wall</td>
<td>North</td>
</tr>
<tr>
<td>Back Door</td>
<td>External Wall</td>
<td>South</td>
</tr>
<tr>
<td>Standard Window</td>
<td>External Wall</td>
<td>Unspecified</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Overshading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Little</td>
</tr>
</tbody>
</table>

### Table 89 Opaque Elements

<table>
<thead>
<tr>
<th>Type</th>
<th>Gross Area</th>
<th>U-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External Elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cavity as built</td>
<td>45.668</td>
<td>0.3</td>
</tr>
<tr>
<td>Pitched Roof</td>
<td>40.51</td>
<td>0.3</td>
</tr>
<tr>
<td>Concrete Suspended Floor</td>
<td>40.51</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Internal Elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Party Wall Cavity Fill</td>
<td>40.169</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### Table 90 Ventilation

<table>
<thead>
<tr>
<th>Ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Test</td>
</tr>
<tr>
<td>Ventilation</td>
</tr>
<tr>
<td>Number of chimneys</td>
</tr>
<tr>
<td>Number of open flues</td>
</tr>
<tr>
<td>Number of fans</td>
</tr>
<tr>
<td>Number of sides sheltered</td>
</tr>
</tbody>
</table>
### Table 91 Heating Robert

<table>
<thead>
<tr>
<th>Heating</th>
<th></th>
</tr>
</thead>
</table>
| Main Heating System | Central heating systems with radiators  
| | Gas boiler  
| | Fuel: mains gas  
| | Info Source: SAP Table 104  
| | Condensing combi with automatic ignition  
| | Pump in heat space: Yes  
| Main heating Control | Programmer and at least two room thermostats  
| | Boiler interlock Yes (Room thermostat turns on/off boiler)  
| Secondary heating system | None  
| Water heating | From main heating system  
| | No hot water cylinder

### Table 92 Other Robert

<table>
<thead>
<tr>
<th>Other</th>
<th></th>
</tr>
</thead>
</table>
| Electricity tariff | Standard tariff  
| Conservatory | No conservatory  
| Low energy lights | 50%  
| Water heating | From main heating system

### Table 93 Predicted Energy use Robert

<table>
<thead>
<tr>
<th>Energy Type Robert</th>
<th>Predicted (SAP) kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>149</td>
</tr>
<tr>
<td>Electricity</td>
<td>28</td>
</tr>
<tr>
<td>Total Energy</td>
<td>177</td>
</tr>
</tbody>
</table>
This is a Predicted Energy Assessment. It includes a predicted energy rating which might not represent the final energy rating of the property on completion. Once the property is completed, an Energy Performance Certificate is required providing information about the energy performance of the completed property.

Energy performance has been assessed using the SAP 2009 methodology and is rated in terms of the energy use per square metre of floor area, energy efficiency based on fuel costs and environmental impact based on carbon dioxide (CO2) emissions.

The energy efficiency rating is a measure of the overall efficiency of a home. The higher the rating the more energy efficient the home is and the lower the fuel bills are likely to be.

The environmental impact rating is a measure of a home’s impact on the environment in terms of carbon dioxide (CO2) emissions. The higher the rating the less impact it has on the environment.
**Property Details Gwen:**
Address: LOUGHBOROUGH, LE11
Located in: England
Region: Midlands
Date of assessment: 11 October 2013
Assessment type: Existing dwelling (SAP)
Tenure type: Tenant
Thermal Mass Parameter for FSAP software: Indicative Value Medium
No information on thermal bridging

---

**Table 94 Property Description Gwen**

<table>
<thead>
<tr>
<th>Property Description</th>
<th>Flat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dwelling type</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Year Built</strong></td>
<td>2000</td>
</tr>
<tr>
<td><strong>Detachment</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Floor Location</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Floor area</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Storey height</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Floor Location</th>
<th>Floor area</th>
<th>Storey height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor 2</td>
<td>61.00 m²</td>
<td>2.38 m</td>
</tr>
<tr>
<td>Living area</td>
<td>36.6 m²</td>
<td>(fraction 0.6)</td>
</tr>
</tbody>
</table>

| Front of dwelling faces | North East |
### Table 95 Opening Types Gwen

<table>
<thead>
<tr>
<th>Name</th>
<th>Source</th>
<th>Type</th>
<th>Glazing</th>
<th>Argon</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corridor Door</td>
<td>SAP 2009</td>
<td>Solid</td>
<td>-</td>
<td>-</td>
<td>Wood</td>
</tr>
<tr>
<td>Standard Window</td>
<td>SAP 2009</td>
<td>Windows</td>
<td>double-glazed</td>
<td>Yes</td>
<td>Wood</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>U-value</th>
<th>Area</th>
<th>No. of Openings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corridor Door</td>
<td>3.0</td>
<td>1.85</td>
<td>1</td>
</tr>
<tr>
<td>Standard Window</td>
<td>2.6</td>
<td>1.3</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corridor Door</td>
<td>Internal Entrance</td>
<td>East</td>
</tr>
<tr>
<td>Standard Window</td>
<td>External Wall</td>
<td>Unspecified</td>
</tr>
</tbody>
</table>

**Overshading**
- Average or Unknown

### Table 96 Opaque Elements Gwen

<table>
<thead>
<tr>
<th>Type</th>
<th>Gross Area</th>
<th>U-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External Elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cavity as built</td>
<td>21.42</td>
<td>0.45</td>
</tr>
<tr>
<td>Pitched Internal Joist</td>
<td>61.00</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Internal Elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Party Wall Standard</td>
<td>21.42</td>
<td>0.0</td>
</tr>
<tr>
<td>Party Floor Standard</td>
<td>61.00</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### Table 97 Ventilation Gwen

<table>
<thead>
<tr>
<th>Ventilation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Test</td>
<td>No</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Natural ventilation (extract fans)</td>
</tr>
<tr>
<td>Number of chimneys</td>
<td>0</td>
</tr>
<tr>
<td>Number of open flues</td>
<td>1 (main: 1, secondary: 0, other: 0)</td>
</tr>
<tr>
<td>Number of fans</td>
<td>2</td>
</tr>
<tr>
<td>Number of sides sheltered</td>
<td>1</td>
</tr>
</tbody>
</table>
### Table 98 Heating Gwen

<table>
<thead>
<tr>
<th>Heating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Heating System</td>
</tr>
<tr>
<td>Gas boiler</td>
</tr>
<tr>
<td>Fuel: mains gas</td>
</tr>
<tr>
<td>Info Source: SAP Table 104</td>
</tr>
<tr>
<td>Condensing combi with automatic ignition</td>
</tr>
<tr>
<td>Pump in heat space: Yes</td>
</tr>
<tr>
<td>Main heating Control</td>
</tr>
<tr>
<td>Boiler interlock Yes (Room thermostat turns on/off boiler)</td>
</tr>
<tr>
<td>Secondary heating system</td>
</tr>
<tr>
<td>Water heating</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

### Table 99 Other Gwen

<table>
<thead>
<tr>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity tariff</td>
</tr>
<tr>
<td>Conservatory</td>
</tr>
<tr>
<td>Low energy lights</td>
</tr>
<tr>
<td>Water heating</td>
</tr>
</tbody>
</table>

### Table 100 Predicted Energy use Gwen

<table>
<thead>
<tr>
<th>Energy Type Gwen</th>
<th>Predicted (SAP) kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>138</td>
</tr>
<tr>
<td>Electricity</td>
<td>29</td>
</tr>
<tr>
<td>Total Energy</td>
<td>167</td>
</tr>
</tbody>
</table>
This is a Predicted Energy Assessment which includes a predicted energy rating which might not represent the final energy rating of the property on completion. Once the property is completed, an Energy Performance Certificate is required providing information about the energy performance of the completed property.

Energy performance has been assessed using the SAP 2009 methodology and is rated in terms of the energy use per square metre of floor area, energy efficiency based on fuel costs and environmental impact based on carbon dioxide (CO2) emissions.

The energy efficiency rating is a measure of the overall efficiency of a home. The higher the rating the more energy efficient the home is and the lower the fuel bills are likely to be.

The environmental impact rating is a measure of a home's impact on the environment in terms of carbon dioxide (CO2) emissions. The higher the rating the less impact it has on the environment.

Figure 37 Predicted Energy Assessment Gwen
Property Details Jane:
Address: LOUGHBOROUGH, LE11
Located in: England
Region: Midlands
Date of assessment: 10 October 2013
Assessment type: Existing dwelling (SAP)
Tenure type: Tenant
Thermal Mass Parameter for FSAP software: Indicative Value Medium
No information on thermal bridging

Table 101 Property Description Jane

<table>
<thead>
<tr>
<th>Property Description</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling type</td>
<td>House</td>
<td></td>
</tr>
<tr>
<td>Detachment</td>
<td>Mid-terrace</td>
<td></td>
</tr>
<tr>
<td>Year Built</td>
<td>1900</td>
<td></td>
</tr>
<tr>
<td>Floor Location</td>
<td>Floor area</td>
<td>Storey height</td>
</tr>
<tr>
<td>Floor 0</td>
<td>31.61 m²</td>
<td>2.74 m</td>
</tr>
<tr>
<td>Floor 1</td>
<td>35.09 m²</td>
<td>2.67 m</td>
</tr>
<tr>
<td>Living area</td>
<td>46.69 m² (fraction 0.7)</td>
<td></td>
</tr>
<tr>
<td>Front of dwelling faces</td>
<td>South</td>
<td></td>
</tr>
</tbody>
</table>
### Table 102 Opening Types Jane

<table>
<thead>
<tr>
<th>Name</th>
<th>Source</th>
<th>Type</th>
<th>Glazing</th>
<th>Argon</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>SAP 2009</td>
<td>Solid</td>
<td>-</td>
<td>-</td>
<td>PVC-U</td>
</tr>
<tr>
<td>Back Door</td>
<td>SAP 2009</td>
<td>Half glazed</td>
<td>double-glazed</td>
<td>Yes</td>
<td>PVC-U</td>
</tr>
<tr>
<td>Standard Window</td>
<td>SAP 2009</td>
<td>Windows</td>
<td>double-glazed</td>
<td>Yes</td>
<td>PVC-U</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>U-value</th>
<th>Area</th>
<th>No. of Openings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>3.0</td>
<td>1.85</td>
<td>1</td>
</tr>
<tr>
<td>Back Door</td>
<td>2.8</td>
<td>1.85</td>
<td>1</td>
</tr>
<tr>
<td>Standard Window</td>
<td>2.6</td>
<td>1.3</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>External Wall</td>
<td>South</td>
</tr>
<tr>
<td>Back Door</td>
<td>External Wall</td>
<td>East</td>
</tr>
<tr>
<td>Standard Window</td>
<td>External Wall</td>
<td>Unspecified</td>
</tr>
</tbody>
</table>

| Overshading          | Average or Unknown |

### Table 103 Opaque Elements Jane

<table>
<thead>
<tr>
<th>Type</th>
<th>Gross Area</th>
<th>U-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External Elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid Brick Wall</td>
<td>22.18</td>
<td>2.1</td>
</tr>
<tr>
<td>Solid Brick Wall</td>
<td>16.18</td>
<td>2.1</td>
</tr>
<tr>
<td>Solid Brick Wall</td>
<td>10.82</td>
<td>2.1</td>
</tr>
<tr>
<td>Pitched Roof</td>
<td>35.09</td>
<td>0.4</td>
</tr>
<tr>
<td>Suspended Timber Floor</td>
<td>40.51</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>Internal Elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Party Wall Solid Brick</td>
<td>54.49</td>
<td>0.0</td>
</tr>
<tr>
<td>Party Wall Solid Brick</td>
<td>38.34</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### Table 104 Ventilation Jane

<table>
<thead>
<tr>
<th>Ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Test</td>
</tr>
<tr>
<td>Ventilation</td>
</tr>
<tr>
<td>Number of chimneys</td>
</tr>
<tr>
<td>Number of open flues</td>
</tr>
<tr>
<td>Number of fans</td>
</tr>
<tr>
<td>Number of sides sheltered</td>
</tr>
</tbody>
</table>
### Table 105 Heating Jane

<table>
<thead>
<tr>
<th>Heating</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Heating System</td>
<td>Central heating systems with radiators Gas boiler Fuel: mains gas Info Source: SAP Table 107 Non-condensing combi with permanent pilot light Pump in heat space: Yes</td>
</tr>
<tr>
<td>Main heating Control</td>
<td>TRV’s and bypass Boiler interlock No</td>
</tr>
<tr>
<td>Secondary heating system</td>
<td>None</td>
</tr>
<tr>
<td>Water heating</td>
<td>From main heating system No hot water cylinder</td>
</tr>
</tbody>
</table>

### Table 106 Other Jane

<table>
<thead>
<tr>
<th>Other</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity tariff</td>
<td>Standard tariff</td>
</tr>
<tr>
<td>Conservatory</td>
<td>No conservatory</td>
</tr>
<tr>
<td>Low energy lights</td>
<td>83.3%</td>
</tr>
<tr>
<td>Water heating</td>
<td>From main heating system</td>
</tr>
</tbody>
</table>

### Table 107 Predicted Energy use Jane

<table>
<thead>
<tr>
<th>Energy Type Jane</th>
<th>Predicted (SAP) kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>238</td>
</tr>
<tr>
<td>Electricity</td>
<td>24</td>
</tr>
<tr>
<td>Total Energy</td>
<td>262</td>
</tr>
</tbody>
</table>
This is a Predicted Energy Assessment. It includes a predicted energy rating which might not represent the final energy rating of the property on completion. Once the property is completed, an Energy Performance Certificate is required providing information about the energy performance of the completed property.

Energy performance has been assessed using the SAP 2009 methodology and is rated in terms of the energy use per square metre of floor area, energy efficiency based on fuel costs and environmental impact based on carbon dioxide (CO2) emissions.

The energy efficiency rating is a measure of the overall efficiency of a home. The higher the rating the more energy efficient the home is and the lower the fuel bills are likely to be.

The environmental impact rating is a measure of a home’s impact on the environment in terms of carbon dioxide (CO2) emissions. The higher the rating the less impact it has on the environment.

Figure 38 Predicted Energy Assessment Jane
Property Details Juliette:
Address: LOUGHBOROUGH, LE11
Located in: England
Region: Midlands
Date of assessment: 15 October 2013
Assessment type: Existing dwelling (SAP)
Tenure type: Owner
Thermal Mass Parameter for FSAP software: Indicative Value Medium
No information on thermal bridging

Table 108 Property Description Juliette

<table>
<thead>
<tr>
<th>Property Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling type</td>
</tr>
<tr>
<td>Detachment</td>
</tr>
<tr>
<td>Year Built</td>
</tr>
<tr>
<td>Floor Location</td>
</tr>
<tr>
<td>Floor 0</td>
</tr>
<tr>
<td>Floor 1</td>
</tr>
<tr>
<td>Living area</td>
</tr>
<tr>
<td>Front of dwelling faces</td>
</tr>
</tbody>
</table>
Table 109 Opening Types Juliette

<table>
<thead>
<tr>
<th>Name</th>
<th>Source</th>
<th>Type</th>
<th>Glazing</th>
<th>Argon</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>SAP 2009</td>
<td>Solid</td>
<td>-</td>
<td>-</td>
<td>PVC-U</td>
</tr>
<tr>
<td>Back Door</td>
<td>SAP 2009</td>
<td>Solid</td>
<td>-</td>
<td>-</td>
<td>Wood</td>
</tr>
<tr>
<td>Standard Window</td>
<td>SAP 2009</td>
<td>Windows</td>
<td>double-glazed</td>
<td>Yes</td>
<td>PVC-U</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>U-value</th>
<th>Area</th>
<th>No. of Openings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>3.0</td>
<td>1.85</td>
<td>1</td>
</tr>
<tr>
<td>Back Door</td>
<td>3.0</td>
<td>1.85</td>
<td>1</td>
</tr>
<tr>
<td>Standard Window</td>
<td>2.6</td>
<td>1.3</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>External Wall</td>
<td>North West</td>
</tr>
<tr>
<td>Back Door</td>
<td>External Wall</td>
<td>North</td>
</tr>
<tr>
<td>Standard Window</td>
<td>External Wall</td>
<td>Unspecified</td>
</tr>
</tbody>
</table>

| Overshading | Very Little |

Table 110 Opaque Elements Juliette

<table>
<thead>
<tr>
<th>Type</th>
<th>Gross Area</th>
<th>U-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External Elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid Brick Wall</td>
<td>8.46</td>
<td>2.1</td>
</tr>
<tr>
<td>Solid Brick Wall</td>
<td>4.57</td>
<td>2.1</td>
</tr>
<tr>
<td>Cavity as built</td>
<td>6.86</td>
<td>0.3</td>
</tr>
<tr>
<td>Cavity as built</td>
<td>22.32</td>
<td>0.3</td>
</tr>
<tr>
<td>Pitched Roof</td>
<td>34.78</td>
<td>0.16</td>
</tr>
<tr>
<td>Flat Roof</td>
<td>10.45</td>
<td>2.3</td>
</tr>
<tr>
<td>Solid Floor</td>
<td>45.23</td>
<td>0.73</td>
</tr>
<tr>
<td><strong>Internal Elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Party Wall Solid Brick</td>
<td>38.34</td>
<td>0.0</td>
</tr>
<tr>
<td>Party Wall Solid Brick</td>
<td>16.59</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 111 Ventilation Juliette

<table>
<thead>
<tr>
<th>Ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Test</td>
</tr>
<tr>
<td>Ventilation</td>
</tr>
<tr>
<td>Number of chimneys</td>
</tr>
<tr>
<td>Number of open flues</td>
</tr>
<tr>
<td>Number of fans</td>
</tr>
<tr>
<td>Number of sides sheltered</td>
</tr>
</tbody>
</table>
### Table 112 Heating Juliette

<table>
<thead>
<tr>
<th>Heating</th>
<th>Central heating systems with radiators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Heating System</td>
<td>Gas boiler</td>
</tr>
<tr>
<td></td>
<td>Fuel: mains gas</td>
</tr>
<tr>
<td></td>
<td>Info Source: SAP Table 104</td>
</tr>
<tr>
<td></td>
<td>Condensing combi with automatic ignition</td>
</tr>
<tr>
<td></td>
<td>Pump in heat space: Yes</td>
</tr>
<tr>
<td>Main heating Control</td>
<td>Programmer, TRV's and boiler energy manager</td>
</tr>
<tr>
<td></td>
<td>Boiler interlock: Yes</td>
</tr>
<tr>
<td>Secondary heating system</td>
<td>None</td>
</tr>
<tr>
<td>Water heating</td>
<td>From main heating system</td>
</tr>
<tr>
<td></td>
<td>No hot water cylinder</td>
</tr>
</tbody>
</table>

### Table 113 Other Juliette

<table>
<thead>
<tr>
<th>Other</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity tariff</td>
<td>Standard tariff</td>
</tr>
<tr>
<td>Conservatory</td>
<td>Separated unheated conservatory</td>
</tr>
<tr>
<td>Low energy lights</td>
<td>42.9%</td>
</tr>
<tr>
<td>Water heating</td>
<td>From main heating system</td>
</tr>
</tbody>
</table>

### Table 114 Predicted Energy use Juliette

<table>
<thead>
<tr>
<th>Energy Type Juliette</th>
<th>Predicted (SAP) kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>172</td>
</tr>
<tr>
<td>Electricity</td>
<td>27</td>
</tr>
<tr>
<td>Total Energy</td>
<td>199</td>
</tr>
</tbody>
</table>
Figure 39 Predicted Energy Assessment Juliette
Property Details Wendy:
Address: LOUGHBOROUGH, LE11
Located in: England
Region: Midlands
Date of assessment: 03 October 2013
Assessment type: Existing dwelling (SAP)
Tenure type: Tenant
Thermal Mass Parameter for FSAP software: Indicative Value Medium
No information on thermal bridging

Table 115 Property Description Wendy

<table>
<thead>
<tr>
<th>Property Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dwelling type</strong></td>
</tr>
<tr>
<td><strong>Detachment</strong></td>
</tr>
<tr>
<td><strong>Year Built</strong></td>
</tr>
<tr>
<td><strong>Floor Location</strong></td>
</tr>
<tr>
<td>Floor 2</td>
</tr>
<tr>
<td>Living area</td>
</tr>
<tr>
<td>Front of dwelling faces</td>
</tr>
</tbody>
</table>
### Table 116 Opening Types Wendy

<table>
<thead>
<tr>
<th>Name</th>
<th>Source</th>
<th>Type</th>
<th>Glazing</th>
<th>Argon</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corridor Door</td>
<td>SAP 2009</td>
<td>Solid</td>
<td>-</td>
<td>-</td>
<td>Wood</td>
</tr>
<tr>
<td>Standard Window</td>
<td>SAP 2009</td>
<td>Windows</td>
<td>double-glazed</td>
<td>Yes</td>
<td>PVC-U</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>U-value</th>
<th>Area</th>
<th>No. of Openings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corridor Door</td>
<td>3.0</td>
<td>1.85</td>
<td>1</td>
</tr>
<tr>
<td>Standard Window</td>
<td>2.6</td>
<td>1.5</td>
<td>3</td>
</tr>
<tr>
<td>Standard Window</td>
<td>2.6</td>
<td>2.5</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corridor Door</td>
<td>Internal Entrance</td>
<td>West</td>
</tr>
<tr>
<td>Standard Window</td>
<td>External Wall Solid</td>
<td>North</td>
</tr>
<tr>
<td>Standard Window</td>
<td>External Wall Solid</td>
<td>South</td>
</tr>
</tbody>
</table>

**Overshading** Very Little

### Table 117 Opaque Elements Wendy

<table>
<thead>
<tr>
<th>Type</th>
<th>Gross Area</th>
<th>U-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External Elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External Wall Solid</td>
<td>7.78</td>
<td>2.1</td>
</tr>
<tr>
<td>External Wall Solid</td>
<td>2.55</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>Internal Elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Wall (Check this)</td>
<td>5.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Internal Ceiling</td>
<td>33.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Internal Floor</td>
<td>33.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### Table 118 Ventilation Wendy

<table>
<thead>
<tr>
<th>Ventilation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Test</td>
<td>No</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Natural ventilation (extract fans)</td>
</tr>
<tr>
<td>Number of chimneys</td>
<td>0</td>
</tr>
<tr>
<td>Number of open flues</td>
<td>0 (main: 0, secondary: 0, other: 0)</td>
</tr>
<tr>
<td>Number of fans</td>
<td>2</td>
</tr>
<tr>
<td>Number of sides sheltered</td>
<td>0</td>
</tr>
</tbody>
</table>
### Table 119 Heating Wendy

<table>
<thead>
<tr>
<th>Heating</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Heating System</td>
<td>Room Heaters</td>
</tr>
<tr>
<td></td>
<td>Electric (direct acting) Room Heaters</td>
</tr>
<tr>
<td></td>
<td>Fuel: electricity</td>
</tr>
<tr>
<td></td>
<td>Info Source: SAP Table 691</td>
</tr>
<tr>
<td></td>
<td>Panel, convector or radiant heaters</td>
</tr>
<tr>
<td>Main heating Control</td>
<td>Appliance Thermostats</td>
</tr>
<tr>
<td>Secondary heating system</td>
<td>None</td>
</tr>
<tr>
<td>Water heating</td>
<td>Electric instantaneous at point of use</td>
</tr>
<tr>
<td></td>
<td>No hot water cylinder</td>
</tr>
</tbody>
</table>

### Table 120 Other Wendy

<table>
<thead>
<tr>
<th>Other</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity tariff</td>
<td>Standard tariff</td>
</tr>
<tr>
<td>Conservatory</td>
<td>No conservatory</td>
</tr>
<tr>
<td>Low energy lights</td>
<td>80.0%</td>
</tr>
<tr>
<td>Water heating</td>
<td>Direct Electric</td>
</tr>
</tbody>
</table>

### Table 121 Predicted Energy use Wendy

<table>
<thead>
<tr>
<th>Energy Type Wendy</th>
<th>Predicted (SAP) kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>222</td>
</tr>
<tr>
<td>Total Energy</td>
<td>222</td>
</tr>
</tbody>
</table>
This is a Predicted Energy Assessment. It includes a predicted energy rating which might not represent the final energy rating of the property on completion. Once the property is completed, an Energy Performance Certificate is required providing information about the energy performance of the completed property.

Energy performance has been assessed using the SAP 2009 methodology and is rated in terms of the energy use per square metre of floor area, energy efficiency based on fuel costs and environmental impact based on carbon dioxide (CO2) emissions.

The energy efficiency rating is a measure of the overall efficiency of a home. The higher the rating the more energy efficient the home is and the lower the fuel bills are likely to be.

The environmental impact rating is a measure of a home’s impact on the environment in terms of carbon dioxide (CO2) emissions. The higher the rating the less impact it has on the environment.

Figure 40 Predicted Energy Assessment Wendy
Property Details Anne:
Address: LOUGHBOROUGH, LE11
Located in: England
Region: Midlands
Date of assessment: 10 October 2013
Assessment type: Existing dwelling (SAP)
Tenure type: Tenant
Thermal Mass Parameter for FSAP software: Indicative Value Medium
No information on thermal bridging

<table>
<thead>
<tr>
<th>Property Description Anne</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Table 122 Property Description Anne</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Property Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling type</td>
<td>House</td>
</tr>
<tr>
<td>Detachment</td>
<td>Semi-detached</td>
</tr>
<tr>
<td>Year Built</td>
<td>1930</td>
</tr>
<tr>
<td>Floor Location</td>
<td>Floor area</td>
</tr>
<tr>
<td>Floor 0</td>
<td>35.84 m²</td>
</tr>
<tr>
<td>Floor 1</td>
<td>35.84 m²</td>
</tr>
<tr>
<td>Living area</td>
<td>53.76 m² (fraction 0.75)</td>
</tr>
<tr>
<td>Front of dwelling faces</td>
<td>North</td>
</tr>
</tbody>
</table>
### Table 123 Opening Types Anne

<table>
<thead>
<tr>
<th>Name</th>
<th>Source</th>
<th>Type</th>
<th>Glazing</th>
<th>Argon</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>SAP 2009</td>
<td>Half glazed</td>
<td>double-glazed</td>
<td>Yes</td>
<td>PVC-U</td>
</tr>
<tr>
<td>Back Door</td>
<td>SAP 2009</td>
<td>Half glazed</td>
<td>double-glazed</td>
<td>Yes</td>
<td>PVC-U</td>
</tr>
<tr>
<td>Standard Window</td>
<td>SAP 2009</td>
<td>Windows</td>
<td>double-glazed</td>
<td>Yes</td>
<td>PVC-U</td>
</tr>
<tr>
<td>Window Single Glazed</td>
<td>SAP 2009</td>
<td>Windows</td>
<td>Single-glazed</td>
<td>No</td>
<td>Wood</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>U-value</th>
<th>Area</th>
<th>No. of Openings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>2.8</td>
<td>1.85</td>
<td>1</td>
</tr>
<tr>
<td>Back Door</td>
<td>2.8</td>
<td>1.85</td>
<td>1</td>
</tr>
<tr>
<td>Standard Window</td>
<td>2.6</td>
<td>1.3</td>
<td>7</td>
</tr>
<tr>
<td>Window Single Glazed</td>
<td>4.8</td>
<td>1.3</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>External Wall Solid</td>
<td>North</td>
</tr>
<tr>
<td>Back Door</td>
<td>External Wall Solid</td>
<td>South</td>
</tr>
<tr>
<td>Standard Window</td>
<td>External Wall Solid</td>
<td>Unspecified</td>
</tr>
<tr>
<td>Window Single Glazed</td>
<td>External Wall Solid</td>
<td>Unspecified</td>
</tr>
</tbody>
</table>

**Overshading**: Average or Unknown

### Table 124 Opaque Elements Anne

<table>
<thead>
<tr>
<th>Type</th>
<th>Gross Area</th>
<th>U-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External Elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid Brick Wall</td>
<td>32.00</td>
<td>2.1</td>
</tr>
<tr>
<td>Solid Brick Wall</td>
<td>28.00</td>
<td>2.1</td>
</tr>
<tr>
<td>Solid Brick Wall</td>
<td>28.00</td>
<td>2.1</td>
</tr>
<tr>
<td>Pitched Roof</td>
<td>35.84</td>
<td>0.16</td>
</tr>
<tr>
<td>Suspended Timber Floor</td>
<td>35.84</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>Internal Elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Party Wall Solid Brick</td>
<td>32.00</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### Table 125 Ventilation Anne

<table>
<thead>
<tr>
<th>Ventilation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Test</td>
<td>No</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Natural ventilation (extract fans)</td>
</tr>
<tr>
<td>Number of chimneys</td>
<td>0</td>
</tr>
<tr>
<td>Number of open flues</td>
<td>0 (main: 0, secondary: 0, other: 0)</td>
</tr>
<tr>
<td>Number of fans</td>
<td>2</td>
</tr>
<tr>
<td>Number of sides sheltered</td>
<td>1</td>
</tr>
</tbody>
</table>
### Table 126 Heating Anne

<table>
<thead>
<tr>
<th>Main Heating System</th>
<th>Central heating systems with radiators</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gas boiler</td>
</tr>
<tr>
<td></td>
<td>Fuel: mains gas</td>
</tr>
<tr>
<td></td>
<td>Info Source: SAP Table 103</td>
</tr>
<tr>
<td></td>
<td>Non-condensing combi with automatic ignition</td>
</tr>
<tr>
<td></td>
<td>Pump in heat space: Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Main heating Control</th>
<th>Programmer, room thermostat and TRV's</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boiler interlock: Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Secondary heating system</th>
<th>None</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Water heating</th>
<th>From main heating system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No hot water cylinder</td>
</tr>
</tbody>
</table>

### Table 127 Other Anne

<table>
<thead>
<tr>
<th>Electricity tariff</th>
<th>Standard tariff</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Conservatory</th>
<th>Separated unheated conservatory</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Low energy lights</th>
<th>33.3%</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Water heating</th>
<th>From main heating system</th>
</tr>
</thead>
</table>

### Table 128 Predicted Energy use Anne

<table>
<thead>
<tr>
<th>Energy Type Anne</th>
<th>Predicted (SAP) kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>288</td>
</tr>
<tr>
<td>Electricity</td>
<td>29</td>
</tr>
<tr>
<td>Total Energy</td>
<td>317</td>
</tr>
</tbody>
</table>
Figure 41 Predicted Energy Assessment Anne
Property Details Arabella:
Address: LOUGHBOROUGH, LE11
Located in: England
Region: Midlands
Date of assessment: 11 October 2013
Assessment type: Existing dwelling (SAP)
Tenure type: Tenant
Thermal Mass Parameter for FSAP software: Indicative Value Medium
No information on thermal bridging

Table 129 Property Description Arabella

<table>
<thead>
<tr>
<th>Property Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling type</td>
</tr>
<tr>
<td>Detachment</td>
</tr>
<tr>
<td>Year Built</td>
</tr>
<tr>
<td>Floor Location</td>
</tr>
<tr>
<td>Floor 0</td>
</tr>
<tr>
<td>Floor 1</td>
</tr>
<tr>
<td>Living area</td>
</tr>
<tr>
<td>Front of dwelling faces</td>
</tr>
</tbody>
</table>
### Table 130 Opening Types Arabella

<table>
<thead>
<tr>
<th>Name</th>
<th>Source</th>
<th>Type</th>
<th>Glazing</th>
<th>Argon</th>
<th>Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>SAP 2009</td>
<td>Half glazed</td>
<td>Single-glazed</td>
<td>No</td>
<td>Wood</td>
</tr>
<tr>
<td>Standard Window</td>
<td>SAP 2009</td>
<td>Windows</td>
<td>double-glazed</td>
<td>Yes</td>
<td>PVC-U</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>U-value</th>
<th>Area</th>
<th>No. of Openings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>3.9</td>
<td>1.85</td>
<td>1</td>
</tr>
<tr>
<td>Standard Window</td>
<td>2.6</td>
<td>1.3</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Door</td>
<td>External Wall Solid</td>
<td>North East</td>
</tr>
<tr>
<td>Standard Window</td>
<td>External Wall Solid</td>
<td>Unspecified</td>
</tr>
</tbody>
</table>

Overshading: Average or Unknown

### Table 131 Opaque Elements Arabella

<table>
<thead>
<tr>
<th>Type</th>
<th>Gross Area</th>
<th>U-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External Elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid Brick Wall</td>
<td>30.50</td>
<td>2.1</td>
</tr>
<tr>
<td>Solid Brick Wall</td>
<td>34.00</td>
<td>2.1</td>
</tr>
<tr>
<td>Solid Brick Wall</td>
<td>34.00</td>
<td>2.1</td>
</tr>
<tr>
<td>Pitched Roof</td>
<td>41.48</td>
<td>0.16</td>
</tr>
<tr>
<td>Solid Floor</td>
<td>54.00</td>
<td>0.73</td>
</tr>
<tr>
<td><strong>Internal Elements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Party Wall Solid Brick</td>
<td>30.50</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### Table 132 Ventilation Arabella

<table>
<thead>
<tr>
<th>Ventilation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Test</td>
<td>No</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Natural ventilation (extract fans)</td>
</tr>
<tr>
<td>Number of chimneys</td>
<td>0</td>
</tr>
<tr>
<td>Number of open flues</td>
<td>0 (main: 0, secondary: 0, other: 0)</td>
</tr>
<tr>
<td>Number of fans</td>
<td>3</td>
</tr>
<tr>
<td>Number of sides sheltered</td>
<td>1</td>
</tr>
</tbody>
</table>
### Table 133 Heating Arabella

| Main Heating System | Central heating systems with radiators  
|                     | Gas boiler  
|                     | Fuel: mains gas  
|                     | Info Source: SAP Table 104  
|                     | Condensing combi with automatic ignition  
|                     | Pump in heat space: Yes  
| Main heating Control | Programmer, room thermostat and TRV’s  
| Secondary heating system | None  
| Water heating | From main heating system  
|               | No hot water cylinder |

### Table 134 Other Arabella

<table>
<thead>
<tr>
<th>Other</th>
</tr>
</thead>
</table>
| Electricity tariff | Dual rate tariff  
| Conservatory | Separated unheated conservatory  
| Low energy lights | 11.1%  
| Water heating | From main heating system |

### Table 135 Predicted Energy use Arabella

<table>
<thead>
<tr>
<th>Energy Type Arabella</th>
<th>Predicted (SAP) kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>254</td>
</tr>
<tr>
<td>Electricity</td>
<td>34</td>
</tr>
<tr>
<td>Total Energy</td>
<td>288</td>
</tr>
</tbody>
</table>
This is a Predicted Energy Assessment which might not represent the final energy rating of the property on completion. Once the property is completed, an Energy Performance Certificate is required providing information about the energy performance of the completed property.

Energy performance has been assessed using the SAP 2009 methodology and is rated in terms of the energy use per square metre of floor area, energy efficiency based on fuel costs and environmental impact based on carbon dioxide (CO₂) emissions.

**Energy Efficiency Rating**

- Very energy efficient - lower running costs
- (92 plus) A
- (81-91) B
- (60-80) C
- (55-59) D
- (45-54) E
- (25-44) F
- (15-24) G

**Environmental Impact (CO₂) Rating**

- Very environmentally friendly - lower CO₂ emissions
- (92 plus) A
- (81-91) B
- (60-80) C
- (51-80) D
- (31-50) E
- (21-30) F
- (11-20) G

The energy efficiency rating is a measure of the overall efficiency of a home. The higher the rating the more energy efficient the home is and the lower the fuel bills are likely to be.

The environmental impact rating is a measure of a home's impact on the environment in terms of carbon dioxide (CO₂) emissions. The higher the rating the less impact it has on the environment.

Figure 42 Predicted Energy Assessment Arabella
Appendix 5 Detailed Quantitative Results, UK Case Study Participants

Quantitative Results, Robert

Lounge

Figure 43 below shows the actual temperature data monitored in the lounge area of Robert's house from midnight Wednesday 16 October 2013 until midnight Tuesday 11 February 2014. Temperatures were recorded half hourly over the period.

![Figure 43 Raw Temperature °C Robert Lounge](image)

In figure 44, average temperatures are displayed for the lounge area of Robert's house. While the daily average hovers around the 20° C mark, with a maximum daily average of 22.3° C and a minimum daily average of 17.7° C, it is evident from the raw data above, temperatures swing between a maximum of 33.6° C and the minimum of 16.6° C. The raw data gives a complete picture of temperatures recorded every half-hour during the 17 week monitoring period, and provides a context to the average temperatures that are assessed.
There is surprisingly little difference between the daily average temperature in the living area, and the daily occupied average temperature in this part of the house. Total daily average temperatures are 20.2° C, while total daily average occupied temperatures are 20.3° C.

Maximum occupied and minimum occupied temperatures also only have minor variations from the overall daily averages, with a maximum daily occupied average temperature of 22.7° C and a minimum daily occupied average temperature of 17.5° C.

Occupied hours are calculated on the assumption that the property is occupied and using energy between 5 PM and 11 PM on weekdays, and between 7 AM and 11 PM on weekends (Saturday and Sunday). In order to maintain some consistency when making comparisons between the case study occupants, these hours have been investigated, irrespective of particular holiday periods during the time of the study. The purpose of examining these nominated occupied hours is to
see how the energy use for each individual varies from the overall average energy use.

These occupied hours are assumed for all of the 7 UK participants. One might expect an individual's energy use to increase when they are assumed to be occupying the property, however, this may not be the case. In Robert's case, average temperatures do not vary to a great degree, whether the property is (assumed) occupied or not. There could be a number of explanations for this, and these could include Robert believing that it is in fact more efficient to maintain his property at a constant temperature, or that the energy efficiency of his relatively new house makes energy use sufficiently cheap, so that cost is not an issue.

**Bedroom**

Figure 45 shows the actual temperature data monitored in the main bedroom area of Robert's house from midnight Wednesday 16 October 2013 until midnight Tuesday 11 February 2014. Temperatures were recorded half hourly over the period.

![Figure 45 Raw Temperature °C Robert Bedroom](image)

In figure 46, average temperatures are displayed for the main bedroom area of Robert's house. While the daily average stays close to the 21° C mark, with a maximum daily average of 22.4° C and a minimum daily average of 18.5° C, it can be seen from the raw data above that temperatures swing between a maximum of 30.5° C and the minimum of 17.3° C.
Maximum occupied and minimum occupied temperatures are 22.3°C and 18.7°C, again very similar to daily average temperatures. Total daily average bedroom temperatures are 20.8°C, while total daily average occupied temperatures are 20.6°C.

**Actual Energy Use**

The energy use readings at each case study could not be taken concurrently, so actual energy readings are adjusted so that assumed energy use between 16 October 2013 and 11 February 2014 can be evaluated. This was done by dividing the readings by the number of days they represented, and then multiplying this by 119 days, which equates to the number of days in the formal monitoring period.

In Robert's case, actual readings were taken on 12 October 2013 with final readings being taken on 17 February 2014. This represented nine extra days over
the monitoring period. So units were divided by 128 and then multiplied by 119 to give the assumed energy use over the period.

The energy from 293 m$^3$ of gas needs to be converted to kilowatt hours, as explained in section 5.2.1.2 Winter Energy Use. Using the link http://energylinx.co.uk/gas_meter_conversion.html, this gives 3,329 kWhs.

Total energy use is in Table 136 below.

Table 136 Robert Total Energy Use

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Start Reading 12/10/2013</th>
<th>End Reading 17/2/2014</th>
<th>Actual Total</th>
<th>Adjusted Total</th>
<th>Total kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas m$^3$</td>
<td>0845</td>
<td>1160</td>
<td>315</td>
<td>293</td>
<td>3,329</td>
</tr>
<tr>
<td>Electric kWh</td>
<td>01649</td>
<td>02033</td>
<td>384</td>
<td>357</td>
<td>357</td>
</tr>
<tr>
<td>Total Consumption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3,686</td>
</tr>
</tbody>
</table>
Quantitative Results, Gwen

Lounge

Figure 47 below shows the actual temperature data monitored in the lounge area of Gwen’s flat from midnight Wednesday 16 October 2013 until midnight Tuesday 11 February 2014. Temperatures were recorded half hourly over the period.

In figure 48, average temperatures are displayed for the lounge area of Gwen’s house. While the daily average is around the 19°C mark, with a maximum daily average of 21.1°C and a minimum daily average of 15.2°C, the raw data above confirms that temperatures alter between a maximum of 22.4°C and the minimum of 14.9°C.
Total daily average temperatures are 18.9° C, while total daily average occupied temperatures are 19.0° C.

Maximum occupied and minimum occupied temperatures also only have minor variations from the overall maximum and minimum daily averages, with a maximum daily occupied average temperature of 21.3° C and a minimum daily occupied average temperature of 15.1° C.

**Bedroom**

Figure 49 shows the actual temperature data monitored in the main bedroom area of Gwen's flat from midnight Wednesday 16 October 2013 until midnight Tuesday 11 February 2014. Temperatures were recorded half hourly over the period.
In figure 50, average daily temperatures are shown for the main bedroom area of Gwen's flat. While the daily average is just over the 18° C mark, with a maximum daily average of 20.7° C and a minimum daily average of 14.8° C, it can be confirmed from the raw data above that temperatures range between a maximum of 21.6° C and the minimum of 14.6° C.
Maximum occupied and minimum occupied temperatures are 21.0°C and 14.8°C, again very similar (max) and the same (min) as daily average temperatures. Total daily average bedroom temperatures are 18.2°C, exactly the same as total daily average occupied temperatures of 18.2°C.

**Actual Energy Use**

In Gwen's case, actual readings were taken on 05 October 2013 with final readings being taken on 18 February 2014. This represented eighteen extra days over the monitoring period between 16 October 2013 and 11 February 2014. So units were divided by 137 and then multiplied by 119 to give the assumed energy use over the period.

The energy from 148 m³ of gas needs to be converted to kilowatt hours, as explained in section 5.2.1.2 Winter Energy Use. Using the link http://energylinx.co.uk/gas_meter_conversion.html, this gives 1,682 kWhs. Total energy use is in Table 137 below.

**Table 137 Gwen Total Energy Use**

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Start Reading 12/10/2013</th>
<th>End Reading 17/2/2014</th>
<th>Actual Total</th>
<th>Adjusted Total</th>
<th>Total kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas m³</td>
<td>4308</td>
<td>4479</td>
<td>171</td>
<td>148</td>
<td>1,682</td>
</tr>
<tr>
<td>Electric Rate 1 kWh</td>
<td>30547</td>
<td>31263</td>
<td>716</td>
<td>357</td>
<td>357</td>
</tr>
<tr>
<td>Electric Rate 2 kWh</td>
<td>6326</td>
<td>6424</td>
<td>98</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>Total Consumption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,124</td>
</tr>
</tbody>
</table>
Quantitative Results, Jane

Lounge

Figure 51 shows the actual temperature data monitored in the lounge area of Jane's house from midnight Wednesday 16 October 2013 until midnight Tuesday 11 February 2014. Temperatures were recorded half hourly over the period.

![Figure 51 Raw Temperature °C Jane Lounge](image)

In figure 52, average temperatures are displayed for the lounge area of Jane's house. While the daily average is 15° C, with a maximum daily average of 18.2° C and a minimum daily average of 11.0° C, the raw data above shows that temperatures alter between a maximum of 20.8° C and the minimum of 10.8° C.
Small differences between the daily average temperature in the living area, and the daily occupied average temperature in this part of the house can be observed. Total daily average temperatures are 15.0° C, while total daily average occupied temperatures are 14.7° C, surprisingly, below the overall average. Maximum occupied and minimum occupied temperatures also only have minor variations from the overall daily averages, with a maximum daily occupied average temperature of 17.8° C and a minimum daily occupied average temperature of 10.9° C, again lower than overall average temperatures.

Bedroom

Figure 53 shows the actual temperature data monitored in the main bedroom area of Jane’s house from midnight Wednesday 16 October 2013 until midnight Tuesday 11 February 2014. Temperatures were recorded half hourly over the period.
In figure 54, average daily temperatures are displayed for the main bedroom area of Jane's house. While the daily average is approximately 16° C, with a maximum daily average of 19.7° C and a minimum daily average of 11.2° C, it can be seen from the raw data above that temperatures range between a maximum of 1.3° C and the minimum of 11.0° C.

Maximum occupied and minimum occupied temperatures are 19.4° C and 11.2 ° C, again very similar to/ the same as daily average temperatures.
Total daily average bedroom temperatures are 16.3° C, compared with total daily average occupied temperatures of 16.0° C. Further analysis of why this might be the case is undertaken in section 6.5 Discussion of Results.

**Actual Energy Use**

In Jane's case, actual readings were taken on 10 October 2013 with final readings being taken on 25 February 2014. This represented twenty extra days over the monitoring period between 16 October 2013 and 11 February 2014. So units were divided by 139 and then multiplied by 119 to give the assumed energy use over the period.

The energy from 367 m³ of gas needs to be converted to kilowatt hours, as explained in section 5.2.1.2 Winter Energy Use. Using the link http://energylinx.co.uk/gas_meter_conversion.html, this gives 4,170 kWhs.

Total energy use is in Table 138.

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Start Reading 12/10/2013</th>
<th>End Reading 17/2/2014</th>
<th>Actual Total</th>
<th>Adjusted Total</th>
<th>Total kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas m³</td>
<td>6604</td>
<td>7033</td>
<td>429</td>
<td>367</td>
<td>4170</td>
</tr>
<tr>
<td>Electric Rate kWh</td>
<td>21192</td>
<td>21522</td>
<td>330</td>
<td>282</td>
<td>282</td>
</tr>
<tr>
<td>Total Consumption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4452</td>
</tr>
</tbody>
</table>
Quantitative Results, Juliette

Lounge

Figure 55 shows the actual temperature data monitored in the lounge area of Juliette's house from midnight Wednesday 16 October 2013 until midnight Tuesday 11 February 2014. Temperatures were recorded half hourly over the period.

![Figure 55 Raw Temperature °C Juliette Lounge](image)

In figure 56, average temperatures are displayed for the lounge area of Juliette's house. While the daily average is nearly 20° C, with a maximum daily average of 23.4° C and a minimum daily average of 13.9° C, it is clear from the raw data above, temperatures alter between a maximum of 24.9° C and the minimum of 11.7° C. The minimum temperature occurs towards the end of the monitoring period, a time when it is confirmed that Juliette was away from the property. Interestingly, it can be seen in the data covering Juliette's bedroom in the next section, that this drop off in temperature does not seem to occur to quite the same extent.
Small differences between the daily average temperature in the living area, and the daily occupied average temperature in this part of the house can be seen. Total daily average temperatures are 19.8° C, while total daily average occupied temperatures are 19.9° C, very similar to the overall average. Maximum occupied and minimum occupied temperatures also only have minor variations from the overall daily averages, with a maximum daily occupied average temperature of 24.2° C and a minimum daily occupied average temperature of 13.5° C.

**Bedroom**

Figure 57 shows the actual temperature data monitored in the main bedroom area of Juliette’s house from midnight Wednesday 16 October 2013 until midnight Tuesday 11 February 2014. Temperatures were recorded half hourly over the period.
In figure 58, average daily temperatures are displayed for the main bedroom area of Juliette’s house. While the daily average is nearly 19° C, with a maximum daily average of 21.1° C and a minimum daily average of 15.5° C, the raw data above illustrates that temperatures range between a maximum of 23.1° C and a minimum of 13.8° C.
Maximum occupied and minimum occupied temperatures displayed are 21.8°C and 15.9°C, just slightly higher than daily average temperatures. Total daily average bedroom temperatures are 18.7°C, compared with total daily average occupied temperatures of 18.9°C.

**Actual Energy Use**

In Juliette's case, actual readings were taken on 15 October 2013 with final readings being taken on 17 February 2014. This represented seven extra days over the monitoring period between 16 October 2013 and 11 February 2014. So units were divided by 126 and then multiplied by 119 to give the assumed energy use over the period.

The energy from 766 m³ of gas needs to be converted to kilowatt hours, as explained in section 5.2.1.2 Winter Energy Use. Using the link http://energylinx.co.uk/gas_meter_conversion.html, this gives 8,704 kWhs. Total energy use is in Table 139.

**Table 139 Juliette Total Energy Use**

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Start Reading 12/10/2013</th>
<th>End Reading 17/2/2014</th>
<th>Actual Total</th>
<th>Adjusted Total</th>
<th>Total kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas m³</td>
<td>09513</td>
<td>10324</td>
<td>811</td>
<td>766</td>
<td>8704</td>
</tr>
<tr>
<td>Electric Rate kWh</td>
<td>20101</td>
<td>20888</td>
<td>787</td>
<td>743</td>
<td>743</td>
</tr>
<tr>
<td>Total Consumption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9447</td>
</tr>
</tbody>
</table>
Quantitative Results, Wendy

Lounge

Figure 59 shows the actual temperature data monitored in the lounge area of Wendy’s flat from midnight Wednesday 16 October 2013 until midnight Tuesday 11 February 2014. Temperatures were recorded half hourly over the period.

![Figure 59 Raw Temperature °C Wendy Lounge](image)

In figure 60, average temperatures are displayed for the lounge area of Wendy’s house. While the daily average is just over the 15° C mark, with a maximum daily average of 19.4° C and a minimum daily average of 9.5° C, it is evident from the raw data above that temperatures alter between a maximum of 23.4° C and a minimum of 9.2° C.
Only small differences between the daily average temperature in the living area, and the daily occupied average temperature in this part of the flat can be seen. Total daily average temperatures are 15.4°C, while total daily average occupied temperatures are 15.3°C.

However, maximum occupied and minimum occupied temperatures have a significant variation in maximum temperature from the overall daily averages, with a maximum daily occupied average temperature of 21.3°C and a minimum daily occupied average temperature of 9.5°C.

**Bedroom**

Figure 61 shows the actual temperature data monitored in the main bedroom area of Wendy's flat from midnight Wednesday 16 October 2013 until midnight Tuesday 11 February 2014. Temperatures were recorded half hourly over the period.
In figure 62, average daily temperatures are displayed for the main bedroom area of Wendy’s flat. While the daily average is near to the 16°C mark, with a maximum daily average of 20.1°C and a minimum daily average of 10.0°C, it can be seen from the raw data above that temperatures range between a maximum of 23.2°C and the minimum of 9.6°C (raw data temps for bedroom and lounge are very similar).
Maximum occupied and minimum occupied temperatures are 20.4° C and 10.1 ° C, only just marginally higher than daily average temperatures. Total daily average bedroom temperatures are 15.9° C, similar to total daily average occupied temperatures of 15.6° C.

**Actual Energy Use**

In Wendy’s case, actual readings were taken on 03 October 2013 with final readings being taken on 18 February 2014. This represented twenty extra days over the monitoring period between 16 October 2013 and 11 February 2014. So units were divided by 139 and then multiplied by 119 to give the assumed energy use over the period.

Total energy use is in table 140 below. There are clearly significant periods of a number of days when Wendy’s flat was left unoccupied. This will skew the average temperature data.

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Start Reading 03/10/2013</th>
<th>End Reading 18/2/2014</th>
<th>Actual Total</th>
<th>Adjusted Total</th>
<th>Total kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Rate kWh</td>
<td>10029</td>
<td>11267</td>
<td>1238</td>
<td>1060</td>
<td>1060</td>
</tr>
<tr>
<td>Total Consumption</td>
<td></td>
<td></td>
<td></td>
<td>1,060</td>
<td>1,060</td>
</tr>
</tbody>
</table>
Quantitative Results, Anne

Lounge

Figure 63 shows the actual temperature data monitored in the lounge area of Anne's house from midnight Wednesday 16 October 2013 until midnight Tuesday 11 February 2014. Temperatures were recorded half hourly over the period.

![Figure 63 Raw Temperature °C Anne Lounge](image)

In figure 64, average temperatures are displayed for the lounge area of Anne’s house. While the daily average is close to 18° C, with a maximum daily average of 20.3° C and a minimum daily average of 9.9° C, the raw data above confirms that temperatures alter between a maximum of 23.1° C and the minimum of 9.6° C.
Differences between the daily average temperature in the living area, and the daily occupied average temperature in this part of the house can be seen in figure 64. Total daily average temperatures and total daily average occupied temperatures are the same at 17.7°C.

Maximum occupied and minimum occupied temperatures also only have minor/no variations from the overall daily temperatures, with a maximum daily occupied average temperature of 21.3°C and a minimum daily occupied average temperature of 9.9°C.

**Bedroom**

Figure 65 shows the actual temperature data monitored in the main bedroom area of Anne’s house from midnight Wednesday 16 October 2013 until midnight Tuesday 11 February 2014. Temperatures were recorded half hourly over the period.
In figure 66 average daily temperatures are displayed for the main bedroom area of Anne's house. While the daily average is 17.6° C, with a maximum daily average of 20.5° C and a minimum daily average of 8.3° C, the raw data above reveals that temperatures range between a maximum of 22.7° C and the minimum of 8.1° C.
Maximum occupied and minimum occupied temperatures are 20.6° C and 8.3 ° C, again very similar to/ the same as daily average temperatures. Total daily average bedroom temperatures are 17.6° C, compared with total daily average occupied temperatures of 17.4° C.

**Actual Energy Use**

In Anne's case, actual readings were taken on 10 October 2013 with final readings being taken on 25 February 2014. This represented twenty extra days over the monitoring period between16 October 2013 and 11 February 2014. So units were divided by 139 and then multiplied by 119 to give the assumed energy use over the period. Again, there are clearly periods of a number of days when Anne's property was left unoccupied, and Anne also shares the house with two other people.

The energy from 222 ft\(^3\) of gas (meter readings are in cubic feet) needs to be converted to kilowatt hours, as explained in section 5.2.1.2 Winter Energy Use. Using the link http://energylinx.co.uk/gas_meter_conversion.html, this gives 7,139 kWhs.

Total energy use is in table 141.

**Table 141 Anne Total Energy Use**

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Start Reading 12/10/2013</th>
<th>End Reading 17/2/2014</th>
<th>Actual Total</th>
<th>Adjusted Total</th>
<th>Total kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas ft(^3)</td>
<td>8986</td>
<td>9245</td>
<td>259</td>
<td>222</td>
<td>7139</td>
</tr>
<tr>
<td>Electric Rate kWh</td>
<td>75164</td>
<td>76436</td>
<td>1272</td>
<td>1089</td>
<td>1089</td>
</tr>
<tr>
<td>Total Consumption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8228</td>
</tr>
</tbody>
</table>
Quantitative Results, Arabella

Lounge

Figure 67 shows the actual temperature data monitored in the lounge area of Arabella's house from midnight Wednesday 16 October 2013 until midnight Tuesday 11 February 2014. Temperatures were recorded half hourly over the period.

Figure 67 Raw Temperature °C Arabella Lounge

In figure 68, average temperatures are displayed for the lounge area of Arabella's house. While the daily average is close to 15° C, with a maximum daily average of 19.9° C and a minimum daily average of 9.1° C, the raw data above confirms that temperatures alter between a maximum of 22.7° C and the minimum of 8.9° C.
Differences between the daily average temperature in the living area, and the daily occupied average temperature in this part of the house can be seen in figure 41 below. Total daily average temperatures are 15.3° C and total daily average occupied temperatures are virtually the same at 15.4° C. Maximum occupied and minimum occupied temperatures also only have minor variations from the overall daily maximum and minimum temperatures, with a maximum daily occupied average temperature of 20.4° C and a minimum daily occupied average temperature of 9.0° C.

Bedroom

Figure 69 shows the actual temperature data monitored in the main bedroom area of Arabella's house from midnight Wednesday 16 October 2013 until midnight Tuesday 11 February 2014. Temperatures were recorded half hourly over the period.
In figure 70, average daily temperatures are displayed for the main bedroom area of Arabella's house. While the daily average is close to 18° C, with a maximum daily average of 22.8° C and a minimum daily average of 7.0° C, the raw data confirms that temperatures range between a maximum of 28.0° C and a minimum of 6.2° C over the monitoring period (The temperature reached 29.96° C at 10.00 pm on the 26th of November 2013, although this is not visible on the compressed graph of half hourly raw data).
Maximum occupied and minimum occupied temperatures are 24.1° C and 7.0 ° C, again similar to/ the same as daily average temperatures. Total daily average bedroom temperatures are 18.1° C, compared with total daily average occupied temperatures of 17.8° C.

**Actual Energy Use**

In Arabella's case, actual readings were taken on 11 October 2013 with final readings being taken on 18 February 2014. This represented seven extra days over the monitoring period between 16 October 2013 and 11 February 2014. So units were divided by 126 and then multiplied by 119 to give the assumed energy use over the period. There are clearly periods of a number of days when Arabella's house was left unoccupied. Arabella shares the house with one other person.

The energy from 504 m$^3$ of gas needs to be converted to kilowatt hours, as explained in section 5.2.1.2 Winter Energy Use. Using the link [http://energylinx.co.uk/gas_meter_conversion.html](http://energylinx.co.uk/gas_meter_conversion.html), this gives 5,727 kWhs. Arabella has a dual rate electricity supply.

Total energy use is in table 142.

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Start Reading 12/10/2013</th>
<th>End Reading 17/2/2014</th>
<th>Actual Total</th>
<th>Adjusted Total</th>
<th>Total kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas m$^3$</td>
<td>3363</td>
<td>3897</td>
<td>534</td>
<td>504</td>
<td>5727</td>
</tr>
<tr>
<td>Electric Rate 1kWh</td>
<td>36351</td>
<td>37292</td>
<td>941</td>
<td>889</td>
<td>889</td>
</tr>
<tr>
<td>Electric Rate 2 kWh</td>
<td>07315</td>
<td>07552</td>
<td>237</td>
<td>224</td>
<td>224</td>
</tr>
<tr>
<td>Total Consumption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6,840</td>
</tr>
</tbody>
</table>
Appendix 6 Floor Plans And Energy Use, UK Case Study
Participants

Robert: Floor area 81.02 m²  Mid-terrace house, 2012

Figure 71 Downstairs Floor Plan Robert
In order to convert Robert's actual energy use to kWh/m\(^2\)/year, total kWh for the monitoring period should be divided by 119 and multiplied by 365. This figure is then divided by the floor area of the property. Although this "actual" figure is extrapolated, monitoring of energy use and temperature was done over the winter period. For a calendar year it is likely to be slightly overstated. However, this is not particularly important, as the overstatement will apply to all the participants in this study. In addition, of more interest than average temperatures are the actual temperatures recorded, particularly when participants occupied their property, as it provides a measure of the thermal comfort level at which the participant existed.

\[
\text{Gas: } (3,329 \div 119) \times 365 = 10,211 \div 81.02 = 126 \\
\text{Electric: } (357 \div 119) \times 365 = 1,095 \div 81.02 = 13
\]
Table 143 Predicted and Actual Energy Use Robert

<table>
<thead>
<tr>
<th>Energy Type Robert</th>
<th>Predicted (SAP) kWh/m²/year</th>
<th>Actual kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>149</td>
<td>126</td>
</tr>
<tr>
<td>Electricity</td>
<td>28</td>
<td>13</td>
</tr>
<tr>
<td>Total Energy</td>
<td>177</td>
<td>139</td>
</tr>
</tbody>
</table>

Gwen: Floor area 61.00 m²  Top floor flat, 2000

Gas: \((1,682 \div 119) \times 365 = 5,159 \div 61.00 = 85\)
Electric: \((442 \div 119) \times 365 = 1,356 \div 61.00 = 22\)
<table>
<thead>
<tr>
<th>Energy Type Gwen</th>
<th>Predicted (SAP) kWh/m²/year</th>
<th>Actual kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>138</td>
<td>85</td>
</tr>
<tr>
<td>Electricity</td>
<td>29</td>
<td>22</td>
</tr>
<tr>
<td>Total Energy</td>
<td>167</td>
<td>107</td>
</tr>
</tbody>
</table>

Less energy is used than predicted: 38% less gas, 24% less electricity, 36% overall. A Green Deal assessment would calculate savings based on the predicted amount of energy used, and this could mean that the assessment was inaccurate.

Jane: Floor area 66.70 m²  Mid- Terrace House, 1900

Figure 74 Downstairs Floor Plan Jane
### Table 145 Predicted and Actual Energy Use Jane

<table>
<thead>
<tr>
<th>Energy Type Jane</th>
<th>Predicted (SAP) kWh/m²/year</th>
<th>Actual kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>238</td>
<td>192</td>
</tr>
<tr>
<td>Electricity</td>
<td>24</td>
<td>13</td>
</tr>
<tr>
<td>Total Energy</td>
<td>262</td>
<td>205</td>
</tr>
</tbody>
</table>

Less energy is used than predicted: 20% less gas, 46% less electricity, 22% overall. Again, a Green Deal assessment in this case could result in an inaccurate savings prediction.
Juliette: Floor area 66.70 m²  Semi-Detached House, 1931

Figure 76 Downstairs Floor Plan Juliette

Figure 77 Upstairs Floor Plan Juliette
Gas: \((8,704 \div 119) \times 365 = 26,697 \div 80.01 = 334\)

Electric: \((743 \div 119) \times 365 = 865 \div 80.01 = 13\)

Table 146 Predicted and Actual Energy Use Juliette

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Predicted (SAP) kWh/m²/year</th>
<th>Actual kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>172</td>
<td>192</td>
</tr>
<tr>
<td>Electricity</td>
<td>27</td>
<td>28</td>
</tr>
<tr>
<td>Total Energy</td>
<td>199</td>
<td>220</td>
</tr>
</tbody>
</table>

More energy from gas is used than predicted: 11%. Predicted energy use from electricity is almost the same as actual use. Overall Juliette uses around 10% more energy than predicted. A Green Deal assessment could potentially understate the savings she could make by installing energy efficient measures.

**Wendy: Floor area 33.00 m² Mid - Floor Flat, 1900**

![Figure 78 Floor Plan Wendy](image-url)
Electric: \((1060 \div 119) \times 365 \times 3251 \div 33.00 = 98\)

Table 147 Predicted and Actual Energy Use Wendy

<table>
<thead>
<tr>
<th>Energy Type Wendy</th>
<th>Predicted (SAP) kWh/m²/year</th>
<th>Actual kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>222</td>
<td>98</td>
</tr>
<tr>
<td>Total Energy</td>
<td>222</td>
<td>98</td>
</tr>
</tbody>
</table>

Less energy is used than predicted: 56% overall (all from electricity).

Again, a Green Deal assessment in this case could result in a savings prediction that enormously overstated.

Anne: Floor area 66.70 m²  Semi - Detached House, 1930
Figure 79 Downstairs Floor Plan Anne

Figure 80 Upstairs Floor Plan Anne

Gas: \((7139 + 119) \times 365 = 21,897 + 71.68 = 305\)

Electric: \((1089 + 119) \times 365 = 3,340 + 71.68 = 47\)

Table 148 Predicted and Actual Energy Use Anne

<table>
<thead>
<tr>
<th>Energy Type Anne</th>
<th>Predicted (SAP) kWh/m²/year</th>
<th>Actual kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>288</td>
<td>305</td>
</tr>
<tr>
<td>Electricity</td>
<td>29</td>
<td>47</td>
</tr>
<tr>
<td>Total Energy</td>
<td>317</td>
<td>352</td>
</tr>
</tbody>
</table>

More energy is used than predicted: 6% more gas, 60% more electricity, 11% overall.

This house is fully occupied, as Anne shares with two other people. A Green Deal assessment would not take account of electricity used in cooking, or to power
gadgets such as televisions and laptops. As such, it might predict more savings that might actually result in practice.

Arabella: Floor area 66.70 m²  Semi - Detached House, 1935

Figure 81 Downstairs Floor Plan Arabella
Gas: \((5727 \div 119) \times 365 = 17,566 \div 95.48 = 184\)
Electric: \((1,113 \div 119) \times 365 = 3,414 \div 95.48 = 36\)

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Predicted (SAP) kWh/m²/year</th>
<th>Actual kWh/m²/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>254</td>
<td>184</td>
</tr>
<tr>
<td>Electricity</td>
<td>34</td>
<td>36</td>
</tr>
<tr>
<td>Total Energy</td>
<td>288</td>
<td>220</td>
</tr>
</tbody>
</table>

Less energy from gas is used: 28%, but more electricity: 6%, with an overall lower energy use than predicted of 24%.

Arabella’s house has adequate loft insulation (250 mm) but is constructed of solid brick. Her front door is made of wood and part single glazed, with double glazing in all the remaining windows. So one of the main likely Green Deal assessment recommendations would be to install solid wall insulation. This would result in significant energy saving, but it is very costly measure. As Arabella’s house is a similar age and construction to Juliette’s, but completely solid wall rather than part cavity, the installation cost would likely be in a similar range i.e. £9000.