Overcoming barriers to microgeneration in new homes: coevolutionary analysis and attitudes to different deployment models

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Submitted in accordance with the requirements for the degree of
Doctor of Philosophy
as part of the
Integrated MSc and PhD in Low Carbon Technologies

The University of Leeds
Centre for Doctoral Training: Technologies for a Low Carbon Future
Energy Research Institute
School of Chemical and Process Engineering

October 2014

The candidate confirms that the work submitted is her own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

Parts of Chapters 1, 2 and 3 are based on work published in James, H.C., Foxon, T.J. & Gale, W.F. (2012) *Microgeneration in new homes: transition opportunity or transitory non-starter?* Conference Proceedings: International Sustainability Transitions 2012, Copenhagen

The original work contained within this paper is all the candidate's own work with guidance provided by Foxon and Gale.

Acknowledgements

Thank you to Professor Bill Gale and Dr Tim Foxon, whose advice, guidance (and patience!) have been absolutely invaluable. I am honoured to have had them supervising this work. Thanks to Dr Frin Bale and Dr Matthew Hannon for very helpful academic and practical advice at the start and end of my PhD.

Thanks to Matthew Davison and Fran Cousans: the best partner and sister I could ever ask for, who have been unwavering in their support and love throughout this process. I could never thank them both enough. Thanks to my wonderful family and friends: Mike and Katie James, Dreda Lewis, Kat James, Chris Heseltine, Zarashpe Kapadia, Joel Millward-Hopkins, Rebecca Munns, the Pinnocks, Justine Wallis, my LUUSAC buddies, and all the other people who have supported me and are too many to name. Thanks also to my colleagues at POST and AECOM for encouragement and support, and to Katie Goves for the all-important train fare.

Finally, a special mention to fellow members of Cohort 1: Drs Philippa Hardy, Gillian Harrison, Tom Lynch, Sam Pickard and Shem Weekes: for all your help and support, and for making it all so much fun.

Abstract

This research addresses the drivers and barriers for the inclusion of microgeneration in new homes in the UK, and the role of different technology deployment models in overcoming barriers. An interdisciplinary mixed-methods approach is used, drawing on insight from social sciences, economics, innovations theory and psychology to characterise the role of deployment models and assess householder attitudes.

A coevolutionary analysis of drivers and barriers provides evidence that many of the social, economic, technical and institutional issues involved with incorporating microgeneration in new homes are substantially different from those involved with retrofitting the technologies, demonstrating the importance of considering new build domestic microgeneration as an issue in its own right, rather than subsuming it into analyses of retrofitting. The use of Foxon's coevolutionary framework to investigate the diffusion of specific technologies in a certain sector is also demonstrated.

A literature synthesis brings together previously disparate strands of research to draw new insights into the role of different deployment models in overcoming barriers. It is found that the ESCO model is likely to have a significant role to play in facilitating the uptake of microgeneration in new homes, but that householder attitudes towards ESCOs may be mixed.

An existing theory that more innovative householders will prefer private ownership of microgeneration to ESCOs (and vice versa), is tested quantitatively. No relationship between innovativeness and choice of deployment model is found in the present work. However, it is shown that different householders do prefer different models, with younger age, higher levels of education and urban living found to correlate with a preference for the ESCO model. An analysis of occupancy trends in the UK reveals that in the majority of cases, householders' choices of deployment model are likely to align with that which is most economically and technically suitable for their chosen development.

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Abbreviations

ASHP	Air Source Heat Pump
BIS	Department for Business, Innovation and Skills
CFA	Cash Flow Analysis
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CO_2e	CO2 equivalent
CSH	Code for Sustainable Homes
DCLG	Department for Communities and Local Government
DECC	Department of Energy and Climate Change
DER	Dwelling Emission Rate
DSI	Domain-Specific Innovativeness
EPC	Energy Performance Contract
ESC	Energy Services Contract
ESCO	Energy Services Company
EU	European Union
FIT	Feed in Tariff
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GSHP	Ground Source Heat Pump
GW	Gigawatt
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatt
kWh	Kilowatt-hour
kWth	Kilowatt thermal
m/s	Metres per second
MCS	Microgeneration Certification Scheme
Mt	Megatonne
MW	Megawatt
MWh	Megawatt-hour
ppm	Parts per million

PV	(Solar) Photovoltaic
RHI	Renewable Heat Incentive
RHPP	Renewable Heat Premium Payment
TER	Target Emission Rate
TWh	Terawatt-hour
UK	United Kingdom
W	Watt
WTP	Willingness to pay

1 Watt (W)	1 Joule per second
1 kW	1,000 W
1 GW	1,000,000,000 W
1 TW	1,000,000,000,000 W
1 kWh	3,600,000 Joules

1 Introduction

This thesis is about the adoption of microgeneration in new homes in the United Kingdom (UK). I identify the major drivers and barriers to its adoption and use, then consider the role of different deployment models in overcoming some of these barriers. This chapter sets out the motivation for this research. Climate change and its potential consequences are introduced, along with global and UK targets for greenhouse gas emissions reduction. 'Microgeneration' is defined, and its potential contribution to emissions reduction targets is discussed. The chapter ends with a methodological overview and an outline of the rest of the thesis.

1.1 Climate change and greenhouse gas emissions targets

It is widely accepted that anthropogenic emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs) to the atmosphere are causing changes to the global climate beyond those caused by natural fluctuations. The recent Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) stated that "warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased" (IPCC 2013). By 2011, atmospheric concentrations of CO_2 had risen to approximately 391 parts per million (ppm), from approximately 280ppm in pre-industrial times, primarily due to human activity. It is likely that 0.5°C to 1.3°C of global mean surface warming between 1951 and 2010 can be attributed to these increases in GHG concentrations (IPCC 2013).

It is also generally accepted that unmitigated climate change is very likely to have major effects on human life and society and the biosphere. In order to have a chance of avoiding the most dangerous effects of climate change, atmospheric concentrations of GHGs must be stabilised at 550ppm CO_2 equivalent (CO_2e) by 2050 (Tirpak 2005). The economic cost of unmitigated climate change has been estimated at 5 – 20% per year of global gross domestic product (GDP), "now and forever" (Stern 2007). In other words, the cost of climate change will be borne by both current and future generations. The cost of stabilising atmospheric concentrations of CO_2e at 550ppm by 2050 however was estimated in the same review at only 1% of global GDP per year.

In light of the scientific evidence for anthropogenic climate change and its potentially catastrophic effects, a number of international commitments to reducing GHG emissions and increasing the proportions of renewable energy used have been made. The Kyoto Protocol is the largest multilateral commitment to CO_2 emissions reductions, ratified by 187 countries. The Protocol came into force in 2005 and set legally binding limits on signatories' greenhouse gas emissions. Under the first round of the Kyoto Protocol, the UK committed to reducing its emissions by 12.5% compared with 1990 levels by 2012: a target which was exceeded as in 2012 UK emissions were 26.7% below the baseline (DECC 2013f). Under the second round of the Kyoto Protocol, the European Union (EU) has committed to reduce emissions by 20% relative to the base year on average between 2013 and 2020. The UK's contribution to that target is under negotiation at the time of writing.

The UK government has set further national targets and legal limits on greenhouse gas emissions. The Climate Change Act of 2008 is a legal obligation to achieve an 80% reduction in CO_2 emissions compared with 1990 levels by 2050, via a series of five year carbon budgets over the period. The second carbon budget limits UK greenhouse gas emissions to 2,782 $MtCO_2e$ between 2013 and 2017: equivalent to an annual average reduction of 28% below base year levels. Under the EU 2020 target, the UK has committed to reducing emissions from certain sectors by 16% relative to 2005 levels by 2020. Under EU Directive 2009/28/EC on renewable energy, the legally binding UK target for the share of energy from renewable sources in gross final consumption of energy is 15% by 2020 (EU 2009). In 2011 the actual figure was only 3.8% (DECC 2012b). In 2012, renewable sources made up only 11.3% of the UK's generation (in terms of megawatt-hours (MWh) generated), which is still dominated by coal (39%) and natural gas (28%) (DECC 2013a).

1.2 Microgeneration as a response to energy and emissions targets

1.2.1 **Definition of microgeneration**

The term ‘microgeneration’ is usually used to describe small-scale renewable energy generation systems. Beyond this the exact definitions ascribed to it are quite variable. Even the spelling varies (reflecting its relatively recent entry into common use), with the most common permutations being ‘micro-generation’, ‘micro generation’ and ‘microgeneration’. This thesis will use the latter for consistency, unless directly quoting from another source.

The legal definition of microgeneration varies from country to country, and for the UK was set out in Section 82 of the 2004 Energy Act:

“… “microgeneration” means the use for the generation of electricity or the production of heat of any plant which in generating electricity or (as the case may be) producing heat, relies wholly or mainly on a source of energy or a technology mentioned in subsection (7); and the capacity of which to generate electricity or (as the case may be) to produce heat does not exceed [50 kilowatts (kW) for the production of electricity, and 45 kilowatts thermal (kW_{th}) for heat production].”

The sources of energy and technologies listed in subsection 7 are: biomass, biofuels, fuel cells, photovoltaics, water (including waves and tides), wind, solar thermal, geothermal sources, combined heat and power (CHP) systems, air[1], and “other sources of energy and technologies for the generation of electricity or the production of heat, the use of which would, in the opinion of the Secretary of State, cut emissions of greenhouse gases in Great Britain”.

In essence then, microgeneration is legally defined in the UK as a generation plant which uses mostly or exclusively renewable energy sources (or waste heat) and has a capacity of up to 50 kW (or 45 kW_{th} for heat production).

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[1] Added to the list by the Microgeneration (Definition) (Amendment) Act 2008.

Microgeneration is often further qualified as being connected to the electricity distribution system (as opposed to the transmission system) and being located close to the point of use. In addition, despite the legal definition of microgeneration as having a capacity of 50 kW or less, the UK Feed in Tariff (FIT) - introduced in April 2010 to provide payments for renewable energy generation (see Section 2.3.1.1) – applies to systems serving single residences up to 5MW capacity. In July 2013, the Department of Energy and Climate Change (DECC) announced that FIT payments would be extended to community projects up to 10MW capacity. This allows larger installations such as district heating plants and community-scale generating systems to receive payments under the scheme.

Academic descriptions of microgeneration are similarly varied. In addition to the aforementioned definitions which specify fuel and scale, a number of academic papers emphasise the local and self-sufficiency aspects of microgeneration. For example, Bergman et al. (2008) and Staffell et al. (2010) define it as “the generation of zero- or low-carbon heat and/or power by individuals, small businesses and communities to meet their own needs”. Similarly the authors of a Sustainable Consumption Roundtable report “interpret the term micro-generation to apply to on-site renewable [generation]” (Dobbyn and Thomas 2005).

For the purpose of this thesis, ‘microgeneration’ will be defined as **the on- or near-site generation of electricity or production of heat by a system which uses mostly or exclusively renewable sources of energy – including combined heat and power (CHP) – and has a capacity of 10MW or less.** This upper limit for capacity is many orders of magnitude larger than most standalone domestic microgeneration systems, but has been set in order that community-scale distributed generation projects or microgrids are not excluded.

1.2.2 **Contribution to targets**

Estimates of the contribution that microgeneration can make to emissions reduction and renewable energy targets in the UK vary depending on the methods used and the policy or technology scenarios applied. However, several assessments have indicated that under a supportive policy regime, microgeneration could make a significant difference to progress towards these targets.

A 2007 analysis showed that even with extensive refurbishment of the current housing stock to reduce energy demand, at least one microgeneration installation per home was likely to be needed to meet the target of 80% emissions reduction by 2050 in that sector (Boardman 2007). In 2004, the Green Alliance estimated that if a quarter of the 1.3 million gas boilers replaced annually in the UK were replaced by micro-CHP, half of the domestic sector's carbon reduction target could be achieved (Collins 2004). In 2007 the Energy Saving Trust's analysis found that microgeneration had the potential to be saving a maximum of 96 $MtCO_2$ per year in the UK by 2050 compared with business as usual projections. Under a scenario of supportive but realistic policies, they calculated that there could be over 16 million installations in the UK by 2050, saving 84 $MtCO_2$ per year (Energy Saving Trust 2007). A 2008 analysis by Element Energy produced slightly more conservative maximum annual savings (from domestic and non-domestic installations) of 3.3 $MtCO_2$ by 2015, 11.2 $MtCO_2$ by 2020, 36.3 $MtCO_2$ by 2030 and 55.3 $MtCO_2$ by 2050. 55.3 $MtCO_2$ per year would represent 7.6% of the UK's 2020 target for renewable energy capacity, and is also a significant proportion of current emissions from the energy sector, which were 80.6 $MtCO_2$ in 2012 - 2013 (DECC 2013e; Element Energy 2008).

Microgeneration has a number of features which can provide benefits beyond simply decarbonising energy generation. The variety of technology types provide diversity of supply, which provides increased national energy security with decreased reliance on foreign imports (Bergman et al. 2008). A larger number of decentralised energy sources also means that accidental or malicious infrastructural damage is likely to have a smaller impact (Collins 2004). Transmission and distribution losses associated with the transport of electricity through the grid are also avoided. These transmission losses can be quite significant, with centralised power generation systems losing 60% of their primary energy through waste heat and transmission (Energy Saving Trust 2007). In 2011, 6.8TWh of power was lost from the UK's high voltage transmission system (DECC 2013a).

1.3 New homes and microgeneration in the UK

In the year 2012 - 2013, the residential sector was responsible for the emission of 80.6 $MtCO_2$: this was 16.6% of the UK's total emissions over that time (DECC 2013e). In 2012, the residential sector accounted for 57% of the UK's final energy consumption (DECC 2013b). Meanwhile, a growing population and decreasing average number of people per household in the UK means that demand for new homes is increasing. The Department for Communities and Local Government (DCLG) predicts that by 2021 there will be 24.3 million households in England, a growth of just under 1.8 million compared with 2013 (DCLG 2013b). In 2007, the government estimated that a net of 240,000 new homes per year would be required in England by 2016 to meet demand (Wilson 2010). The National Housing and Planning Advice Unit (NHPAU), which provides independent advice to government, estimated that this figure should be 270,000 per year by 2016 (NHPAU 2007). If NHPAU's target were delivered, this would equate over to 1.6 million new homes between the beginning of 2011 and the end of 2016. It should be noted that this is unlikely to be achieved: the housing sector was adversely affected by the recent recession, and the number of new homes completed in the UK in 2012 was 143,590, down from 226,420 in 2007 (DCLG 2013a). Nonetheless, even if this rate of increase remained static, this would lead to just over a million new builds by 2020, making new homes an area of significant potential for energy and emissions savings.

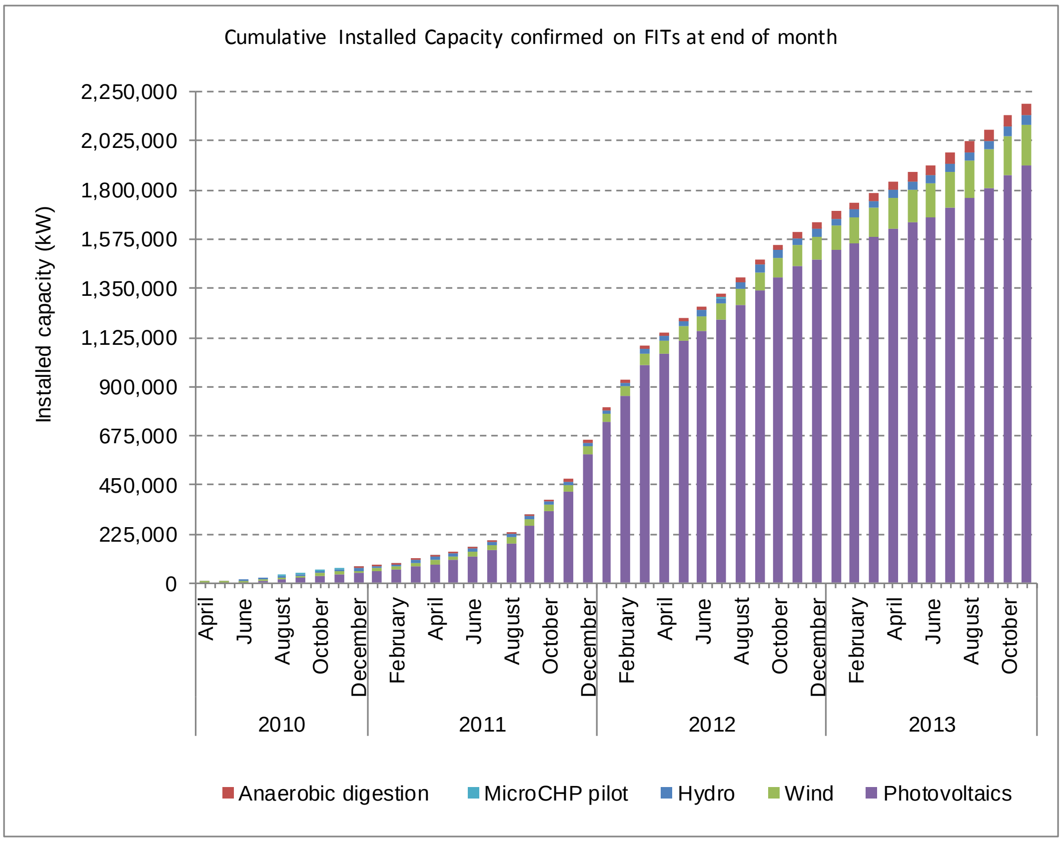
The fourth IPCC report pointed out that energy savings can be much higher in new houses than when retrofitting, as new buildings can be designed and operated as complete systems which are more efficient than a set of discrete measures (Levine et al. 2007). Microgeneration systems are likely to realise their full potential when used in conjunction with energy saving measures, many of which can be built into building fabric. The aforementioned Sustainable Consumption Roundtable report also found some evidence to suggest that buildings with a host of integrated energy saving measures could have a greater effect on residents' energy use practices than standalone measures (Dobbyn and Thomas 2005). There is therefore a significant opportunity to increase the number of domestic microgeneration installations in the UK by including them in new homes, potentially providing significant emissions savings.

1.4 Current status of microgeneration in the UK

Since the introduction of the FIT, the installed capacity of microgeneration in the UK has increased dramatically, from close to zero at the start of 2010, to over 2GW in October 2013. This increase is shown in Figure 1, which also demonstrates that the vast majority of installations are of solar photovoltaics (PV).

Nonetheless, assuming one installation per home, only 5% of homes in the UK had microgeneration in October 2013 (DCLG 2011a; DECC 2013c), and the total installed capacity in 2012 was only 0.74% of the UK's total installed capacity (DECC 2013d).

Figure 1. Cumulative installed capacity registered for FIT, April 2010 - October 2013



Graph reproduced from report of Government FIT register statistics (DECC 2013c)

1.5 Summary and research aims

This chapter has outlined the background information and motivation for the work presented in this thesis. There is now unequivocal evidence that anthropogenic greenhouse gas emissions are contributing to climate change, and that if emissions are left unchecked the results are likely to be devastating to humans and the environment (IPCC 2013). As a result, the UK has committed to reducing its CO_2 emissions by 80% relative to 1990 levels by 2050, and to producing 15% of its energy from renewable sources by 2020.

The potential contribution of microgeneration technologies to GHG emission reductions is significant. Given the contribution of the residential sector to the UK's CO_2 emissions and energy consumption, the use of domestic microgeneration is a potentially valuable strategy for achieving the UK's energy and emissions targets. New homes in particular present a significant opportunity for decarbonising the residential sector. The aim of this thesis is therefore to characterise the barriers and opportunities for microgeneration in new UK homes, and to investigate how these barriers can be overcome. The specific research questions are:

1. **What are the drivers and barriers for microgeneration in new homes in the UK? In particular, do they differ significantly from those relating to retrofitting microgeneration?**

2. **What interventions could be used to overcome barriers to microgeneration in new homes in the UK?**

3. **How can different deployment models for microgeneration be used to overcome barriers to the technology in new homes in the UK?**

4. **What are consumers' attitudes to different microgeneration deployment options, and how do they differ for different demographic groups?**

5. **What effect will differences in attitude (if any) have on consumers' choice of microgeneration deployment model in new builds in the UK?**

Further justification for these research questions is given in subsequent chapters.

1.6 Thesis outline

In response to the growing recognition over the past four decades that social and environmental processes (and hence research questions) are embedded in and emerge from highly complex and interlinked systems, an additional overarching aim of this thesis is to use an interdisciplinary approach to investigating and answering the questions posed above. By using and combining techniques and knowledge from different disciplines, a more flexible approach can be employed, ensuring that interactions between different system elements are not overlooked. As Nissani (1997) points out, "some worthwhile topics of research fall in the interstices among traditional disciplines." This is particularly relevant to Chapter 4 of this thesis, which comprises an investigation of how previously disparate insights from different disciplines can shed new light on the issues and questions around microgeneration deployment options in new homes. However, the entire thesis is informed by this approach.

The thesis therefore uses a mixed-methods approach to investigating the research questions stated above. The methods are described in more detail in the relevant chapters, however as a general overview: Chapter 3 analyses the results of semi-structured interviews using a coevolutionary theoretical framework, Chapter 4 uses literature synthesis and technoeconomic analysis, and Chapter 5 uses qualitative analysis and statistical tests to analyse questionnaire data. In addition to filling in some of the gaps in knowledge identified in Chapter 2, the results presented in Chapter 3 form a large part of the justification and motivation for the remainder of the thesis. Reviews of some of the relevant literature, and the methods used for these stages of the research, are therefore incorporated into Chapters 4 and 5 rather than being presented in standalone chapters at the beginning of the thesis. This structure allows them to be read and understood in the context of the 'groundwork' laid out in Chapter 3, and avoids repetition of information throughout the thesis.

The structure of the thesis is as follows:

Chapter 2 of the thesis comprises an overview of microgeneration technologies and a review of the current literature on drivers and barriers for microgeneration in the UK. It identifies the need for further research on new homes specifically, and introduces the analytical framework used in Chapter 3.

Chapter 3 presents a coevolutionary study of the major drivers and barriers for microgeneration in new homes, and identifies opportunities for interventions and further research.

Chapter 4 builds upon some of the key findings in Chapter 3, synthesising different strands of existing research to investigate how different deployment arrangements for microgeneration could overcome some of the barriers identified. Methods and knowledge from Rogers' work on innovators and contemporary studies of the diffusion of innovations are applied to the issue of microgeneration in new homes. Psychological theories and techniques are considered to investigate how they can be used to test hypotheses posited by contemporary researchers. A technoeconomic analysis is also carried out to investigate one such hypothesis. Where evidence is ambiguous or lacking, research questions are identified and hypotheses formulated.

Chapter 5 investigates some of the hypotheses formed in Chapter 4 in more detail, presenting the method and results of a quantitative study of the relationships between householder characteristics and preferences for different microgeneration deployment arrangements.

Chapter 6 summarises the major findings of the thesis, discussing their implications for stakeholders, policy, and future studies on the uptake of microgeneration technologies in the UK.

2 Research context

2.1 Chapter overview

In Chapter 1, the importance of decarbonising the energy and residential sectors was outlined. The potential contribution of domestic microgeneration to this aim was also discussed, along with evidence showing that the technical potential of microgeneration has not yet been realised in the UK. Having stated the research aims of this thesis in Chapter 1, this chapter describes the research context: different microgeneration technologies, UK policies relevant to microgeneration and new homes, and industry and householder issues. The relevant existing research in these areas is reviewed.

As discussed in Section 1.2.2, despite the technical and infrastructural requirements of microgeneration which differ from conventional centrally-controlled large scale generation and distribution, it already has the potential to make significant contributions to energy generation and emissions reductions in the UK. As a result, many of the barriers to widespread deployment are institutional and social, rather than issues of technical insufficiency (Sauter 2008). There are of course large benefits to be gained from continuing to improve the performance of existing microgeneration technologies and develop new ones. Detailed cutting-edge research on, for example, nano-materials for solar cells, wind resource assessment and building energy management systems is ongoing, and will certainly have an impact on the diffusion and adoption of microgeneration technologies. However, as discussed in Sections 1.5 and 1.6, the aim of this thesis is to identify interdisciplinary system-level issues, then focus specifically on deployment models and the implications of user preferences. Therefore, while acknowledging and considering the importance of technical issues where appropriate, this literature review is primarily focused on institutional, economic and social drivers and barriers for microgeneration in the UK, though the technical features of microgeneration which may have a bearing on their deployment are outlined in Section 2.2.

A number of researchers have considered influences on the diffusion of microgeneration technologies in the context of international comparisons, for example Praetorius et al.'s (2010) comparison of technical innovation systems in the UK and Germany, and Bertoldi et al.'s (2006) study of energy service companies in European countries. None were found that considered microgeneration in new homes specifically, but where these studies add value to the discussion of factors affecting the uptake of microgeneration in the UK, they have been discussed in the sections below. Additionally, where evidence from the UK is lacking, studies conducted in other countries have been discussed in this review, notably Claudy et al.'s work on willingness to pay for microgeneration in the Republic of Ireland (Claudy et al. 2011; Claudy et al. 2010a; Claudy et al. 2010b; Claudy et al. 2010c). However, this literature review and thesis do not focus on international differences or factors affecting microgeneration in countries outside the UK. The UK has been chosen as a focus for this thesis due partly to the current emphasis on decarbonising the residential sector discussed in section, and partly to provide a boundary for the scope of the study. Additionally, a number of existing studies provide international comparisons of policies, attitudes, economics and technical innovation systems for low carbon technologies, therefore inclusion of international comparison in this thesis is considered unlikely to add significant value to this field.

A final general point about literature on microgeneration and low carbon homes in the UK is that policies, industry practices and markets are extremely dynamic, and some older analyses have therefore lost much of their relevance. As a representative example, Allen et al.'s comprehensive 2008 review of drivers and barriers to microgeneration in the UK describes nine Government policies and strategies, of which six are now defunct or have been superseded. As a result, relatively few system-level or policy studies exist, and those that are reviewed here date mostly from the last five to ten years.

Section 2.2 of this chapter discusses some of the technical features of microgeneration. Section 2.3 describes and briefly reviews UK policies relating to microgeneration and new build homes. Section 2.4 considers the role of industry in the uptake of microgeneration in the UK, and Section 2.5 the roles and attitudes of householders. Section 2.6 presents the recent research into new business models for microgeneration. In Section 2.7, the gaps in knowledge and the research aims which this thesis addresses are identified and discussed in more detail. The research framework used in Chapter 3 is described and reviewed in Section 2.8.

2.2 Technology

Apart from the in-depth studies of specific technologies mentioned above, there have been several reviews of microgeneration technologies outlining their current standards, operation, market status and average payback periods. This section describes the different microgeneration technologies available, and features common to most or all of the technologies which have a bearing on their deployment in the UK.

2.2.1 **Microgeneration technologies**

2.2.1.1 Solar photovoltaic

Solar photovoltaic (PV) systems use energy from the Sun to generate electricity, using solar cells. A solar panel consists of a number of solar cells, connected to a circuit.

The basic mechanism behind a solar cell is the p-n junction. This is a junction between two semiconducting materials, one positive-type (p) and one negative-type (n). N-type semiconductors have surplus free electrons, while p-type have a deficit of free electrons (with missing free electrons known as ‘holes’). Free electrons are in the ‘conduction band’, while electrons which are forming covalent bonds (non-free electrons) are in the ‘valence’ band. The energy required to ‘free’ an electron and promote it from the valence band to the conduction band is known as the band gap. In semiconductors, this band gap is small compared to the band gap in insulating materials.

When light falls on a p-n junction, the energy excites electrons, which are promoted from the valence band to the conduction band, leaving behind ‘holes’ in the valence band. The net effect is a layer on the n side of the junction which is more positively charged than before, and a layer on the p side which is more negatively charged than before. This causes a reverse electric field to be present around the junction, which causes electrons to flow into the n-region, and holes to flow into the p-region. A flow of electrons is a current, so there is a current flowing through the semiconductor which can flow out of a metal contact on the cell.

Different types of semiconducting material and different cell designs can be used for greater efficiencies, but the basic p-n junction mechanism is the basis for nearly all solar cells. In recent years nanotechnology has been used to construct more efficient cells, but despite promising results this technology remains very expensive and is not yet used commercially. Most solar cells do not require direct sunlight to function and can use diffuse solar radiation. However, the amount of electricity generated is a function of irradiance (with commercially available cells having a typical efficiency of 10 – 20%), and persistently overcast or shady locations are not suitable for solar PV systems. South facing roofs with a pitch of approximately 30° are ideal, though roofs facing southeast or southwest may also be suitable. North facing roofs are unlikely to allow the generation of enough electricity to pay back the cost of the installation.

In the UK, average domestic scale solar PV systems have a capacity of 3.5 – 4 kW and cost between £5,500 and £9,500. A well sited 4 kW system can generate approximately 3.7 MWh electricity per year (Energy Saving Trust 2013f). Solar PV accounts for the majority of electricity microgeneration installations in the UK, making up approximately 86% of installed capacity and 99% of installations (DECC 2014).

2.2.1.2 Micro wind

Wind turbines capture power from the wind, with the wind turning blades which drive a generator to produce electricity. RenewableUK (the professional body for UK wind and marine renewables) divides ‘small wind technologies’ into three categories: micro-wind (<1.5kW), small wind (1.5 – 15kW) and small-medium wind (15 – 100kW). Roof mounted micro-wind turbines are the most common type of domestic turbine installation (RenewableUK 2011).

Domestic wind turbines are only suitable for sites with an average wind speed of at least 5m/s. Accurately predicting wind speeds for a particular site is difficult, as local topography can have significant effects. As a result, up to a year's worth of wind speed measurements may be needed for the site prior to installation (Energy Saving Trust 2013h). In the UK, domestic wind systems currently cost approximately £2,000 for 1kW, £15,000 for 2.5kW and £22,500 for 6kW (Energy Saving Trust 2013h). Micro wind is the second most common type of electricity microgeneration in the UK, accounting for approximately 9% of installed capacity and 1% of installations (DECC 2014).

2.2.1.3 Micro hydro

Hydroelectric power uses running water to turn a turbine and generate electricity. For domestic scale systems, water is diverted at a small weir to an intake pipe, and passes through a filter to catch debris and a settling tank where flow is slowed sufficiently for suspended particles to sink. The water then flows through a pressure pipe to the turbine (which is installed in a powerhouse along with a generator), then flows back along a tailrace (either a pipe or a sloping channel) to the river.

Hydroelectric systems need very specific site conditions, with sufficient flow rate and height difference over distance, and a waterway which maintains a certain minimum flow throughout the year. A typical UK domestic system of 5kW capacity currently costs approximately £25,000, though the cost is highly dependent on the site (Energy Saving Trust 2013d). Hydroelectricity currently accounts for fewer than 1% of electricity microgeneration installations in the UK (DECC 2014).

2.2.1.4 Combined heat and power

A combined heat and power (CHP) system is one which produces both heat and electricity, usually at a ratio of 6:1 in domestic systems (Energy Saving Trust 2011b). In industrial scale CHP processes, the primary purpose is electricity generation, with waste heat from generation captured for a secondary purpose. In micro-CHP systems which are used in homes, heat generation is the primary purpose, with electricity generation as a useful by-product. The primary fuel (usually natural gas) is combusted in an engine to generate heat (usually in the form of hot water) and electricity. This is achieved using a Stirling engine, an internal combustion engine or a fuel cell, with the Stirling engine currently most commonly installed in UK households (Energy Saving Trust 2011b). The cost of a domestic CHP boiler varies depending on the installer and the property, but the average in the UK is around £3,000 (Baxi 2012). Micro CHP currently accounts for fewer than 1% of electricity microgeneration installations in the UK (DECC 2014).

2.2.1.5 Biomass

Domestic biomass heating systems are fuelled by wood: chips, pellets or logs. They may consist of a stove, which heats a single room, or a boiler, which provides space and hot water heating for a whole house. Biomass boilers can replace a conventional gas boiler, though they are larger and therefore require more space and must often be situated on the ground floor of a house. A flue system is also needed, which must be built, or converted from an existing chimney. Since it is cheaper and easier to buy fuel in bulk, space for a fuel store is often a requirement for a biomass heating system. In the UK, an average pellet boiler costs £7,000 - £13,000, and an average pellet stove £4,300 (Energy Saving Trust 2013i).

2.2.1.6 Solar thermal

Solar thermal systems use energy from the Sun for water or space heating. There are two main types of solar collector which can be used: evacuated tube and flat plate. Evacuated tube solar collectors consist of a series of partially evacuated (vacuum) glass tubes. Each tube contains a metal heat absorber plate connected to a heat pipe, which transfers heat to a header pipe. Water running through the header pipe is thus heated, with the partial vacuum in the tube reducing heat loss. Flat plate collectors consist of a dark flat plate energy absorber (usually metallic, although polymers may be used) under a transparent cover (to allow solar energy through but reduce heat loss) and with insulated backing. Fluid pipes containing water, antifreeze or any other heat transport fluid pass between the backing and the collector plate, which transfers heat to the fluid. In both cases, energy input is required to pump the fluid through the collector. Evacuated tube collectors are more efficient, but are more complex and expensive.

Solar thermal systems require sufficient roof space (around 5m^2) and have the same roof direction requirements as solar PV in order to maximise irradiance. A dedicated hot water tank is also usually required. In the UK, a typical solar thermal system costs £4,800 (Energy Saving Trust 2013g).

2.2.1.7 Heat pumps

Heat pumps use the opposite mechanism to refrigerators or air conditioning units, extracting heat energy from the environment and amplifying the temperature in order to heat air or water. Air source heat pumps (ASHPs) use a heat exchanger consisting of coiled tubing containing refrigerant. Liquid refrigerant with a low boiling point absorbs heat from the air (even at low air temperatures) and evaporates. It is pumped into a compressor to raise its temperature, and then passes through heat exchange coils which have air or water pumped over them. The refrigerant cools and re-condenses in the process, and is drawn at high pressure back into the original evaporator coil. The heat pump may provide space heating for a room (‘air to air’) or be connected to a water heating system for central heating or hot water (‘air to water’), and can often be operated in reverse to provide cooling if required. ASHPs are sited on an external wall so need sufficient exterior space for installation and to allow air flow around the unit.

Ground source heat pumps (GSHPs) operate in a similar fashion to ASHPs, but absorb heat from the ground rather than the air. External heat exchanger tubes are buried underground, either horizontally at a depth of 1.2 – 1.5m which requires a large area of land, or vertically in two boreholes up to 100m deep (Staffell et al. 2010). The evaporation-compression cycle is broadly the same as for ASHPs, but GSHPs tend to be more efficient since the temperature underground is more constant than air temperature (Staffell et al. 2010).

Both types of heat pump work most efficiently when heating constantly at a lower temperature than typical boilers. As a result, large radiators or underfloor heating systems are ideal, and heat pumps are most suitable for well insulated homes. In the UK, a typical domestic ASHP costs £6,000 – £10,000 (Energy Saving Trust 2013a) and a typical GSHP costs £9,000 - £17,000 (Energy Saving Trust 2013c) depending on the site and the size of the system.

2.2.2 **Dispatchability and storage**

In the energy generation sector, the term ‘dispatchable’ is used to describe energy sources or generation techniques which allow generation to start or stop on demand. Many microgeneration technologies are non-dispatchable. That is, they do not generate on demand, and generate at a variable rate throughout the day (depending on for example irradiance, wind speed, ambient temperature etc.). Since household energy demand is also variable, it can be difficult to match supply and demand. Large scale battery storage of electricity is currently difficult and expensive (Staffell et al. 2010) therefore it is often exported to the grid when supply exceeds demand, with electricity imported when the situation is reversed. Heat storage is usually achieved by storing it as hot water, since there is no national ‘heat grid’. This often requires the installation of a specialised storage tank, since most conventional water tanks do not have the capacity to store water at the required temperatures.

2.2.3 Import, export and metering

Since the operation of a domestic microgeneration electricity system usually involves import from and export to the grid, sophisticated metering technology is advantageous. Smart meters can monitor imports and exports, or a net meter can be installed which goes into reverse when electricity is exported. Net meters are not optimal however as they can be tampered with, and do not differentiate between import and export tariffs (Staffell et al. 2010). Smart metering technology is currently rather expensive and is therefore not always installed along with microgeneration technologies. In these cases operators and energy companies will agree feed-in tariff payments for a fixed percentage of metered generation ('deemed tariffs': often 50%), regardless of actual exports.

2.2.4 Capacity and system sizing

It is more efficient to run a generating system at full capacity than partial capacity, since at lower powers fuel may be only partially combusted, ancillary power requirements (the power required to run the system) tend to remain the same regardless of system load (Everett and Boyle 2004), and oversized systems will use more power in starting up and shutting down (Staffell et al. 2010). As a result it is often more efficient to install a microgeneration system which has a capacity lower than required to fulfil a household's demand. Smaller systems will also tend to have lower capital costs, but will receive smaller FIT payments (see Section 2.3.1.1) and will increase reliance on imports from the National Grid or a gas supplier. Balancing these considerations is therefore important when selecting system size and capacity for a household.

2.2.5 Expected versus actual performance

There are often disparities between the rated performance of a microgeneration system as predicted by the manufacturers and its actual performance once installed. This is partly due to the fact that manufacturers usually test their products under highly controlled conditions, rather than the variable conditions of households (Staffell et al. 2010), and partly because optimal performance of microgeneration is conditional on correct installation and operation. The installation issue is addressed in the UK by the Microgeneration Certification Scheme (see Section 2.3.1.3).

2.3 UK Policy

A number of UK policies and regulations relate directly or indirectly to domestic microgeneration. Arguably the most significant policies affecting domestic microgeneration are the Feed-In Tariff (FIT) and Renewable Heat Incentive (RHI). As Figure 1 demonstrated, the introduction of the FIT in 2010 had a profound impact on the number of microgeneration installations in the UK. As such, policy critiques can almost be considered to fall into two distinct 'eras': pre-FIT, in which there were numerous calls and recommendations for such a scheme (for example, Boardman (2007) Element Energy (2008), Keirstead (2006) and Watson et al. (2008) *inter alia*); and post-FIT, in which many papers have been published examining the current and projected effects of the FIT and RHI (for example, Bergman and Eyre (2011) and James (2012) *inter alia*).

Policy reviews also tend to focus either on eco-housing as a whole (including other decarbonisation measures such as fabric efficiency), or on microgeneration with an explicit or implicit focus on retrofit. There is some crossover, with many of the former considering microgeneration and many of the latter mentioning new homes, but no publically available studies to date focusing solely on microgeneration in new homes have been identified. This section describes the UK policies specifically related to microgeneration, and building policies which affect microgeneration in new homes, along with academic and industry views on them.

2.3.1 **Microgeneration policies**

2.3.1.1 Feed-In Tariff

The Feed-In Tariff (FIT) came into effect in April 2010, and is designed to provide an incentive for installing microgeneration by providing payment for small scale renewable electricity generation. The scheme is financed by energy companies (through a levelisation process which ensures costs are spread evenly among companies), who pass the costs onto consumers.

Individual systems up to 5MW capacity installed on or after 15th July 2009 are eligible for payments at varying rates, shown in Table 1 (December 2013 tariffs). Systems installed prior to that are eligible for a reduced flat rate generation tariff of 9p/kWh. Payments are guaranteed for 20 years. In July 2013 the Government announced that community installations up to 10MW will be eligible for FITS when the Energy Bill comes into force (at the time of writing it is before the House of Commons for consideration of amendments by the House of Lords).

In previous years tariffs differed between installations on new buildings and those retrofitted to existing buildings, but none of the current tariffs differentiate between the two.

Table 1. Feed in Tariffs current as of 12th December 2013

Energy source	Scale	Rate[1] or criteria	Tariff (p/kWh)
Anaerobic digestion	≤250kW		15.16
	>250kW – 500kW		14.02
	>500kW		9.24
Hydroelectricity	≤15kW		21.65
	>15 – 100kW		20.21
	>100kW – 500kW		15.50
	>500kW – 2MW		12.48
	>2MW – 5MW		3.23
Micro CHP	<2kW	Available for 30,000 installations, subject to review after 12,000 installations.	12.89
Solar PV	≤4kW	Higher	14.90
	≤4kW	Medium	13.41
	>4 – 10kW	Higher	13.50
	>4 – 10kW	Medium	12.15
	>10 – 50kW	Higher	12.57
	>10 – 50kW	Medium	11.31
	>50 – 150kW	Higher	11.10
	>50 – 150kW	Medium	9.99
	>150 – 250kW	Higher	10.62
	>150 – 250kW	Medium	9.56
	≤250kW	Lower	6.85
	>250kW – 5MW		6.85
	≤5MW	'Standalone' systems not attached or wired to an occupied building.	6.85
Wind	≤100kW		21.65
	>100 – 500kW		18.04
	>500kW – 1.5MW		9.79
	>1.5MW – 5MW		4.15

[1] Lower rate = where the building being supplied is rated lower than D under the Energy Performance Certificate scheme (see section 2.3.2.3). Medium rate = where the technology owner owns 25 or more FIT-registered microgeneration installations. Higher rate = rate used where neither lower or medium rate applies.

Source: Ofgem (2013)

An export tariff is also available for electricity exported to the grid. The flat rate for any energy source is 4.64p/kWh at the time of writing. In the absence of a smart meter (which is currently not always included with microgeneration technology) it is usually assumed that 50% of electricity generated is exported, though this is open to negotiation with the energy company.

To account for the fact that technologies tend to become cheaper over time, the tariffs are subject to degression: both pre-planned and contingent. Pre-planned degression rates are shown in Table 2.

Table 2. Pre-planned degression rates current as of 12th December 2013

Technology	Frequency	Effective on	Degression
Solar PV	Quarterly	1st January, 1st April, 1st July, 1st Nov of every year	3.5%
Anaerobic digestion biogas, Hydroelectricity, Wind	Annually	1st April of every year	5%
Micro CHP, all export tariffs	None	-	-

Contingent degression is a mechanism allowing flexibility in the degression rates. The Government has determined the ranges of expected deployment for each technology, used to determine tariff levels. If deployment is higher or lower than expected, the degression level can be increased or decreased accordingly, by pre-determined amounts. The tariff levels may also be reviewed annually, regardless of deployment levels. The policy, in addition to limits set under the Government's Levy Control Framework, is therefore effectively self-limiting, as high rates of installation will lead to faster tariff degression (James 2012).

2.3.1.2 Renewable Heat Incentive

Since the FIT excludes heat generating microgeneration technologies, a similar scheme for heat: the Renewable Heat Incentive (RHI), came into force on 9th April 2014. It was originally intended to start in 2012 but was subject to several delays.

The RHI is part of a two phase scheme, with the Renewable Heat Premium Payment (RHPP) scheme effective from August 2011 until March 2014, and full RHI payments starting in Spring 2014. The RHPP was a one-off grant rather than a feed-in tariff, with installations of renewable heat technologies from 21st July 2011 eligible for the scheme. A finite number of grants were available. The grant values and eligible technologies, updated in May 2013, are shown in Table 3.

Table 3. RHPP grant values

Technology	Grant value
Air to water heat pump	£1,300
Biomass boiler	£2,000
Ground or water source heat pump	£2,300
Solar Thermal	£600

The RHI operates in a similar fashion to the FIT, with tariffs paid for the generation of heat, guaranteed for seven years. However, the scheme is financed by the Government Treasury rather than energy companies, and since there is no heat equivalent to the National Grid payments are for generation only with no export tariffs. The scheme is aimed at dwellings not connected to the gas grid (though it is not limited to these), and is not available for new build homes. Systems installed on or after 15th July 2009 are eligible, though all applicants will be required to complete a Green Deal assessment (see section 2.3.1.4) prior to receiving payments. The tariff levels are shown in Table 4.

Table 4. RHI tariffs from Spring 2014.

Technology	Tariff (p/kWh)
Air to water heat pumps	7.3
Ground or water source heat pumps	18.8
Biomass boilers	12.2
Solar thermal	19.2

The FIT and RHI have gone some way towards addressing the lack of financial incentive identified in previous studies. However, the continuing lack of upfront capital grants (with the exception of the RHPP) has been criticised (James 2012; Watson et al. 2006). As discussed below in Section 2.5.1.2, upfront capital cost is one of the largest barriers to the adoption of microgeneration by consumers. James (2012) also pointed out that the FIT and RHI could be problematic if householders intended to move before they could recover their initial investment in the technology. However, a report by Element Energy (2008) recommended that while upfront grants would stimulate uptake, a feed in tariff scheme was more likely to achieve genuine emissions cuts as consumers would be incentivised to maintain and operate their equipment correctly. Similarly Bergman and Eyre (2011) pointed out that the FIT and RHI are so far the only policy instruments to reward the actual performance of devices, and – being guaranteed for 20 years – provide a measure of consistency lacking in previous short term grant schemes.

2.3.1.3 Microgeneration Certification Scheme

In order to be eligible for payments under the FIT or RHI, microgeneration systems must be certified under the Microgeneration Certification Scheme (MCS), and installed by MCS accredited installers. The MCS falls under British Standard EN40511 (Product Certification Systems) and is designed to ensure that installed microgeneration systems are of good quality. To become certified, installers, suppliers or manufacturers must apply to a recognised certification body which assesses microgeneration products against MCS standards.

The MCS has been praised for ensuring that good standards of workmanship are achieved for installation, but the lack of any mandatory requirements in terms of maintenance and consumer information post-installation has been criticised (Bergman and Eyre 2011).

2.3.1.4 Green Deal

Launched in October 2012, the Green Deal is a loan system designed to overcome the capital cost barrier of domestic energy saving measures. A home is assessed by a Green Deal adviser (which costs around £120), and agreed-upon measures are installed with no up-front cost to the consumers, who pay back the cost through energy bills over an agreed period of time (up to 25 years). Liability for repayments remains with the property, so if the original owner moves away, the new owner takes over the payments. Installed measures must comply with the 'golden rule': that the financial savings they provide are equal to or greater than their cost.

The Green Deal loans do not cover microgeneration technologies, as these are provided for by the FIT and RHI. However, part of the process of applying for a Green Deal plan is a property assessment by an accredited advisor who suggests which measures should be installed. This advice is intended to extend to microgeneration technologies where appropriate. This approach has been criticised as fragmented, missing an opportunity to join up policies on energy efficiency and microgeneration. James (2012) speculated that "government fears this combination of policies would be too successful and is uneasy unleashing the mass uptake of microgeneration and renewable heat at the respective current and proposed levels of subsidy for fiscal and technical reasons." However, it could be argued that the requirement for properties to achieve Energy Performance Certificate (EPC) rating D or higher (see Section 2.3.2.3) to receive FIT payments ensures that microgeneration is not installed at the expense of fabric efficiency.

2.3.1.5 Tax incentives

Since 2004, the installation of some energy-saving materials and technologies in homes has qualified for reduced rates of VAT, documented in HMRC notice 708/6. The reduced-rated technologies include GSHP, ASHP, micro-CHP, wood fuelled boilers, solar panels, wind turbines and water turbines, which all qualify for VAT at 5% rather than the usual 20%.

In the December 2006 pre-Budget Report the government announced that the sale of surplus electricity from microgeneration designed for personal use would not be subject to income tax. This was written into legislation in the 2007 Finance Bill.

2.3.1.6 2006 Microgeneration Strategy

The government's 2006 Microgeneration Strategy explored and recommended actions to mitigate the barriers to uptake of microgeneration technologies. The stated objective of the strategy was "to create conditions under which microgeneration becomes a realistic alternative or supplementary energy generation source for the householder, for the community and for small businesses" (Department of Trade and Industry 2006).

The strategy made government support for a growth in the number of microgeneration installations explicit, citing its role in reducing carbon emissions and reducing reliance on foreign imports. It was noted that Local Authority interest in microgeneration technology was increasing, as it was seen as a way to tackle fuel poverty. It was also clear that microgeneration was expected to deliver carbon savings indirectly through a change in behaviour and attitudes, with a quote from a Sustainable Consumption Round table report: "[the] qualitative impacts of microgeneration technology can be substantial, presenting a living, breathing and emotionally engaging face to energy consumption" (Dobbyn and Thomas 2005).

Although the strategy set out a number of objectives and planned actions, none was associated with a quantifiable target. The potential benefit of a specific government microgeneration target was acknowledged, but it was stated that it was too early in the development of the market to set one and that more information on the potential of different technologies and likely consumer uptake was needed. It was decided to review this decision in 2008, and upon this review a target was not set.

In addition to the 2008 review, the significant policy outcomes of the Microgeneration Strategy were a commitment to implement an accreditation scheme covering microgeneration products, installers and manufacturers, and a commitment to take "swift and appropriate action" if it was found that planning policy was discouraging or failing to adequately support the implementation of microgeneration schemes by local authorities. The former was fulfilled by the Microgeneration Certification Scheme (see Section 2.3.1.3).

2.3.1.7 2006 Climate Change and Sustainable Energy Act

The 2006 Climate Change and Sustainable Energy Act contained a provision to allow the Secretary of State to set legally binding targets for energy companies requiring them to source a proportion of their energy from microgeneration schemes. At the time of writing this has not yet happened, which some researchers have argued reduces the institutional 'legitimacy' of microgeneration, and fails to sufficiently direct industry activities to it (Praetorius et al. 2010).

2.3.1.8 2011 Microgeneration Strategy

In June 2011 DECC published a new microgeneration strategy. As part of the associated consultation, the Microgeneration Government-Industry Contact Group (MGICG) was formed, and published an action plan alongside the strategy document. The MGICG's membership comprises trade associations and consumer-facing organisations from the microgeneration industry, and is intended as "a single point of contact with Government to discuss and tackle the non-financial barriers facing mass deployment of microgeneration technologies and implementation of the Microgeneration Strategy" (MGICG 2011). The key regulatory change arising from the strategy and action plan was the planned introduction of the RHI.

2.3.1.9 Smart Meter Rollout

While not exclusively used with microgeneration, and not mandatory, smart meters are complementary to the technologies as they facilitate accurate monitoring of energy generation, use, import and export. The government's Smart Meter Rollout scheme recognises this, with the aim of providing a smart meter for every household and small business by 2020. In 2013 the Data and Communications Company was established to run the smart metering system.

2.3.1.10 Electricity Market Reform

In 2013 DECC published a plan for delivering a raft of reforms to the UK's electricity market, with the aim of increasing the security of electricity supply and reducing consumer bills. Relevant to microgeneration is the planned Capacity Market mechanism, whereby generators can 'auction' generating capacity at times of high demand, entering into capacity agreements. While this would not apply to owners of individual systems, remotely controlled 'fleets' of microgeneration units could be used to fulfil this demand (Ecuity 2013).

2.3.2 **UK housing and building regulations**

2.3.2.1 Building Regulations

New buildings in the UK are subject to Building Regulations, which set out standards for all aspects of building design and function. Part L1A of the Building Regulations: *Conservation of fuel and power in new dwellings*, contains the standards relevant to microgeneration installations (HM Government 2010). A Standard Assessment Procedure (SAP) is used to calculate the target CO_2 emission rate (TER): defined as CO_2 emissions per floor area per year ($kgCO_2/m^2/year$). The TER for a planned new dwelling must not exceed that for a 'notional dwelling' which is defined in the official SAP document. Appendix R of the current SAP document (set out in 2009) sets out reference values wherein the variable factors are dwelling size, shape and living area. Non-variable reference values are heat loss parameters (U values), type and rating of heating system, the heating fuel used (natural), window and glazed door quality, shading, ventilation, chimneys, and other such building parameters (DECC 2011a).

The requirements for fabric efficiency and TER are progressively tightened with each revision to the Building Regulations. From 6th April 2014, the following changes applied (with respect to the current 2010 regulations):

- 6% TER carbon reduction
- Introduction of specific fabric energy efficiency target
- Flexibility in building specifications, as long as CO_2 and efficiency targets are met.

Part L of the Building Regulations does not mandate the use of microgeneration, but it can be used to achieve the required CO_2 emissions standard.

2.3.2.2 Code for Sustainable Homes

The Code for Sustainable Homes (CSH) is a Government national standard environmental assessment method for homes. It rates dwellings against six levels (level 6 being the highest sustainability standard), and covers nine categories of sustainable design, one of which is Energy and CO_2 Emissions. The code is not legally binding in most cases, but level 3 is required for social housing in Northern Ireland, housing funded by the Homes and Communities Agency (England's national housing agency) and housing promoted by the Welsh Assembly Government. Some local authorities in the UK require a certain CSH level to be met before granting planning permission.

The current version of the CSH was set out in 2010. It uses a points system to calculate the level awarded to a dwelling, along with some mandatory standards which must be met to achieve a certain level. The TER standards required to meet certain levels are shown in Table 5. Levels 5 and 6 require a fabric energy efficiency of $\leq$ 39 kWh/m^2/year for flats and mid terrace houses, and $\leq$ 46 kWh/m^2/year for end terrace, semi-detached and detached houses.

Table 5. Mandatory TER standards required by CSH

TER: Percentage improvement with respect to 2010 Building Regulations Part L1A	Code Level
≥ 25%	Level 4
≥ 100%	Level 5
Zero net CO_2 emissions	Level 6

2.3.2.3 Energy Performance Certificates

As a result of EU Directive 2002/91/EC, which requires member states to implement energy performance certification systems for buildings, the UK introduced Energy Performance Certificates (EPCs) in 2007. EPC assessors rate a building from A (best) to G (worst) based on efficiency and heat loss features such as insulation, type of boiler and double glazing. Originally applying only to properties with four or more bedrooms, the scheme is now also mandatory for three bedroom homes, which must have an EPC rating if put up for sale. Microgeneration is not essential to achieve a high EPC rating, but it does contribute to a higher score if installed appropriately.

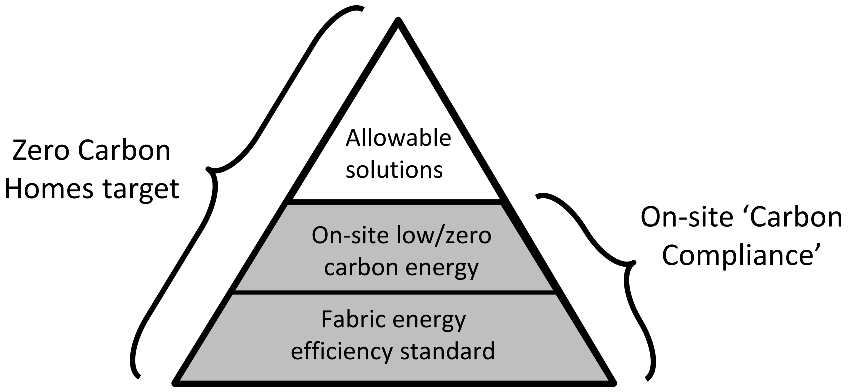
2.3.2.4 The Merton Rule

The Merton Rule is named after the London Borough of Merton, whose council requires new building developments with over 10 buildings to source 10% of their energy needs (once built) from on-site renewable sources, i.e. microgeneration or district heating. In its wider application, the Merton Rule allows local authorities to set renewables targets for new developments that exceed those stipulated in the Building Regulations. Efficiency measures are currently included, but it has been proposed that they be removed from local authority control by the Deregulation Bill, which is before the House of Commons at the time of writing.

2.3.2.5 Zero Carbon Homes Target

In 2007, the Department for Communities and Local Government committed to regulating for zero carbon new homes by 2016, with interim targets of a 25% improvement to the TER figures set in the Building Regulations by 2010, and a 44% improvement by 2013 (DCLG 2007a). The Zero Carbon Homes target was linked at the outset to the CSH, with the progressive targets defined as meeting level 3, level 4 and level 6 respectively. After several iterations of the policy, the specific definition for 'Zero Carbon Homes' has now been decoupled from the CSH and was finally set in the March 2011 *Plan for Growth* report associated with that year's Budget (HM Treasury and BIS 2011). The key features are that only emissions from fixed lighting, heating, hot water and building services are now included in the regulation, and that although specific on-site reductions are still required in the form of a Fabric Energy Efficiency Standard (FEES), off-site carbon reduction measures known as 'allowable solutions" are also permitted, as shown in Figure 2. The specifics of what will constitute allowable solutions have yet to be officially confirmed, although a number of suggestions have been made such as improving the efficiency of existing buildings in the vicinity, and paying to fund approved 'green' projects (Zero Carbon Hub 2011). For a number of years, the lack of a specific definition has been criticised for slowing progress in this area and reducing the impact of the target on building practices (Chan 2008). The Government initiated a consultation on allowable solutions in August 2013, with final comments received on 15th October 2013.

Figure 2: Carbon compliance and allowable solutions under the Zero Carbon Homes target (Zero Carbon Hub 2011)



2.4 Industry

Industry has a significant role to play in the mainstreaming (or otherwise) of microgeneration, since commercial activity drives a number of activities relating to the diffusion of innovations, such as industry research, manufacturing, supply chain formation and (particularly for microgeneration in new homes) adoption. As a result, many studies have considered industrial drivers and barriers to microgeneration and low carbon homes, often as part of larger system studies.

2.4.1 **Microgeneration**

In terms of manufacture and supply, levels of entrepreneurial action for microgeneration in the UK are heterogeneous, with different technology types attracting different levels of interest and activity. The micro CHP market tends to be dominated by established companies including large energy companies, which have branched out into micro CHP. Micro wind is dominated by smaller startups, while both incumbents and new companies operate in the small PV market (Praetorius et al. 2010).

Due to the generally limited market for microgeneration in the UK, some studies have warned that there are insufficient skilled installers to cope with a larger market (Bergman and Eyre 2011; Element Energy 2008). Bergman and Eyre (2011) observed that most installers specialise in a single technology type, and that skill levels are not as high as they could be, since best practice courses are often shunned in favour of cheaper courses run by manufacturers of individual components. In response to previous time-limited grant schemes, and degression deadlines for the FIT, some supplier and installers have been accused of using aggressive sales tactics and false advertising about payback periods to maximise sales while demand is high (Keirstead 2007b; Staffell et al. 2010). Due also to reports of some ‘cowboy’ installers who do not properly install technology, and large variations in quoted prices for similar installations (Bergman and Jardine 2009), there is a risk of the microgeneration industry suffering from a ‘reputation problem’ (Bibbings 2006). It should be noted however that studies reporting these problems were published prior to the launch of the MCS in 2009, which may have gone some way towards alleviating these problems. Praetorius et al. (2010) have also pointed out that the microgeneration industry has developed significant ‘legitimacy’ in the UK due to political representation in the form of Parliamentary groups such as the All-Party Parliamentary Renewable and Sustainable Energy Group, industry associations such as the Sustainable Energy Association (formerly the Micropower Council), and the Microgeneration Government Industry Contact Group.

2.4.2 **New Homes**

As with much of the literature on decarbonising new build homes, the majority of industry reviews in this area consider the full range of decarbonisation measures rather than focusing on microgeneration. As a result, supply chain management and decarbonisation is frequently a focus (Chan 2008; Udeaja 2008), and studies tend to focus on the construction industry. A frequently cited issue is that the construction industry tends to have a culture of conservatism, with market incumbents slow to innovate and resistant to change (Osmani and O'Reilly 2009; Udeaja 2008; Williams and Adair 2007).

Contemporary insight on industry attitudes to decarbonisation targets comes from a study by Osmani and O’Reilly (2009), who disseminated questionnaires and conducted interviews with house builders to gain their perspectives on the feasibility of zero carbon homes by 2016. Although they made reference to ‘low carbon or renewable technologies’ along with other decarbonisation measures, the questions were on decarbonisation as a whole. At the time, the zero carbon target for new homes was not mandatory, so the focus of the study was therefore the CSH. A large number of respondents to Osmani and O’Reilly’s study stated that a driver for offering low carbon homes was increased reputation for ethical practices, and the opportunity to differentiate their offering from their competitors in the market. They also stated that there was a growing desire among people in the UK for sustainable lifestyles, although 46% of respondents said that lack of consumer demand for zero carbon housing was the most significant barrier for them. The most important driver was legislation for zero carbon housing, and interviewees said that the industry would respond best to legislation rather than other incentives. However, lack of financial incentives was cited by many as a significant barrier – these differing viewpoints likely due to differences in opinion between respondents. Regarding microgeneration specifically, the study showed that it is still perceived by some in the construction industry (and their clients) as unreliable. Some respondents also perceived it as aesthetically displeasing, and opined that it took up too much outdoor space.

2.5 Householders

Given that the nature of microgeneration is that the energy end user is much more involved with the means of generation (in terms of choice, operation, maintenance or even just physical proximity) compared with centralised energy delivery, its successful implementation and use often hinges on consumer attitudes and actions. A large body of research has therefore built up concerning consumer adoption and interaction with microgeneration. Studies with a consumer focus tend to deal with either the decision to adopt (or reject) the technologies, or changes in energy use behaviours or attitudes post-adoption; though some studies (Caird and Roy 2010; Keirstead 2007a; Sauter and Watson 2007) consider both.

2.5.1 **Motivations for and barriers to adoption**

There are three broad categories of methodology for consumer-focused studies which consider microgeneration adoption: questionnaire and interview studies with qualitative or quantitative analysis; willingness-to-pay studies using either hedonic analysis from installation data or stated preference through choice experiments; and meta-analyses, which often also contain theoretical analyses (the application of, for example, behavioural and choice theories). Some studies use a combination of two or more of these techniques. A number of studies have provided insights into consumers' motivations for and barriers to adoption, differing perceptions of different microgeneration technologies, and the variations in attitude between different sociodemographic groups. The main findings from these studies are discussed here.

2.5.1.1 Awareness

As Claudy et al. (2010a) point out, a prerequisite for the adoption of a technology is awareness of it. Their study of householders in the Republic of Ireland (ROI) is one of few in recent years which aim to quantify awareness of microgeneration in a Western European population. Using a telephone survey of 1010 adult ROI residents, they found that although a large proportion of the sample was not familiar with the term “microgeneration”, awareness of solar PV and solar thermal was high (80% and 75% of the sample respectively). Awareness of biomass boilers and micro wind turbines was somewhat lower (66% and 58% respectively), and awareness of micro CHP was very low (18%). These results are likely due to the increased visibility of solar PV and solar thermal technologies, which are installed on rooftops, as opposed to micro CHP which is installed inside. The result for micro wind would not be surprising in a UK context, since the overwhelming majority of installations there are of PV. In the ROI at the end of 2010 however, 85.2% of installations were of micro wind (Sustainable Energy Authority of Ireland 2010), so the relatively low awareness there is unexpected. The authors do not discuss this point, but it may be due to significant cultural overlap between the ROI and the UK, or because they surveyed the population at large rather than adopters, and the number of people who have actually installed microgeneration is small enough not to have had a significant impact.

2.5.1.2 Financial

Nearly all studies of consumer uptake of microgeneration find that the biggest barrier to adoption is the upfront capital cost (Balcombe et al. 2013; Bergman et al. 2008). For example, in a survey of 924 UK residents in 2010, 86% cited the purchase price of microgeneration technologies as a barrier to adoption (Caird and Roy 2010). Three recent willingness-to-pay (WTP) studies sampling large numbers of households from the UK (Caird and Roy 2010; Scarpa and Willis

2010) and the Republic of Ireland (Claudy et al. 2011) have found that average upfront WTP for all microgeneration types (except for micro hydro) is less than the actual capital cost. In their study of 1279 households, eliciting WTP through choice experiments, Scarpa and Willis (2010) found an implied average acceptable payback period for respondents of five years: significantly lower than the actual typical 10 – 25 year payback periods. Surprisingly, when Claudy et al. (Claudy et al. 2010b) measured resistance to microgeneration as opposed to WTP for adoption, they found that perception of upfront cost did not have a significant effect on resistance to micro wind turbines. However, as they point out, resistance is a measure of technology rejection, which is not the opposite of adoption. Householders may still have the will to adopt a technology in spite of upfront cost, but lack the means to actually do so. Unsurprisingly therefore, grants towards the upfront cost of microgeneration technologies have been found to stimulate uptake. In a study by Jager (2006) of people who had taken up grants under a Dutch energy subsidy scheme , the grant was one of the two most important reasons for adoption.

One of the most common motivations for adoption is also financial (Balcombe et al. 2013; Caird and Roy 2010), specifically money saving on energy bills or through FIT payments. Given the financial barriers mentioned above, this may seem paradoxical, but for those who have sufficient capital to invest, microgeneration can provide financial benefits. One is independence from volatility in energy prices, which is another commonly cited motivation for adoption (Claudy et al. 2011; Palm and Tengvard 2011). Ongoing financial incentives such as the UK FIT have also been seen to have a significant effect (Balcombe et al. 2013). According to the 2011 Microgeneration Strategy, (DECC 2011b) 40% of people in the UK who consider adopting microgeneration would not consider it without the FIT.

Despite the high importance of costs and savings to consumer decisions over whether to adopt microgeneration, Claudy et al. (2011) found that WTP for thermal systems was higher than other technologies in the study, despite other technologies offering higher cost savings. This is an indication that other factors contribute to consumer decisions in this area.

2.5.1.3 Environmental protection

Coming closely second to financial considerations in importance in most studies (Balcombe et al. 2013), environmental protection is a significant motivator for many adopters of microgeneration. In Caird et al.'s (2008) UK study, 75% of respondents who had adopted microgeneration stated that reducing CO_2 emissions was one of the reasons: ahead of financial concerns in this case (72% of adopters); and a recent survey of 2047 Dutch households found a similar result (Leenheer et al. 2011). For some householders, microgeneration is a tangible symbol of their commitment to a 'green' lifestyle (Dobbyn and Thomas 2005; Fischer 2004), and may even represent independence from 'mainstream' environmentally detrimental lifestyles (Palm and Tengvard 2011). This evidence seems somewhat at odds with other theories that people's moral values are demonstrated in public initiatives while their individual investments are more a function of their personal utility (Ek 2005; Sauter and Watson 2007). However, a visible symbol of environmental commitment could be considered an aspect of personal utility for the householders in question.

In a small number of cases, environmental concerns may pose a barrier to the installation of certain microgeneration technologies. Interviews with business stakeholders in Camden (London) found that the potential impacts of biomass combustion on local air quality were a barrier to the installation of biomass boilers (Warren 2010), and a study of 49 Norwegian households found that some residents thought ASHPs would reduce indoor air quality due to dust recirculation (Sopha et al. 2010). Aside from these studies, consumer perceptions about microgeneration and local air quality are not often raised in the literature. This may be because it is not an important issue for potential adopters, or because researchers – informed about the low risk posed in this area – do not suggest it as an area for discussion.

2.5.1.4 Effort and compatibility

Several studies of consumer attitudes to microgeneration cite Rogers' (1995/2003) evidence that relative advantage, compatibility with routines, perceived complexity and observability (opportunity to test a technology before buying, sometimes called trialability) are likely to explain 49 – 87% of the variation in innovation adoption rates. For further discussion of Rogers' work, see Section 4.4 of this thesis. The relative lack of trialability of microgeneration technologies could explain the importance of normative influences and uncertainty in consumer decision making, discussed in Sections 2.5.1.6 and 2.5.1.7 below. Perceived compatibility with routines and habits, often a function of effort required, has been shown to be important in a number of studies, but only for microgeneration heating systems, particularly biomass boilers. For example, perceived compatibility increases WTP for wood pellet boilers (Claudy et al. 2011). The labour required to buy, store and load fuel into biomass boilers has been found to be a significant barrier to adoption (Caird and Roy 2010), and Element Energy (2008) calculated that on average householders are willing to pay £6 upfront to avoid every £1 in annual maintenance for heating systems. This is much higher than the £2.91 WTP per £1 annual fuel bill saving calculated by Scarpa and Willis (2010), and while methodological variations may account for some of this difference, it does indicate the relative importance of time and effort costs to consumers compared with financial costs. The additional space required for most microgeneration heating systems also has a statistically significant negative effect on householder attitudes towards them (Caird and Roy 2010; Scarpa and Willis 2010). These effects tend not to be present for CHP, solar systems and micro wind (Claudy et al. 2010b; Claudy et al. 2010c; Warren 2010) - unsurprisingly since once installed they require very little maintenance.

The effort, cost and disruption involved in retrofitting microgeneration systems is also a barrier to many people. 54% of non-adopters in Caird and Roy's (2010) study stated that they did not want to undergo the "hassle of home modification", and Claudy et al. (2010b; 2010c) found that the cost and disruption involved were significant contributors to resistance to microgeneration. More specifically, Scarpa and Willis (2010) found that having the garden dug up for GSHP installation was the "most dreaded" inconvenience, followed by the need to store fuel and/or sacrifice space for a hot water tank.

2.5.1.5 Self-efficacy

Several studies of public attitudes to renewable energy have revealed a lack of self-efficacy amongst many UK residents with regards to climate change and environmental protection (Devine-Wright 2007; Dobbyn and Thomas 2005; London Renewables et al. 2003; Theobold and Walker 2008). That is, many people either fail to realise the effects of their energy consumption, feel that their personal efforts can have little or no impact on mitigating climate change, or believe that the responsibility for mitigation and change lies with government or other authorities, rather than themselves. It has been proposed that self-efficacy is an important determinant of willingness to adopt microgeneration, as people may be unwilling to spend time and effort on it if they don't believe it will make a difference to the environment (Claudy et al. 2010b; Claudy et al. 2010c). Indeed, Jager (2006) showed empirically that a sample of solar PV adopters had a statistically significant higher than average environmental 'problem awareness' score (relating to personal actions). However in their study of innovation resistance, Claudy et al (2010b; 2010c) found that the perceptions of microgeneration which are linked to self-efficacy – knowledge, perceived complexity and trialability – did not have a statistically significant effect on resistance. They concluded that this is in line with research which has shown that experts in a particular area tend to rate the benefits of radical innovations in that area lower than non-experts, often as a result of a more informed appraisal: "they know what they don't know" (Moreau et al. 2001; Mukherjee and Hoyer 2001).

2.5.1.6 Uncertainty

Lack of knowledge and uncertainty over technology function, performance and payback period is often a hindrance for those considering microgeneration. Despite the MCS, some people are concerned that it is difficult to find a trustworthy installer, or that advice from installers will be biased as they want to sell products (Caird et al. 2008; DECC 2011b). Balcombe et al. (2013) also highlight the prevalence of uncertainty and concerns over the performance of microgeneration, and a lack of information about or confidence in the payback period of investments in it. In Caird and Roy's 2008 study, over 20% of the sample had been put off adopting solar or wind systems due to uncertainty over their output, and in their 2010 study 68% of non-adopters cited long or uncertain payback times as a barrier. Conversely however, Claudy et al. (2011) found that performance uncertainty led to lower WTP for solar thermal systems and wood pellet boilers, but not for PV systems or micro wind. An possible explanation for these seemingly conflicting results can be found in a different study by the same authors, which showed that perceived functional risk had no significant effect on resistance to micro wind (Claudy et al. 2010b; Claudy et al. 2010c). Here, the authors pointed out that if a respondent does not plan to adopt microgeneration anyway for different reasons, risk or performance uncertainty is unlikely to be a consideration.

Issues around consumer uncertainty link to the broader problem that a high level of technical knowledge and understanding is often required in order to judge whether investing in microgeneration will be beneficial or not (Bergman et al. 2008; Caird et al. 2008).

2.5.1.7 Normative influences

Social normative influences can play both a positive and negative role in the uptake of microgeneration. This may relate to neighbourhood aesthetics, with some people considering adoption being discouraged due to concerns that neighbours will not approve of visible technologies such as solar PV or thermal, or micro wind (Ellison 2004; Palm and Tengvard 2011). Claudy et al. (2010b; 2010c) also describe ‘social risk perception’ as a negative impact on WTP for micro wind. Given the recent sharp increase in microgeneration installations in the UK and ROI, it would be interesting to carry out a longitudinal study to investigate how aesthetic perceptions change over time and how they relate to familiarity with microgeneration technologies. While more direct discouragement in the form of warnings from dissatisfied previous adopters are not often addressed in the literature, the potential effect could be large. Marketing studies in other areas have shown that negative word of mouth reports have a larger effect on consumer decisions than positive ones (Herr et al. 1991). However, given that post-installation satisfaction for microgeneration has found to be high (Caird and Roy 2010), this may not be a concern.

In terms of positive normative influence, Claudy et al. (2010b; 2010c) found that support from social networks decreases resistance to microgeneration both directly, and indirectly by increasing its perceived benefits. In their other 2010 study they also found that support from friends and family increases WTP for micro wind, solar hot water systems and wood pellet boilers. Similarly, knowing someone with a solar hot water system was also found to increase WTP (Claudy et al. 2011). This could be linked to a reduction in uncertainty over performance and payback period, which can be a significant barrier to adoption as discussed above. Scarpa and Willis (2010) also found that recommendations from friends increased WTP, though this effect was not statistically significant when entered into a logit model.

2.5.1.8 Differences between technologies

Several of the examples given above have indicated the heterogeneity of attitudes to different types of microgeneration technology. This is quantified in Claudy et al.'s (2011) WTP study, where they found that respondents were willing to pay most for micro wind, then solar PV, then wood pellet boilers, then solar thermal. This is in line with the observation in Section 2.5.1.1 above that micro wind has the majority share of the microgeneration market in the ROI. Bergman et al. (2008) stress the importance of normative influences here, whereby familiarity with a certain technology tends to foster a more positive perception. They suggest that visibility and familiarity account for the relative popularity of solar and wind technologies compared with CHP, anaerobic digestion and incineration.

2.5.1.9 Differences between people and households

Many studies have investigated the variation in attitudes and adoption between different types of household, and people with different demographic attributes. With regards to individual attributes, age, income and education have all been shown to have an effect. Rates of adoption and attitudes have also been shown to vary by household size, location and type.

Age is a consistent factor in attitudinal variance with a complex non-linear relationship to adoption (Balcombe et al. 2013). Most studies show that adopters of microgeneration are predominantly middle aged, particularly in the 45 – 65 age range (Balcombe et al. 2013; Jager 2006). Rates of adoption tend to rise steadily until this point, then decline in retirees and people aged over 65 (Balcombe et al. 2013; Claudy et al. 2010a; Leenheer et al. 2011). The reason for this is not totally clear, but most researchers suggest that the increases in income and home ownership associated with increasing age are likely to be the cause (Balcombe et al. 2013). While environmental concerns tend to be higher in young people, Claudy et al. (2010a) point out that actual adoption of microgeneration is often a predominantly financial consideration, and many younger people do not have the capital to invest. Upon retirement, microgeneration may become less attractive due to a drop in income, a desire to downsize to a smaller home or move to retirement properties, and concerns over payback periods. Willis et al. (2011) found that microgeneration even has disutility for some retirees, that is, they would be willing to pay *not* to install it. Surprisingly then, Caird et al. (2008) found that 45% of survey respondents who had adopted solar thermal were retired. However, this is likely because the sample was self-selected rather than stratified: non-adopters also comprised a similar percentage of retirees.

Adopters of microgeneration are predominantly middle class with medium to high incomes (Caird et al. 2008; Devine-Wright 2007; Ellison 2004). Income may also affect technology choice: Sopha et al. (2010) found that people classed as having ‘high’ incomes were more likely to choose grid-powered electric heaters rather than biomass boilers or heat pumps, but people with ‘middle’ incomes were more likely to choose biomass. The authors suggested that this is because those with middle incomes are ‘between barriers’: like those with higher incomes they are not put off by capital cost, but unlike them, they are deterred by ongoing fuel costs. Higher levels of education have also been linked to earlier adoption (Balcombe et al. 2013; Keirstead 2007a), with Fischer (2004) even describing early adopters as an ‘academic elite’.

Regarding household type, adoption is usually found to be more likely amongst those in larger, detached houses (Balcombe et al. 2013; Caird et al. 2008; Fischer 2004; Roy et al. 2008). Balcombe et al. (2013) suggest that this is because these houses have more available space and a higher energy demand, making it easier and more economically rational to install microgeneration. Fischer (2004) also points out that those in larger houses are more likely to own them rather than rent, removing the problem of the landlord-tenant divide which provides little motivation to install for either party. It is also likely that those living in larger houses have higher incomes and are therefore more able to invest in microgeneration. Interestingly however, despite noting some variation between household types, Claudy et al. (2011) concluded that there was no statistically significant difference in WTP for microgeneration between them.

Finally, Claudy et al. (2010a) found that people living in rural areas are more likely to be aware of microgeneration than those in urban areas. They suggested that this was due to the higher number of people in urban areas who live in rented flats, which are less suitable for individual installation of microgeneration. It is also possible that a rural lifestyle fosters more of an ethos of self-sufficiency, though this has not yet been explored in the open literature.

2.5.2 **Post-adoption studies**

Studies focusing on post-adoption behaviour change tend to fall into two broad categories: qualitative studies using interview data or secondary and theoretical data; and quantitative studies of energy use based on either meter readings or self-reported usage.

It has been suggested that the presence of microgeneration in homes can engage users and make them aware of their energy use in ways that centrally-delivered energy cannot (Collins 2004). Energy consumption behaviour is an important aspect of increased energy efficiency, and behavioural changes have proven difficult to effect in the past, so any changes caused by the presence of microgeneration are of significant interest. As Keirstead (2007a) states, “there is a danger that if behavioural responses to microgeneration technologies are not considered now, when consumer technologies and protocols are still being developed, …households [could] become locked into behaviours that may be undesirable in the longer term”. However, the effects of microgeneration technologies on residents’ energy use practices are still poorly understood, with existing studies few in number and showing ambiguous results (Bergman et al. 2008).

Keirstead (2007a) suggested that the installation of domestic solar PV could give rise to a “double dividend” if residents became more aware of their energy use and reduced it as a result. Using responses to a closed-format questionnaire from 91 UK households with solar PV, he identified two significant differences between pre- and post-installation energy use. The first was that the use of green electricity tariffs increased from 50% to 76% of respondents, most of whom switched on the advice of the solar PV installer. The second was that the use of energy-efficient lighting increased from 49% to 58% of lighting points. Similarly, Caird and Roy (2010) found that 25% of those who had installed microgeneration also installed extra efficiency measures. No significant differences in the efficiency of other appliances were seen in Keirstead’s study, though as he points out, these tend to have long turnover times and 75% of survey respondents had owned their PV systems for less than two years. Respondents also provided self-assessed estimates of electricity saving since installing their PV system. When the responses were weighted by self-assessed certainty in these estimates, an overall saving of 5.6% was found. Self-assessed savings are however likely to be somewhat inaccurate, and as Keirstead points out, do not necessarily equate to a long-term change in consumption. He concluded that the ‘double dividend’ will not be realised without a “supportive sociotechnical system in place”, including appropriate generation tariffs, feedback and recognition from energy companies and accessible information about the operation and monitoring of solar PV systems. He also suggested that further research could investigate how long any changes in consumption behaviour last, whether there is a rebound effect, and whether these effects vary demographically.

The question of how long any changes in consumption behaviour might last was addressed by a 2007 study of a development of nine ‘eco houses’ with solar PV systems in the UK (Bahaj and James 2007). Energy generation and energy consumption by each household was monitored over the course of a year. The researchers found little evidence that occupants altered their energy consumption patterns to coincide with periods when the PV panels were generating. They also found that although energy consumption in many households was reduced following informal discussions with the researchers at the beginning of the study, the effect did not last and energy consumption increased throughout the year. A study by Erge et al. (2001) of the German 1000-Rooftop PV scheme, in which between 68 and 1340 households per year were monitored between 1992 and 1999, found similar results: energy consumption in participating households was not significantly different from households without PV systems.

A study by Haas et al. (1999) comparing electricity use in Austrian households before and after the installation of solar PV systems appeared to show an impact on energy consumption. The researchers’ conclusion was that the effect of installation varied depending on the initial energy use of the household. Most households with initial electricity use above 3,500kWh/year saved electricity after installation, while most households with initial use below this threshold increased their energy use. This led Haas et al. to speculate that “PV is an energy conservation tool for the rich”. However, the sample size for this study was 21 households, and there are two outlying data points (both with high initial use and very high reported savings) which could have skewed the results significantly. The authors also fail to mention how soon before and after installation electricity use was measured, and whether the figures are averages or one-off readings, which makes it somewhat difficult to draw meaningful conclusions from the paper.

A less technology-specific study in the UK was commissioned in 2005 by the Sustainable Consumption Roundtable (SCR), to discover how microgeneration can change attitudes towards environmental issues in general, and energy efficiency and energy practices. Actual energy use was not quantified, as the focus was more on awareness and attitude. Face-to-face and telephone interviews were conducted with three groups: ‘active’ householders (who had chosen to install microgeneration technologies in their homes), ‘passive’ householders (who lived in social housing in which the housing provider had installed microgeneration), and ‘mainstream’ householders who lived in homes without any form of microgeneration. People of a variety of ages and socio-economic grades were interviewed, and the types of technology used were micro-wind, ASHP, micro CHP, solar PV and solar thermal, including some combinations of these.

Despite a large amount of variation in attitudinal changes, some trends emerged. Mainstream households tended to have very little awareness of environmental issues, the link between energy use and the environment, and even in some cases the link between energy use and energy bills. Passive householders tended have a much better understanding of and interest in both environmental issues and the link with energy use, and active householders even more so. The authors classified attitudinal shifts in the passive households along two axes: low to high environmental awareness and low to high energy self-efficacy, with the latter signifying “when the household makes the connection between their concern over consumption and their awareness about when, how and why that consumption is occurring”. This allowed them to pinpoint some of the factors affecting responses to microgeneration. “Eco-housing with multiple features” (that is, with efficiency measures such as grey water recycling in addition to microgeneration) appeared to stimulate the most increase in environmental awareness, with the buildings symbolising an ‘ethos’ which residents were eager to take on, though this did not necessarily equate to reductions in energy use. Microgeneration technologies with a visible presence encouraged the largest shifts to energy self-efficacy, but only when residents had a good understanding of how the technology worked. The latter was a particular issue for passive households, where in some cases people were unaware of how the technology was supposed to function and therefore either ignored it or used it incorrectly (Dobbyn and Thomas 2005).

Feedback on energy use has been found in many studies to reduce energy demand. A review by Darby (2006) found that direct feedback from real-time energy monitors or smart meters yielded reductions of 5 - 15%, while reductions from indirect feedback such as billing were observed as 0 – 10%. As a result, smart meters are often considered to be essential to maximise the benefits of microgeneration installation (Bergman and Eyre 2011; Watson et al. 2006). Indeed, Watson et al. (2006) recommend 'future-proofing' legislation to make smart meters mandatory when microgeneration is installed.

In summary, there is mixed and limited evidence to support the theory that the presence of microgeneration alone induces long term changes in energy consumption by residents. However, some positive changes have been observed when residents are well informed and supported: in particular when smart meters are installed alongside microgeneration. Providing information about correct use of the technologies along with clear visual feedback about their performance is most effective in reducing energy demand, along with fair and clearly reported export tariffs or reductions in energy bills.

2.5.3 **New homes**

Although there is much evidence to show that efficiency, 'green features' or microgeneration can provide economic and social benefits to home occupants, quantitative evidence of a tangible effect on house prices is very limited. Willingness to pay studies, such as those discussed above, suggest that many people are willing to pay for microgeneration. However, other research has shown that prospective house buyers tend not to evaluate homes in terms of their constituent parts, but consider them as a whole and form abstract impressions from clusters of attributes rather than considering them in isolation (Lundgren and Lic 2010; Zero Carbon Hub 2010). As a result, willingness to pay for individual microgeneration technologies cannot be expected to directly translate into a higher willingness to pay for a house incorporating them.

A comprehensive review of evidence commissioned by the Royal Institution of Chartered Surveyors (Sayce et al. 2010) found that most of the research on the valuation of ‘green features’ on homes is theoretical or opinion-based, with very few studies based on actual home sale transactions. Much of the data on people’s willingness to pay is based on surveys which present hypothetical scenarios. In the UK for example, a survey of 1,563 adults found that 24% of respondents would be prepared to pay between £1,000 and £5,000 on top of the asking price of a home for energy efficiency measures, and 11% would be prepared to pay up to £10,000 (Wolseley 2006). However the only publically available source on this report does not specify how the questions were posed or what the specific efficiency measures were.

Most of the quantitative studies available have been carried out in the USA on office buildings (Sayce et al. 2010). For example, Fuerst and McAllister (2011) used hedonic regression analysis to measure the effect of two energy efficiency measures (LEED and Energy Star) on office rental and sale prices. Controlling for price-determining building characteristics, they found that rents were 4-5% higher on average in certified buildings than non-certified buildings, and sale prices were 25% higher for LEED and 26% higher for Energy Star. Similarly, Eichholtz et al. (2013) found that LEED or Energy Star certified office buildings commanded 3% greater rental prices and 13% higher selling prices than equivalent non-certified buildings. In the residential sector, a comparison of 19 apartments retrofitted for thermal efficiency and 45 non retrofitted apartments in Romania found that retrofitting increased the price by an average of 2 – 3% (Popescu et al. 2012). A study in Canberra, Australia, found that although energy efficiency accounted for only a small proportion of the variation in house prices, a one-star increase in the national Home Energy Rating (HER) standard led to an average increase of AUS$11,000 in the asking price for a detached house at the median price of AUS$365,000 (Berry et al. 2008).

Only one study specifically considering the impact of microgeneration technologies on house prices in the UK could be located in the open literature at the time of writing. In association with Oxford City Council, Morris-Marsham and Moore (2011) gathered information from prospective home buyers and local estate agents. Prospective buyers were shown images of PV panels and solar thermal units and asked how much extra they would pay for a house if they were included. 47% of respondents indicated that the presence of solar thermal would make them more likely to buy a home, 10% less likely and 43% no effect. For solar PV, 33% indicated that they would be more likely to buy, 17% less likely and 50% no effect. Those who were willing to pay more indicated that they would pay on average £1,500 more for a property with solar thermal, and £1,750 more for solar PV. By multiplying these values by the percentage of people willing to pay more, the authors derived average 'added value' figures of £250 per house for solar thermal and £233 for solar PV, though they added the caveat that their small sample size meant that the figures were unlikely to be statistically robust. Despite the apparent increase in desirability of houses incorporating microgeneration, interviews with local estate agents revealed that this was not being reflected in house prices for the most part. 80% of those interviewed said that the presence of solar panels on a property would not affect their valuation; and 60% believed that there was no demand for properties with solar panels while the remaining 40% did not know if there was demand or not. The authors commented that "a common explanation was that house buyers had a list of features they were looking for and renewable energy installations were not included" (Morris-Marsham 2010; Morris-Marsham and Moore 2011).

2.6 New business models

A number of different arrangements for the ownership, operation and maintenance of microgeneration technologies are available. Broadly, they can be separated into two groups: 'plug and play' arrangements - a term coined by Watson (2004) - under which householders own, operate and maintain the microgeneration in their home; and energy services contracting arrangements, under which some or all ownership, operation and maintenance responsibilities are contracted out to a third party. Energy services contracting has been proposed as a method by which the rollout of microgeneration can be streamlined and achieved more quickly (James 2012).

2.6.1 **Plug and play**

Under plug and play arrangements householders own the microgeneration technologies in their home and are fully responsible for their operation and maintenance. In the case of new build housing, this means that ownership passes from the developer to the householder at the point of sale and that, aside from obligations under the warranty, the developer has no further involvement.

2.6.2 **Energy services contracting**

Energy provision in the UK is currently dominated by the utility provision paradigm, with consumers paying utility companies per unit of electricity or gas provided. Conversely, energy services contracting is based on the idea that consumers are not concerned with *units* of energy, but rather *energy services*: the physical benefit, utility or good that they derive from energy conversion (EU 2006; Eyre 2008), such as ambient temperature, lighting and appliance use (Steinberger et al. 2009). Under an energy services contracting arrangement, consumers pay for the delivery of these energy services rather than for units of energy.

Energy services contracting arrangements fall under the broader concept of a 'performance economy' (Steinberger et al. 2009), or 'functional service economy', the objective of which is to maximise the function of or benefit derived from goods or services while minimising the consumption of resources and energy. Unlike the incumbent industrialised economy in which the focus is on maximising the sale of products, the focus of a performance economy is on selling services or functions. In a performance economy, suppliers usually retain ownership of their products over their lifetime and sell their functions, hence products become cost centres as opposed to profit centres (White et al. 1999) and profits are maximised by increasing product longevity, reusing and recycling components, and providing the function or service more efficiently. A performance based economy has therefore been proposed as a viable, more sustainable alternative to the industrialised economy (Stahel 2010). Steinberger et al. (2009) define three main types of provision model under a performance economy:

Product-oriented

Providers do not retain ownership of the product, but offer lifetime maintenance, financing options and/or 'takeback' services in which they dispose of, recycle or redeploy the product at the end of its lifetime or when the consumer has no further need for it. This type of arrangement does not deviate significantly from current standard business models, and as such is unlikely to have a large impact on environmental outcomes.

Use-oriented

The provider retains ownership of the product, and sells its use or functions under a leasing arrangement. Tukker and Tischner (2006) predict that use-oriented provision has the potential to deliver up to factor two decreases in resource use.

Result-oriented

This arrangement focuses not on the use or functions of a particular product, but on the final service being provided. Under a result-oriented contract, the customer pays a fixed fee in return for having specified needs met. Tukker and Tischner (2006) predict that result-oriented provision has the potential to deliver up to factor ten decreases in resource use.

Energy service contracting – offered by energy service companies (ESCOs) - offers an alternative to the traditional business model of energy utility companies. Under the traditional business model, the company's goal of maximising profits requires that they maximise their sales, since they are paid per unit of product sold. In the case of energy provision, where the 'product' is energy, this goal is at odds with political and societal goals of reducing energy consumption and by extension reducing GHG emissions. Energy services contracting removes this 'throughput incentive' (York and Kushler 2011), as ESCOs are paid to provide useful energy streams or energy services rather than units of energy (Boait 2009).

A number of different activities fall under the heading of energy service contracting, and contracting arrangements differ in their scope, financing mechanisms and delivery methods. All share two determining characteristics to be considered energy service contracts: they are based on the supply of either useful energy or energy services (Sorrell 2005, 2007; Steinberger et al. 2009), and they involve the transfer of decision rights over some or all energy equipment from consumer to ESCO (Sorrell 2005, 2007). Energy service contracting arrangements can be broadly divided into two categories: energy supply contracting and energy performance contracting.

2.6.2.1 Energy supply contracting

Energy supply contracts (ESCs) fall under the use-oriented provision model defined above. The ESCO owns the primary energy conversion equipment (e.g. a boiler), which converts energy from its imported form (e.g. gas) to a useful energy stream such as hot water (Sorrell 2007). The customer is charged for units of *useful* energy, as opposed to units of gas or electricity. Alternatively under some arrangements the customer pays a fixed fee for the provision of useful energy streams within contractually agreed limits (Marino et al. 2011). The scope of a typical energy supply contract is shaded blue in

Figure 3. Owning the primary conversion equipment allows an ESCO to reduce customer demand for delivered energy (fuel) because it can control and improve the efficiency of the equipment through expert maintenance and operation. Guaranteed energy saving is not usually built into the contract however, as secondary conversion equipment is still under the consumer's control (Sorrell 2007).[1]

2.6.2.2 Energy performance contracting

Energy performance contracts (EPCs) fall under the result-oriented provision model defined above. Under these arrangements, the ESCO owns the secondary conversion equipment (e.g. radiators and kitchen appliances) which provides energy *services* such as a comfortable room temperature or the ability to cook food. The customer is not charged per unit of delivered or useful energy, but for an agreed level of energy services. The scope of a typical energy performance contract is shaded pink in

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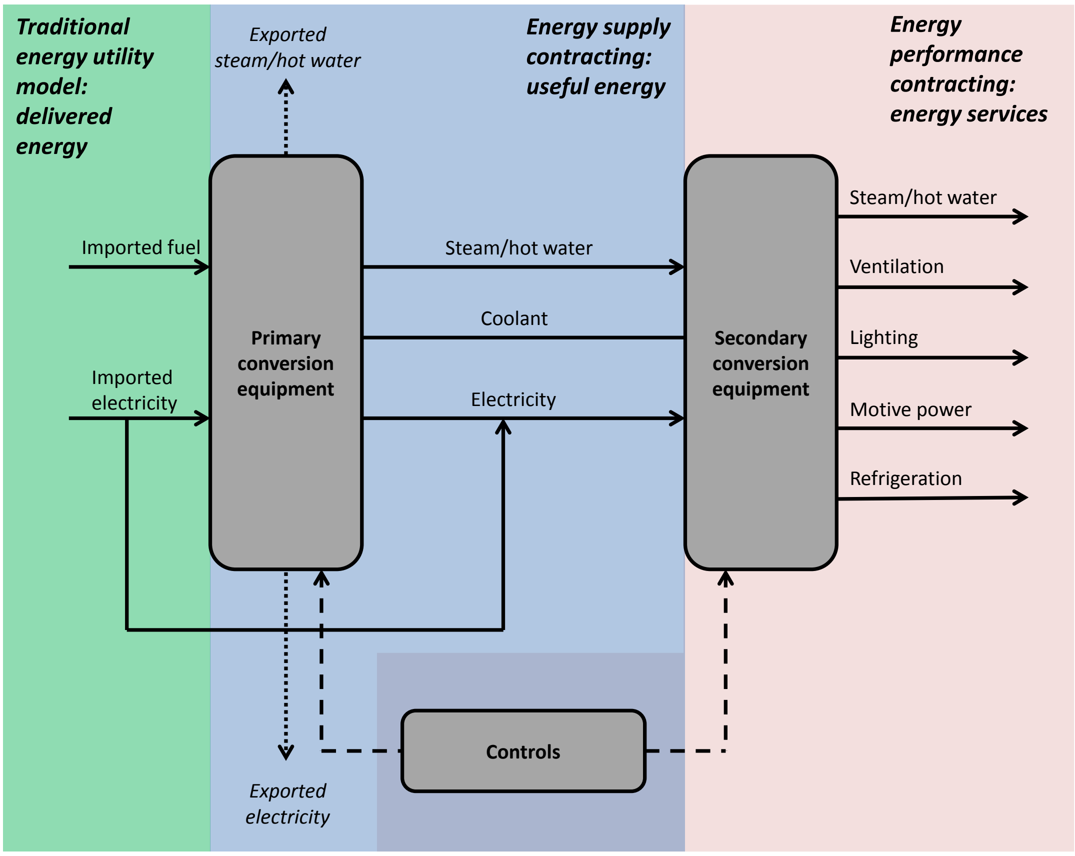
[1] Companies offering these types of contract are sometimes known as energy service provider companies (ESPCs), differentiating them from 'true' ESCOs which also guarantee energy savings as in Bertoldi et al. (2006) for example. However in this thesis, both companies supplying ESCs and those supplying EPCs are referred to as 'ESCOs'.

Figure 3. Since under this arrangement the ESCO owns the secondary conversion equipment (and usually the primary conversion equipment), an even greater degree of control over the consumer's demand for delivered energy can be achieved. As a result, EPCs often contractually guarantee a minimum standard of energy services for a fixed cost.

Sorrell (2007) points out that in practice, many energy service contracts take a hybrid form partway between an ESC and an EPC. For example, it is common for ESCs to include the provision and operation of controls for secondary conversion equipment, or for an EPC to initially cover only one final energy service before eventually expanding to others. Sellers of secondary conversion equipment may also offer EPCs based only on the final energy service provided by that equipment.

Figure 3: Scope of the different types of energy service contract
(Adapted from Sorrell, 2007)



2.6.2.3 Financing for ESCOs

In simple terms, an energy service contract will be financially viable for an ESCO if its revenue exceeds its outgoings, and for the customer if their savings exceed their payments to the ESCO. Outgoings can be separated into production costs and transaction costs. Sorrell (2007) provides a useful summary of these, adapted below along with potential revenue streams.

Production costs

- Capital cost of conversion equipment, associated infrastructure and controls.
- Staff costs of operating and maintaining energy equipment.
- Material costs of operating and maintaining energy equipment.
- Purchase of energy commodities (e.g. gas or electricity).

Sorrell (2007) identifies two main ways in which an energy contracting arrangement can reduce production costs relative to the traditional energy supply model: through economies of scale and market incentives. Economies of scale are achieved through bulk buying fuel, electricity and equipment, and having dedicated experts to manage energy services (potentially across more than one site). In addition to the efficiency incentives of operating in a performance economy, ESCOs will be incentivised to minimise production costs and maximise efficiency for their clients in order to win contracts in a competitive market.

Transaction costs

Staff, consulting and legal costs of:

- Finding a supplier and drawing up a contract.
- Monitoring contract performance.
- Enforcing compliance with the contract.
- Negotiating contract changes as needed.

The greater degree of control assumed (and often the savings guarantee) under an EPC means that transaction costs for EPCs tend to be higher than for ESCs.

Potential revenue streams

- Reductions to customer energy bills.
- Fee per unit of useful energy delivered.
- Fixed fee for specified performance minimum.
- Feed in tariff payments for energy generated.
- Payments for energy exported to the grid.

The capital costs of establishing an energy service contract are: the purchase of new equipment for energy conversion and control, the associated infrastructure (e.g. wiring), and any secondary conversion equipment included in the contract. These capital costs may be met by internal or third party (debt) financing. Under internal financing, the capital cost is met by the internal funds of either the ESCO ('ESCO financing') or the customer ('Energy user/customer financing') (Bertoldi et al. 2006), with no debts incurred by either party. With third party financing, some or all of the capital cost is provided by a third party (a bank or financial institution) from which either the ESCO or the customer will borrow.

Since an ESCO assumes a financial risk when borrowing from a third party, taking on further 'performance risk' (Bertoldi et al. 2006; Painuly et al. 2003) relating to the function of the technology is undesirable. It is therefore common for energy service contracts arranged with ESCO borrowing not to include a guaranteed minimum level of energy service provision (i.e. they are likely to be ESCs rather than EPCs), with savings split between the customer and the ESCO (Bertoldi et al. 2006). The nature of the split will be contractually agreed according to project characteristics such as length of contract, cost, levels of risk and risk sharing arrangements (Energy Charter Secretariat 2003). This arrangement is illustrated in Figure 4.

When the customer takes on financial risk by borrowing the capital costs of a project, they are likely to expect a minimum level of energy service provision, with the ESCO taking on the performance risk (i.e. these funding arrangements are likely to be suited to EPCs rather than ESCs) and guaranteeing a certain level of savings to the customer (Bertoldi et al. 2006) This arrangement is illustrated in Figure 5.

Figure 4. Third party financing with ESCO borrowing

(Adapted from Bertoldi et al., 2006; Sorrell, 2007)

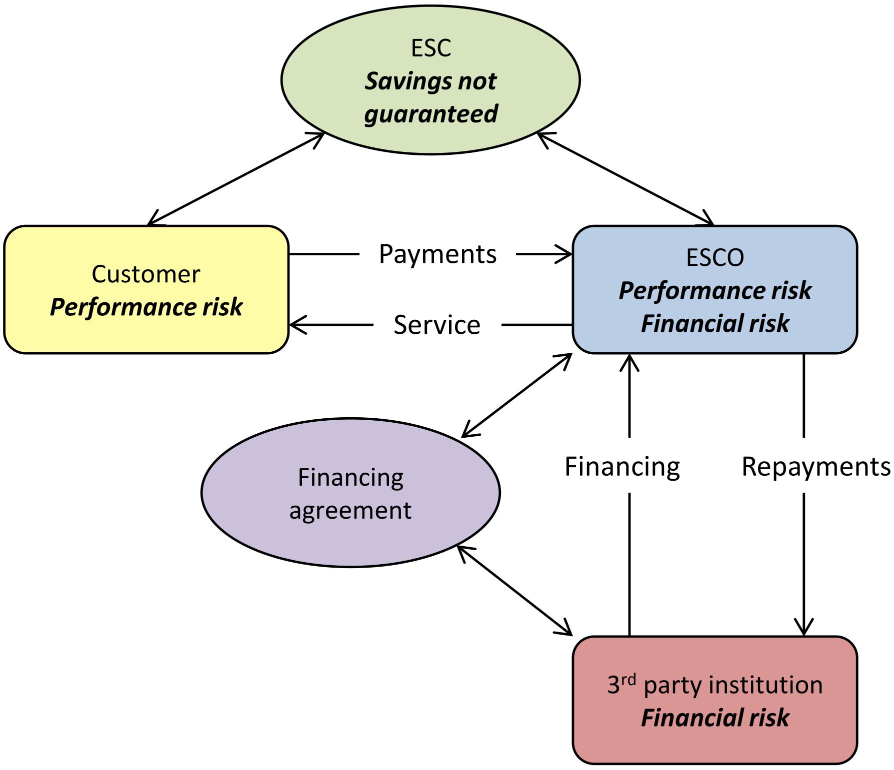
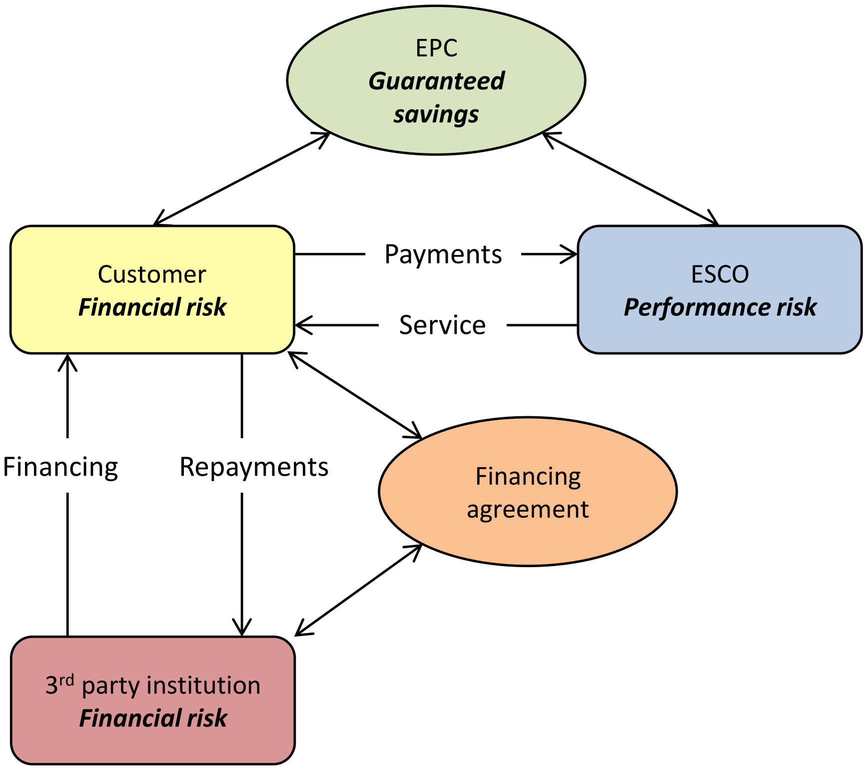


Figure 5. Third party financing with customer borrowing

(Adapted from Bertoldi et al., 2006; Sorrell, 2007)



2.6.2.4 *Summary*

In summary, ESCO arrangements vary considerably in terms of their potential impact, scope, financing, costs and revenue streams. An overview of the main differences between ESCs and EPCs is illustrated inTable 6.

Table 6. Summary of differences between supply and performance contracting (Adapted from Hannon, 2012; Helle, 1997; Sorrell, 2007)

	Supply contracting	Performance contracting
Provision to customer	Useful energy streams *e.g. hot water*	Energy services *e.g. ambient temperature*
Technologies	Primary conversion equipment *e.g. boilers, CHP plants*	Secondary conversion equipment *e.g. radiators, lighting*
Production cost savings	Low – medium	Medium - high
Transaction costs	Low – medium	Medium - high
Revenue streams	- Reduced customer energy bills - Fee per unit of useful energy delivered - Fixed fee for specified performance minimum - Feed in tariff payments for - energy generated. - Payments for energy exported to the grid.	- Reduced customer energy bills - Price per unit of energy - Fixed fee for specified performance minimum
Typical financing arrangement	ESCO financing (third party or internal)	Customer financing (third party or internal)

2.6.3 **New roles for consumers**

In addition to offering new methods for financing microgeneration, some deployment arrangements also offer energy users new roles beyond that of the passive consumer. Watson (2004) stated that sophisticated microgeneration control and feedback systems will facilitate consumer participation in its operation, allowing them to become ‘co-providers’ of energy and energy services, and take more responsibility for efficient energy provision and use.

Watson et al. (2006) expanded on this point in *Unlocking the Power House*, in which they described three possible deployment models: plug and play, 'company driven' (ESCO) and 'community microgrid' – the latter describing community-scale schemes which may be fully owned by community co-operatives or part-owned by an ESCO. Watson et al. considered that the most active role would be played by participants in community microgrid schemes, due to their partnerships with the private sector and the state in co-providing energy. Plug and play was considered to offer a slightly less active role to consumers, but still afford them independence from conventional energy suppliers, and to require active operation and maintenance of the technologies. The company driven model, despite differing technically from conventional generation, was considered to be no different from the 'status quo' for householders, who would retain the passive consumer role as the microgeneration is controlled remotely by an ESCO.

Citing evidence from some of the studies discussed in Section 2.5.2, some authors have suggested that more active roles for consumers will lead to greater behavioural changes: reductions in overall energy use, and shifting demand to times of peak generation (Bergman and Eyre 2011; Watson 2004; Watson et al. 2006). However, the greatest potential gains may be in increasing 'energy literacy' (Bergman and Eyre 2011) and fostering positive attitudes towards and increased uptake of microgeneration, since, as discussed above, much of the evidence for quantitative changes in energy use is ambiguous or anecdotal.

2.7 Gaps in knowledge and research aims

2.7.1 **Microgeneration in new homes: drivers and barriers**

As demonstrated in the existing research discussed throughout this chapter, the majority of studies on drivers and barriers for microgeneration in the UK focus on retrofit and adoption by existing households. Similarly, studies on decarbonising new homes tend to cover a range of decarbonisation measures rather than focusing on microgeneration. Where there is overlap, this tends to form part of a wider study as opposed to one focused on the issue. Given the potential contribution of microgeneration in new homes to the UK’s renewable energy and emissions reduction targets a more focused study dealing with microgeneration in new homes specifically is proposed. This will allow the identification of issues specific to new build, and highlight known issues which are of greater importance in a new build context. A particular issue is that the majority of adoption studies focus on householders, while in new builds it is the developer’s decision whether to use microgeneration. Osmani and O’Reilly’s (2009) study provided useful insights here, and it will be useful to validate and expand upon this since no other recent studies of building industry attitudes to microgeneration appear to be available.

Additionally, due to the changing policy landscape in the UK many previous system level studies of microgeneration or low carbon homes were conducted in the context of different policies and regulations than those extant currently. For example, Watson et al.’s (2006) comprehensive system study of microgeneration in the UK, *Unlocking the Power House*, and Boardman’s (2007) widely cited *Home Truths* report on decarbonising the residential sector were published prior to the establishment of the FIT and the Zero Carbon Homes Target. In particular, the Zero Carbon Homes target has undergone several changes and iterations since many of the studies discussed above were published. It will therefore be of value to investigate the drivers for and barriers to microgeneration in new homes in the current policy context, and to investigate if and how industry and consumer attitudes have changed in the intervening period. This is the basis for the work presented in Chapter 33 of this thesis. A whole system study covering political, social, industry, economic and technical drivers and barriers will allow linkages and feedback mechanisms between sub-systems to be identified, providing insights into which areas should be the focus of efforts to overcome current barriers to microgeneration in new homes.

2.7.2 The role of different deployment models in new builds

Following from the need for a study that focuses specifically on microgeneration drivers and barriers in new builds, consideration of the role that different business/deployment models might play in overcoming any barriers identified is proposed. As with microgeneration more generally, there has been no study focused solely on new UK homes, and there is scope for new insights to be drawn in light of the current policy regime. In particular, the introduction of the FIT since Watson et al.'s (2006) *Power House* report will have altered the economics of different models. Chapter 4 will therefore start with an analysis of existing evidence, and additional discussion in light of updated policies, to draw conclusions and make informed hypotheses about the potential for different deployment models to overcome economic barriers to the adoption of microgeneration in new homes. A simple technoeconomic analysis will also be conducted, drawing on and updating previous analyses in light of new policies and prices.

Additionally, as discussed in Section 2.6.3, several studies have identified potentially significant differences in householder roles in energy provision, depending on the deployment model used. Theoretical potential for certain deployment models to overcome some of the psychological barriers to adoption has been identified, but no attempts have yet been made to quantify the likelihood or magnitude of any such effects. An interdisciplinary synthesis approach is therefore proposed: bringing together insights from social studies on microgeneration adoption, marketing research, and quantitative psychology research on predictors of consumer choice to form testable hypotheses which are presented in Chapter 4. Together with the technoeconomic discussion and analysis, this will help to clarify the roles that different deployment models can play in overcoming the barriers identified in Chapter 3.

2.7.3 Consumer attitudes to different deployment models

Having generated testable hypotheses on consumer attitudes to different deployment models in new homes, it will be possible to conduct a quantitative investigation. Despite the wealth of studies on consumer attitudes to and adoption of microgeneration, none have yet included consideration of attitudes towards different deployment models. Quantifying consumer attitudes towards different deployment models for microgeneration in new homes (and generally) will provide insights for industry in terms of likely future demand and marketing strategies. In particular, identifying differentiation between demographic groups (if present) will allow targeted information campaigns, deployment model choices or incentives to be used to encourage microgeneration adoption. Quantifying the relative importance of different deployment model features for householders – identified by Balcombe et al. (2013) as an area for further research into microgeneration generally – will also facilitate these endeavours. Chapter 5 therefore comprises a report on a quantitative investigation of some of the hypotheses generated in Chapter 4.

2.8 A framework for systems-level analysis

Having reviewed the issues associated with different aspects of microgeneration uptake in the UK, a framework for analysing research questions at the systems level will now be described. Systematically investigating the drivers and barriers for a technology within a complex political, social and economic context is challenging. As seen already in this literature review, many issues do not stand alone but are interlinked and dynamic. It is therefore desirable to identify a suitable theoretical framework for the study of drivers and barriers for microgeneration in new homes in the UK, to inform the directions of the research, and to allow for a coherent presentation of complex interdependent factors.

Some existing whole system studies of microgeneration have made use of theoretical frameworks from the field of transitions studies and technical innovations systems studies (described in more detail below). For example, Allen et al.'s (2008) study of prospects for and barriers to microgeneration in the UK used a system innovations approach, emphasising the interactions between "elements and relationships in the production, diffusion and use of new, and economically-useful knowledge" (Foxon et al. 2005). The authors considered a transition to domestic microgeneration in terms of overcoming incumbent locked-in centralised fossil fuel technologies, with a focus on policy interventions and their effects. The system innovations approach was used in this paper to highlight areas of policy where incentives for technical innovation and improvement were lacking. Similarly Bergman and Eyre (2011) reviewed the drivers and barriers to domestic MG in new homes using transition theory and strategic niche management as an analytical framework to identify areas where future policies could facilitate its uptake. Finally, Praetorius et al. (2010) conducted a functional analysis and comparison of the UK and Germany's technical innovation systems, comparing "supportive and obstructive" factors and the diffusion of microgeneration in each country. Transitions frameworks have also been widely used to analyse UK and European low carbon transition pathway options and policy regimes: see for example Foxon and Pearson (2008), Foxon et al. (2010), Kern (2012) and Verbong and Geels (2007). There is therefore significant precedent for the use of these types of framework in system studies of low carbon energy and microgeneration.

2.8.1 System innovations

Transitions and system innovation studies is a relatively new discipline with a growing body of literature, concerned with whole-system changes and transitions in socio-technical regimes. There tends to be a particular focus on technologies and user practices, with studies drawing on a range of disciplines such as cultural studies, economics, technology studies and innovation studies (Geels et al. 2004). While technological innovations studies have traditionally focused on changing individual "technological artefacts", transitions studies are concerned with more wide-reaching changes which give rise to "new markets, user practices, regulations, infrastructures and cultural meanings", known as system innovations (Geels et al. 2004). A frequent focus is transitions to more sustainable systems, since step-changes in efficiency and sustainability usually require changes in whole systems. This is particularly relevant to the case of microgeneration, which represents a significant change to the currently dominant energy provision paradigm.

The sociotechnical system (or sociotechnical regime) is an important concept in transition studies, emphasising the importance of considering technologies in context, rather than their performance in isolation. Use and function are more relevant in reality than technological artefacts, with technologies only "reali[sing] functionalities in… user contexts" (Geels et al. 2004). A sociotechnical system therefore describes technology in context, comprising policy, regulations, societal and cultural norms, supporting infrastructure, supply chains and markets as well as the technology itself. This framing differs from more traditional technology performance analyses by considering cultural aspects to be equally important as technical and infrastructural. Lie and Sørensen (2002) describe the process of societal integration as the 'domestication' of technology. This 'domestication' is a two-way process however, with social and cultural practices both influencing the development and function technologies, and being influenced by them (Aune 2002). A relevant example would be an emerging sociotechnical system for microgeneration technologies. They do not function in isolation, but require demand from the purchaser, planning permission, installation and connection to a grid, user competence and maintenance. User practices in energy consumption might in turn be changed by the presence of the technology (as discussed in Section 2.5.2), and so form part of the sociotechnical system. Although these processes have traditionally been described and analysed separately (Lie and Sørensen 2002), they are mutually interdependent.

The term 'transition' denotes a change from one state to another. Geels et al. (2004) expound on this by noting that states have defining internal characteristics which give them "coherence and stability", and that the term 'transition' connotes a *rapid* step change from one state to another, rather than slow incremental change. Since this research is concerned with a transition from centrally-generated energy to domestic microgeneration, a transitions approach will be informative. Analytical frameworks used in transition studies can identify key agents and processes in such a transition, shedding light on how it could be facilitated.

2.8.2 **Evolutionary processes in system innovations**

Complementary to transitions frameworks are evolutionary economic frameworks, which examine the causal interactions between elements of sociotechnical systems. Like transitions approaches, they examine the interactions between system elements such as technologies, policies and social norms, but rather than focusing on the coalescence of heterogeneous elements into a “working configuration” (Geels 2002, 2005b), coevolutionary economic theories draw upon the theory and language of natural selection (Foxon 2011). Foxon (2011) suggests that the consideration given to the roles and choices of actors (including individual user choices, business strategies and government activity) by coevolutionary approaches can usefully complement transitions approaches and provide new insights. Four key concepts in evolutionary economics are bounded rationality, path dependency and lock-in, generalised Darwinism, and coevolution.

2.8.2.1 Bounded rationality

The idea of bounded rationality was first discussed by Simon (1955) as a rejection of ‘economic man’: the neo-classical economic assumption of perfectly rational economic agents. Rather, due to an inability to access and analyse every piece of information about an economic decision (incomplete information), actors in an economic system exhibit imperfectly rational choices and behaviours. Rather than maximising utility and profits as classical economic theory would dictate, firms and individuals tend to use routines, heuristics and decisions based on past experience (van den Bergh et al. 2006), which ‘satisfice’: provide satisfactory levels of profit or performance; and will only change when internal or external changes cause them to no longer be satisfactory (Nelson and Winter 1982).

2.8.2.2 Path dependency and lock-in

Lock-in, a term coined by Arthur (Arthur 1989), describes the process by which routine practices and functionalities are embedded in (‘locked-into’) socio-technical systems and become difficult to change. Thus “technological developments tend to follow irreversible pathways”: path dependency (van den Bergh et al. 2006). A new technology which gains an early lead in the market (for any reason, often by chance) is likely to ‘corner the market’ due to the process of increasing returns to adoption. The more a technology is adopted and used, the more it is likely to improve – a positive feedback loop which ‘locks-out’ competitors. Five key reasons for these increasing returns were identified by Arthur (1988) and summarised by Geels (2004):

Learning by using: the more a technology is used the more is learned about it, allowing improvements to be made faster.

Network externalities: the more a technology is used, the more related products and infrastructure are developed.

Scale economies in production: the more a technology is produced, the lower the price per unit.

Informational increasing returns: the more a technology is used, the more awareness there is among consumers, encouraging other users to adopt it.

Technological interrelatedness: the more a technology is used, the more complementary technologies are developed.

A contemporary example of lock-in offered by van den Bergh et al. (2006) is the global dominance of the Windows computer operating system, which despite the existence of well developed alternatives such as MacOS and Linux continues to hold the majority of the market share. As van den Bergh at al. point out, the ancillary software that has developed around the Windows operating system now means that non-Windows users are often unable to access certain services or communicate with Windows users: a classic example of network externalities, technological interrelatedness and informational increasing returns. North (1990) has argued that institutions and their associated processes are also subject to these types of positive feedbacks.

2.8.2.3 Generalised Darwinism

Darwinism is the theory of biological evolution developed by Charles Darwin. Variations in living organisms arise as a result of random spontaneous genetic mutation and may be passed on through reproduction. Those genetic variations which give an organism a competitive advantage are more likely to be inherited by successive generations as the carriers are more likely to successfully reproduce. Generalised Darwinism, first suggested by Richard Dawkins (1983) as ‘Universal Darwinism’, refers to the practice of applying Darwinian ideas to non-biological systems such as sociotechnical systems. ‘Generalised Darwinism’ is most commonly used in ecological economics to describe the analysis of socio-technical innovation and diffusion processes, with the three main processes of interest being variation, selection and inheritance. Some researchers classify these processes differently – for example as diversity, innovation and selection (van den Bergh et al. 2006) – but the key concepts remain the same.

2.8.2.3.1 Variation

Analogous to the mutation and recombination of alleles in organisms, variation in economic systems describes the heterogeneity of technologies, strategies, structure and agents (van den Bergh et al. 2006). It can be characterised in terms of organisational changes (Aldrich and Ruef 2006), or innovation (van den Bergh et al. 2006). van den Bergh et al. (2006) distinguish between radical and incremental innovations. Radical innovations are those which give rise to the step-change transitions described in Section 2.8.1, and are outside existing sociotechnical paradigms. Incremental innovations are usually improvements on existing technologies or systems, and arise within the current technological paradigm.

Variation occurs in the selection environment described below (Nelson 1995). Many researchers consider variation and innovation to be the most important processes in the evolution of sociotechnical and economic systems, emphasising the importance of maintaining heterogeneity for as long as possible, since in dynamic and complex systems it is extremely difficult to judge at the outset which developments will be the most beneficial socially, environmentally and economically (van den Bergh et al. 2006).

2.8.2.3.2 Selection

Referred to by Nelson (1995) as “mechanisms that systematically winnow on [variation]”, selection is the process by which variations either persist or fail. In economic systems this occurs in a ‘selection environment’ which comprises technological, organisational, economic and institutional pressures which act to reduce diversity by eliminating unsuccessful variations (van den Bergh et al. 2006).

2.8.2.3.3 Inheritance

The retention of traits in organisms between generations occurs via the inheritance of genetic material by the descendants of the original carrier. Similarly in evolutionary economics, inheritance is the "survival and reproduction of successful agents or strategies in a system" (van den Bergh et al. 2006). Hodgson (2002) attributes the ability of non-living entities, processes and ideas to persist in this way to the "propensity of human beings to communicate, conform and imitate". Cordes (2006) and Ziman (2003) point out that unlike in nature, there is little concept of a 'generation' in technological development (though I would contend that some technologies such as games consoles do exhibit a 'generational' structure and are even named as such), and the development of a technology therefore resembles a web or network rather than a 'family tree'.

2.8.2.4 Coevolution

In another example of generalised Darwinism, two evolving systems or entities which are both evolving and have a direct causal impact on each other's survival are said to be coevolving (Murmann 2003). Murmann is insistent upon *mutual* causality, but Kallis and Norgaard (2010) suggest that a slight relaxation of this definition – to include for example a situation where one system's influence on another is not directly reciprocated, or where only one of multiple mutually influential systems is evolving – would usefully allow a wider range of situations to be considered.

Altered likelihood of survival can be as a result of altering the selection criteria, for example a new incentive within the institutional structure increasing the likelihood of a technology being selected (the UK FIT is a good example of this), or a change in the ability of individual entities to replicate: for example, a firm adopting a new business strategy which increases its investment in technological innovation (Foxon 2011). These examples are of cooperative coevolution, but as in nature coevolutionary processes can also be interferential: predatory or parasitic (Kallis and Norgaard 2010; van den Bergh et al. 2006). Cooperative coevolution has been described in terms of 'virtuous cycles', for example by Hekkert et al. (2007) who give the example of entrepreneurs lobbying for mechanisms of market creation, with market creation in turn stimulating entrepreneurial activity[2]. Foxon (2011) provides an example from Spain, where a supportive institutional framework in the form of a FIT system for renewable energy has caused selective pressure for investment in wind farms by incumbent energy companies, who are now in turn lobbying for enhancement of the FIT. These processes are closely related to the lock-in and path dependency described above. Conversely, inferential coevolution gives rise to vicious cycles. Here Hekkert et al. (2007) use an example from the Netherlands, where high hopes for biomass gasification were dampened by poor performance in field trials. The resulting collective disillusionment caused a reduction in new projects, research and resources for the technology, fuelling further disappointment and setting back its development by several years.

2.8.3 Foxon's coevolutionary framework

Developed in response to a call for applied coevolutionary approaches (Kallis and Norgaard 2010), and a need for a flexible analytical framework which could be applied by non-specialists (Foxon 2010), Foxon's coevolutionary framework combines insights from both ecological economics and sociotechnical transitions approaches (Foxon 2011). Developing Norgaard's (1994) classification and description of the coevolutionary process illustrated in Figure 6, the framework describes the way in which "key events in the transition to a low carbon economy may occur through technological changes, forming of institutions, revisions to business strategies or changes in user practices, and how these changes interact with changes in natural ecosystems" (Foxon 2011). Each element described (technologies, institutions, business strategies, user practices and ecosystems) is a system in its own right, coevolving with the other elements (Freeman and Louça 2001). The elements are defined further below. The framework is illustrated in Figure 7.

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[2] Hekkert et al. do not frame their discussion in terms of coevolution, but rather reciprocal influences between functions of innovation systems. However, as hinted earlier in the same paper, this is essentially coevolution by a different name.

Figure 6. Norgaard's characterisation of the coevolutionary process

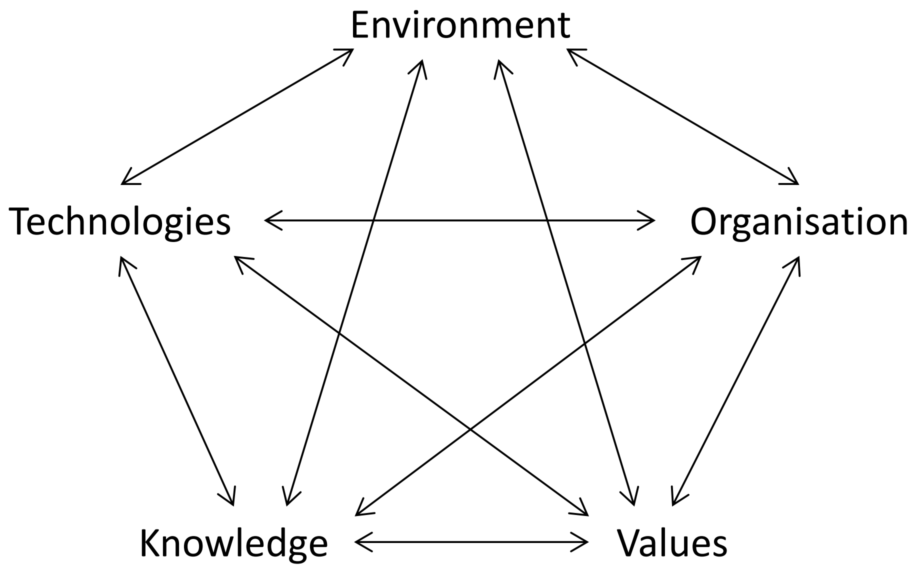
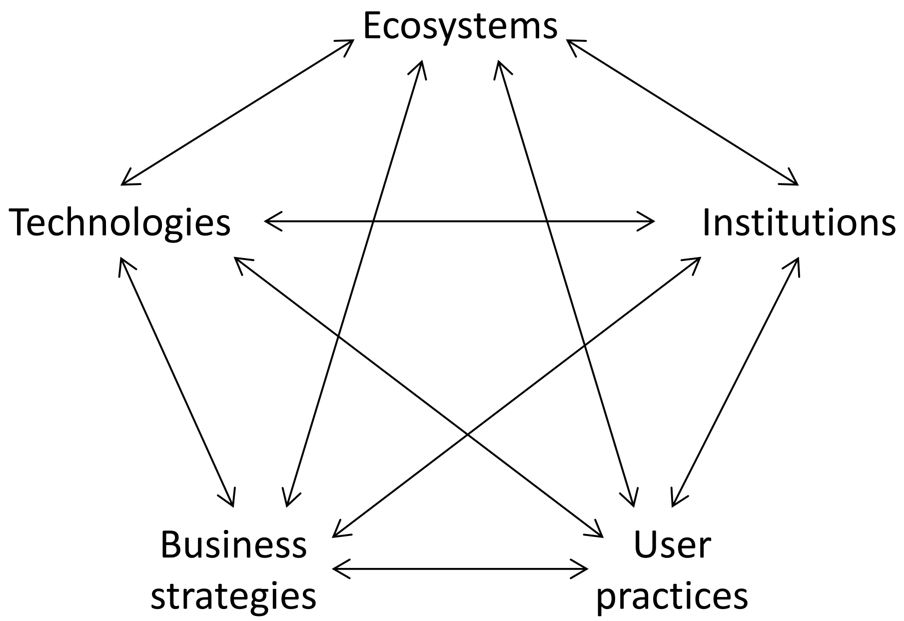


Figure 7. Foxon's coevolutionary framework



2.8.3.1 Ecosystems

Foxon (2011) describes ecosystems as "systems of natural flows and interactions that maintain and enhance living systems". As discussed in Chapter 1 with respect to climate change, human techno-economic systems have had and continue to have a profound impact on ecosystems by altering or preventing these natural flows and interactions.

2.8.3.2 Technologies

There is no universally agreed definition for 'technology'. Older definitions tended to concentrate on the physical aspects or 'hardware' (Orlikowski 1992), such as "the substitution of equipment for human labo[u]r" (Blau et al. 1976). Later definitions extend to include functionalities, processes and purposes, such as Beinhocker's (2007) "methods and designs for transforming matter, energy and information from one state to another in pursuit of a goal", and Arthur's (2009) "[natural] phenomena captured and put to use … to fulfil a human purpose". For the purpose of the framework, Foxon uses the latter two definitions to describe technological systems.

2.8.3.3 Institutions

'Institutions' is a frequently-used term in transitions studies and economics. Foxon (Foxon 2011) describes them as "ways of structuring human interactions. In other words, the definition of 'institutions' encapsulates both formal systems such as regulations, property rights and business organisations, as well as less formal unwritten rules such as cultural norms. Nelson (2005) states that institutions both enable and constrain behaviour: providing a social context for actions, but also defining the limits of socially acceptable behaviour.

2.8.3.4 Business strategies

Foxon (2011) defines business strategies as "the means and processes by which firms organise their activities so as to fulfil their economic purposes". For commercial firms this translates to 'means by which profits are generated', though it can also extend to charities, social enterprises or public sector organisations for which the primary economic purpose is to deliver goods or services.

2.8.3.5 User practices

This term denotes behaviours (by individuals, households or social groups) which occur in the course of interactions with technology, which are usually routine and shaped by cultural context. This 'societal embedding' (Foxon 2011) was described in terms of technology domestication and technology in the social context in Section 2.8.1. User practices may be defined in terms of fulfilling social needs via processes which are constrained by social structures and available technology (Foxon 2011; Spaargaren 2003). In terms of Darwinian processes, both variations in user practices and the 'recruitment' of new users to these practices (inheritance) are of interest (Foxon 2011).

2.8.3.6 Application of the coevolutionary framework to research questions

Foxon's coevolutionary framework has been chosen to frame the analysis of drivers and barriers for microgeneration in new homes in this thesis. The framework provides guidance on a systematic approach to complex issues. It allows analysis of the mutual causal influences within and between systems and can help to identify the relative importance of different factors (Kallis and Norgaard 2010). For this reason it is eminently suited to the challenge of identifying the drivers and barriers to microgeneration that exist in the complex interlinked systems of renewable energy generation, construction and home-buying. Indeed, Foxon (2011) recommends that it is suitable for empirical analyses of challenges relating to the adoption of low carbon technologies, and it has recently been applied to an analysis of the coevolution of ESCOs and the UK energy system, in which it was integrated with Osterwalder and Pigneur's (2010) nine building blocks of a business model to identify positive and negative feedback mechanisms affecting the development and diffusion of the ESCO business model in the UK (Hannon et al. 2013).

As discussed in this chapter, many similar studies in the field of low carbon innovations and technological diffusion have used other models and frameworks. A number of these analytical are in their infancy and have generally been developed and applied in the context of a one or two studies. Since the primary purpose of this thesis is to investigate the diffusion of a particular technology, rather than contribute to the development of analytical frameworks, the use of a more established framework was desired. In addition to the coevolutionary framework described above, Geels' Multi-Level Pathway (MLP) framework is prevalent in the field of low carbon innovations. It has been used extensively in recent years to develop low carbon transition pathway scenarios (Foxon et al.

2010; Verbong and Geels 2010), analyse historical transitions (Geels 2005a; Verbong and Geels 2007), and assess the effectiveness of policy (Kern 2012; Kern and Smith 2008) . It has been observed however that the MLP gives relatively little weight to the role of actors (particularly individual actors) in the sociotechnical system and the role of economic factors in sociotechnical transitions (Foxon 2011). Additionally the MLP has predominantly been applied to large-scale transitions involving multiple technologies, and arguably pre-supposes a 'complete' transition by describing a process of transition from one relatively stable equilibrium to another. The potential transition under discussion in this thesis (from centralised to decentralised energy provision) is currently in the early stages, and is not necessarily planned as a complete transition but may been seen as one option among many which will contribute to the decarbonisation of the UK's energy supply system. This thesis is also concerned with a specific sub-system: – new build homes – rather than the large scale systems analysed in previous studies using the MLP. As a result, the coevolutionary framework, which provides a more flexible structure for analysis, was felt to be the most suitable to frame the analysis of drivers and barriers for microgeneration in new UK homes in Chapter 3.

This chapter has reviewed the literature on the diffusion of microgeneration in the UK, and relevant studies of low carbon homes, in order to situate this thesis in context and identify the gaps in knowledge which this thesis will address. Having identified the need for an up-to-date system level study of the drivers and barriers to microgeneration in new UK homes in this chapter, and described the analytical framework which will be employed, Chapter 3 presents the methodology, results and discussion of this system level study.

3 Unique drivers and barriers for microgeneration in new UK homes

3.1 Chapter overview

The literature review in Chapter 2 identified a lack of research on the drivers and barriers to the deployment of microgeneration in new homes in the UK, and the number of policy developments which have occurred since previous system studies of microgeneration. This chapter therefore comprises an up to date investigation of the drivers and barriers for microgeneration in new homes in the UK, using information from existing literature and semi-structured stakeholder interviews, analysed using a coevolutionary framework. Section 3.2 outlines the methods used for data collection and analysis. 3.3 presents the results, which are discussed in a coevolutionary context in Section 3.4. Section 3.5 summarises the conclusions, and considers the opportunities for further research arising from them.

3.2 Methods

To identify the key drivers, barriers, opportunities and emerging business models for microgeneration in new homes, a series of interviews were carried out. Interviewees were identified in the first instance from a desk study of relevant Government organisations, trade organisations, companies and research institutions. Subsequently a ‘snowballing’ technique was used, by asking those approached for recommendations on who to contact.

Twelve face to face or telephone interviews with stakeholders and experts from the fields of energy and construction were conducted. Anonymised information about interviewees is shown in Table 7. The interviews were semi-structured and lasted between 30 minutes and one hour. During interviews, participants were encouraged to discuss issues from across the whole system, with interviewer bias avoided by asking broad, open questions initially to prompt interviewees' own assessments of the major issues. Questions included general enquiries about microgeneration in new buildings and more specific questions tailored to the expertise and experience of individual interviewees. The interviews were recorded, and after each interview the recording was reviewed to identify possible improvements to the questions in the next interview. Since the interviews were intended for qualitative rather than quantitative analysis, changes could be made to the interview script between interviews. A representative interview transcript can be seen in Appendix A.

Table 7. Interviewee details

Date of interview	Role or organisation type	Identifier	Sector
14/11/2011	Low carbon strategy and innovation consultant	Consultant 1	Private
22/11/2011	Low carbon buildings consultant/structural engineer	Consultant 2	Private
02/12/2011	Construction industry knowledge transfer consultant	Consultant 3	Public/Private
12/12/2011	Energy systems researcher	Researcher 1	Academic
15/12/2011	Low carbon energy technologies researcher	Researcher 2	Academic
15/12/2011	Local council	Council	Public
19/12/2011	Specialist green developer	Developer 1	Private
20/12/2011	Energy systems researcher	Researcher 3	Academic
16/01/2012	Senior civil servant, BIS[1]	Civil Servant 1	Public
19/01/2012	Senior civil servant, DECC	Civil Servant 2	Public
20/01/2012	Community energy consultant/developer	Developer 2	Public/Private
26/01/2012	Developer	Developer 3	Private

The interviews were transcribed and analysed using QSR NVivo software version 9. Coding for thematic analysis was carried out using a deductive approach, using Foxon's coevolutionary framework (described in Section 2.8.3) as a guide. Coding reliability was improved by an iterative coding process, with three

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[1] Department for Business, Innovation and Skills.

transcript reading and coding exercises separated by a week each. Thematic analysis is widely used for qualitative data as an exploratory approach: identifying both explicit and implicit themes from the data (Guest et al. 2011). It was judged to be appropriate for this analysis as it is both systematic and flexible, requiring rigorous analysis of the data but allowing for more nuanced interpretation than approaches such as word counts.

Foxon's coevolutionary framework was used to inform and organise the results and discussion which follow. The rationale for the use of this framework was given in Section 2.8. In addition to information from the interviews, existing literature was also used where appropriate.

3.3 Drivers and barriers

This section presents the drivers and barriers for microgeneration in new UK homes identified from the interviews and literature review. To provide structure, the discussion has been grouped under the five different systems in Foxon's coevolutionary framework: technologies, institutions, business strategies, user practices and ecosystems. Of course, as illustrated by the framework diagram, these systems interact with each other, and several of the issues identified here could fit under multiple headings.

3.3.1 **Technologies**

A key difference in the technology choice process between retrofitting microgeneration and including it in new builds is that the home designer/developer is the decision-maker, not the householder. This is likely to have a significant bearing on the selection environment for microgeneration technologies, as developers may seek only to maximise their profit from a technology, whereas a householder may also seek to maximise their utility. For example, householders may be more concerned with ease of use and aesthetics as they will ultimately live with and operate the technologies.

3.3.1.1 New homes as a solution to lock-in

As discussed in Chapter 2, some microgeneration technologies have specific infrastructural requirements which may be difficult to meet when retrofitting, and hence cause 'lock out' the technologies. For example, biomass boilers may require installation space on the ground floor due to their size and weight, and space for fuel storage. While these would usually be prohibitively difficult to retrofit to an existing home, new homes could be designed to include these features from the outset, avoiding the difficulty of infrastructural lock-out. Other examples could include the inclusion of boreholes for GSHPs, exterior space for ASHPs, and the avoidance of skylights or dormer windows to leave room for solar PV or solar thermal systems on the roof. Building integrated PV (BIPV) is an example of a technology which is particularly suited to new buildings. BIPV refers to solar cells which are integrated into building components such as glass panes or roof shingles, rather than panels which are added to an existing building.

Similarly, new developments can be designed to optimise the performance of some types of microgeneration. Examples might include designing roof angle and pitch to maximise solar irradiance or positioning buildings and trees to avoid overshadowing roofs.

3.3.1.2 Phased developments

Most large developments are phased rather than being delivered at one go, and this has implications for the choice of district scale microgeneration versus individual installations. District scale installations may offer greater intrinsic potential for efficient energy conversion than individual installations. However, a single district-scale installation serving a phased development will be under-used until the entire development is completed and the homes occupied (if sized to meet anticipated demand when the entire development is complete), and risks being technologically outdated by the time later phases appear. District scale schemes could be rolled out with separate installations for each phase, but this has implications for capital and operational costs and energy conversion efficiency. Different builders (be these separate companies or different branches of one company) may be involved in different phases and the use of a single district heating scheme will depend on a technological and financial consensus being reached between these entities.

3.3.2 **Institutions**

3.3.2.1 Policies for new homes

Despite the UK government's commitment to the development of microgeneration, and several consecutive policies designed to stimulate retrofit (culminating in the FIT and RHI), there is no specific policy measure aimed at microgeneration in new homes. Policy with the potential to indirectly influence the incorporation of microgeneration in new build construction is instead delivered via the building regulations which govern the design and construction of buildings, and the Code for Sustainable Homes (CSH), described in Sections 2.3.2.1 and 2.3.2.2. Potentially the most significant policy for microgeneration in new homes at present is the Zero Carbon Homes target (described in detail in Section 2.3.2.5), which requires all new homes to be zero carbon by 2016, and is delivered through the building regulations.

Interviewees consistently named the Zero Carbon Homes target as the primary or only driver for property developers to install microgeneration. A lack of market demand and the additional cost of microgeneration compared with conventional technologies were mentioned frequently in reinforcement of the point that regulation currently has to 'force' developers to use it.

"My feeling is that legislation, if the Government stays strong… will ultimately force developers to [install microgeneration]. If it was left to market forces I don't think it would happen. Not at all." (Consultant 2)

Despite the vital role of policy in encouraging the use of microgeneration, the current policy landscape in some cases appears to be holding back innovation and investment in the domestic energy sector. The most frequent criticism of policy for microgeneration in new builds among interviewees was inconsistency in the longevity and content of policies – echoing similar criticisms of broader UK renewable energy policy (Foxon et al. 2005; Mitchell and Connor 2004). A frequently raised point by interviewees was that while grants and tariffs for microgeneration tend not to apply directly to developers of new builds, they nonetheless affect investment in the technologies, affecting their affordability and desirability. Policy churn also undermines confidence in selecting microgeneration technologies. In the past two decades several relevant grant schemes and policies have come and gone (e.g. the Major Photovolataic Demonstration Programme which ended six years early, the Clear Skies Act and the Low Carbon Buildings Programme). There was also controversy after a fast track review by DECC in 2011 led to the announcement of substantial reductions in FIT payments for solar PV installations (DECC, 2011c) which was subsequently reversed after a legal challenge by the Friends of the Earth charity and solar firms Solarcentury and HomeSun.

"The more often [policy] changes, the less likely it is that microgeneration is going to take off, because it's… quite a considerable risk for the investor to take on board microgeneration, because the period over which return on that investment is going to happen is certainly five years, maybe 30 years." (Civil Servant 1)

"With PV the FITs [caused] a bit of a take-up with people who might otherwise not have considered it, and now that the FITs for PV have been reduced I think we may well see a drop in that, I'm not sure. So, I think it's a very tenuous market." (Researcher 2)

"Our most high profile [local initiative] was sadly unsuccessful – it was an attempt to get solar panels put on 5000 council homes. Which would have happened, as we speak! Had not the feed in tariff been cut. So that put the whole scheme on ice." (Council)

The Zero Carbon Homes target has also been subject to a number of changes since its inception. In a policy document released in 2007, DCLG committed to regulating for zero carbon new homes by 2016, with interim targets of a 25% improvement to the carbon targets set in the Building Regulations by 2010, and a 44% improvement by 2013 (DCLG, 2007a). The Zero Carbon Homes target was linked at the outset to the CSH, with the progressive targets defined as meeting Level 3, Level 4 and Level 6 of the Code respectively. However, the definition of a Level 6 dwelling has changed with every subsequent publication of the CSH. In the 2007 edition, it was explicitly required that heat and power used in a Level 6 home "must be generated either in the home or on the development or through other local community arrangements… and must be renewable" (DCLG, 2007b), suggesting that microgeneration would be essential for developers to meet the target. After several iterations of the policy, the specific definition for 'Zero Carbon Homes' has now been decoupled from the CSH and was finally set in the March 2011 Plan for Growth report associated with that year's Budget (HM Treasury and BIS, 2011). The key features are that only emissions from fixed lighting, heating, hot water and building services are now included in the regulation, and that although on-site reductions are still required the allowable solutions described in Section 2.3.2.5 are also permitted. At the time of writing, the specifics of what will constitute allowable solutions have yet to be officially confirmed, although a number of suggestions have been made such as improving the efficiency of existing buildings in the vicinity, and paying to fund approved 'green' projects (Zero Carbon Hub, 2011).

These frequent changes and a failure to fully define regulation after nearly six years have led to a lack of industry confidence in the Zero Carbon Homes target, with interviewees reporting that many developers are *"hoping that all the regulation goes away"* (Consultant 1). The shifting definitions of what constitutes 'zero carbon' have potentially altered the significance of the role of microgeneration in meeting the target, which reinforces aforementioned investor uncertainty. If off-site allowable solutions prove cheaper than integration of microgeneration technologies into new build housing developments, this may significantly hinder the growth of the market for microgeneration in new homes.

Compounding the lack of confidence in the Zero Carbon Homes target is the lack of a defined process for monitoring the emissions performance of new build homes. None of the interviewees was aware of any procedures for ensuring compliance, and indeed none is set out in any policy documents. Equally, it is not known what the penalty, if any, for non-compliance will be.

"There [have] been debates in Whitehall about standards for measurement and for compliance, and as far as I know it's not got off the ground... I think it's going to be a very difficult thing for anyone to make stick. The only people who make money out of that will be the lawyers." (Civil Servant 1)

As a result of this inconsistency and uncertainty, it appears to be almost universally accepted among stakeholders that the 2016 target will not be met. For example:

"I think the 2016 target will probably come and go with very little fanfare other than a sense of growing realisation that we're not actually achieving it" (Researcher 2)

"I think we'll probably miss [the target] by quite a long way." (Civil Servant 1)

If the target is further diluted by overly permissive allowable solutions, or if it is simply not met, it is likely that the majority of new homes will continue to be built without microgeneration technologies. The turnover rate for homes in the UK (in terms of demolition and new build) is very slow (Boardman et al. 2005), therefore it may be expected that homes built now will be extant for decades or even centuries. While retrofitting may still be possible in many cases, building homes without microgeneration means missing out on the additional benefits discussed above in Section 3.3.1.1 and reinforcing the lock-in of centralised energy delivery systems. Additionally, the aforementioned investor uncertainty caused by policy churn and delayed decision making is likely to affect investment in research and development for microgeneration. This may start to impact technology performance, and further weaken investor uncertainty, in a coevolutionary 'vicious circle'.

While inconsistency in policy and a lack of monitoring are perhaps the biggest policy barriers to the use of microgeneration in new homes, another criticism of the Zero Carbon Homes target is its links to the CSH with its points-based approach to compliance. Despite its having been decoupled from the CSH, as a result of the initial definition for zero carbon homes in 2007, interviewees stated that CSH Level 6 is widely considered within the construction industry to be the 'ideal standard' for compliance. However, some of the measures through which developers can reach Level 6 do not support the goals of the Zero Carbon Homes target:

"I think if a developer is concerned about compliance, so he wants to say 'well I've built these houses and they comply with CSH Level 4', for example, then... because it's a points system, obviously what they're going to do is go for what they see as the most cost-effective way of building up enough points to comply. So you get your cycle sheds because you get a little tick in the box for those, but they're not really helping in terms of [carbon reduction] performance." (Researcher 2)

Another example given during interviews was sizing stipulations which can actually reduce efficiency:

"A lot of technologies [start] being sized to meet [targets] as opposed to being the optimum engineering solution." (Consultant 2)

As a result, the majority of interviewees were of the opinion that the policy framework for zero carbon homes should be based on net emissions only, separate from other standards such as the CSH which stipulate specific measures; and that market forces should dictate the measures used.

"So, what policy measures need to be brought into place? Should it drive microgeneration technologies? I don't think it should. I think really you should be setting an absolute target and then allow all developers, all the design teams, to actually come up with their own methodology... it's better to just set the desired outcome in terms of carbon reduction, and let the developers do it in their own way." (Consultant 2)

"The government position, and I completely agree with it, is that where possible you need the market to deliver." (Civil Servant 2)

However, as discussed in Section 2.8.2.1, the assumption of perfectly rational actors and the ability of free markets to deliver optimal solutions is flawed, as businesses and consumers may continue to follow 'satisficing' routines rather than seeking out new ways of working which optimise environmental or economic outcomes. Additionally, this 'hands off' approach may lead to reductions in the diversity of technology options if certain types of microgeneration (or efficiency measures) gain an early advantage, due to lock-in and increasing returns to adoption. For this reason, and due to the potential additional benefits of microgeneration outlined in Sections 1.2.2 and 2.5.2 beyond simply decarbonisation, some interviewees were of the opinion that specific policies or targets for microgeneration would be beneficial.

"I think it would be good to have a distinct policy for microgeneration, because it is fundamentally different from your large wind or large solar in that it does involve people on an individual household basis, or perhaps on an office or school basis." (Researcher 1)

3.3.2.2 Housing markets

Another institution which has the potential to impact on microgeneration in new homes is the housing market and the policies associated with it. Currently home prices are rising relative to average salaries, and the average age of first time home buyers is increasing (LSL Property Services 2014). In addition, the number and proportion of retirees in the UK is growing rapidly, and the majority of them live in 'mainstream' housing which they own outright, as opposed to assisted living facilities or care homes (Age UK 2011; Knight Frank 2010). Given the differences in attitudes, WTP and likelihood of adoption between different demographic groups, this may start to affect householder awareness of and demand for microgeneration. Since the 45 – 65 age group is most likely to adopt microgeneration, older buyers may equate to greater uptake; but conversely the increased cost of homes relative to salaries may leave buyers less willing to spend extra for non-mandatory installations. As discussed in Section 2.5.1.9, retirees may also be less likely to invest in microgeneration technologies. It has been predicted however that there will be a large increase in assisted living retirement 'villages' over the next decade (Knight Frank 2010). Since these are usually run by an umbrella organisation, they may be suited to district heating or microgrid schemes, decisions about which would be made by the company owning the retirement community rather than the residents. This could therefore represent an area of opportunity for microgeneration in new builds.

Government policy is also having an effect on patterns of home purchases, primarily through the Help to Buy scheme which allows first time buyers to receive government loans for home purchases, and all buyers to purchase homes with a smaller mortgage deposit. Launched in 2013, it has resulted in an increase in the number of first time buyers (DCLG 2014). By making it easier to purchase first homes, the policy may dampen the effect of the trend described above.

3.3.2.3 Uncertain financial incentives

While the FIT and the Green Deal can allow home owners to offset the cost of retrofitting microgeneration, no similar mechanism is in place to assist developers. Including microgeneration incurs additional costs compared with using conventional technologies. While the additional cost will vary depending on building size and the type of microgeneration used, as a representative example: in 2008 the additional cost of the energy measures required to move from CSH Level 3 to Level 6 ranged from approximately £14,000 to £36,000 per house (DCLG 2008). Capital costs are usually considered to be less problematic for firms compared with consumers, as consumer discount rates are usually significantly higher than those used by firms. However, this increased capital cost is particularly problematic for the building industry as margins on new construction are often very small (Royal Institution of Chartered Surveyors 2011) hence cash flow management and keeping construction costs to a minimum is vital. These issues reinforce the earlier point that developers are likely to take not the most technologically and environmentally effective but the most cost-effective measures to comply with regulations, both in terms of the types of technology chosen and sizing.

"Cash flow, as in any business but especially in the construction business, is a killer. I mean, Businesslink and Government have statistics that say, 50-plus percent of construction businesses go out of work, and out of business because of poor cash flow management. Not for any other reason, but for cash flow management. Now, as a statistic alone, that's pretty big. Pretty damning." (Consultant 3)

The question of who ultimately pays for the additional cost of microgeneration technology on a new home is a source of uncertainty. While DCLG's impact assessment for the Zero Carbon Homes target suggests that developers will bear the additional costs (DCLG 2011d), consensus among interviewees was that the cost is likely to be met at least partially by whoever purchases the new home through the purchase price.

"Well [developers] will price it accordingly, won't they. We've got these standards and they're required to fulfil them. Then they will price [houses] accordingly. It would seem to be odd if Government would give them money. Because they should be keeping within the regulations." (Civil Servant 2)

However, as discussed in Sections 2.5.1.2 and 2.5.3, consumer WTP for microgeneration is usually less than the actual capital cost. Hence if these technologies cause a large disparity in purchase price between new and existing homes, prospective buyers may shun new houses in favour of older, cheaper properties. Interviewees pointed out the danger of assuming perfectly economically rational home buyers:

"As a consumer, if you're thinking "well I have £10,000" or whatever, "should I buy a new kitchen, should I put up PV?" It's not a simple comparison. And this is one of the major things where a lot of policy just [uses] the rational actor paradigm, thinking that information and money is all it takes, when this is clearly not the case. If you're considering a new kitchen versus PV, you don't think about the

payback time of a new kitchen obviously, why should you think about the payback time of PV?" (Researcher 2)

Interviewees also expressed concern over the preparedness of surveyors and estate agents to accurately and consistently calculate the added value of microgeneration technologies to new homes – also discussed in Section 2.5.3. At least some homeowners who have planned extensions which include microgeneration have been unable to negotiate a sufficient mortgage because banks will not recognise the added value of the technology (Pers. comm. Nigel Wright 2011) .

3.3.3 **User practices**

3.3.3.1 Choosing a home

Consumer decisions on whether to adopt microgeneration are complex and multi-faceted. The majority of studies on the subject have focused on retrofit situations, but including microgeneration in the context of a home purchase introduces additional issues which may act as drivers or barriers. The most significant difference is that the initial impetus for householders to choose and install the technology is not required – rather, prospective home buyers must choose to purchase a home which has microgeneration already installed on it.

As discussed in Section 2.5.1.4, the effort and disruption involved in installing microgeneration technologies is a significant barrier to adoption for many householders. A potential advantage of new homes with microgeneration is that the 'hassle factor' for householders is removed as the technology is already present when they purchase the home. In other words, rather than the 'active' technology acceptance required when retrofitting microgeneration, only 'passive' acceptance is required. New homes could present a less pressured selection environment for technology options such as GSHPs which are more disruptive upon installation, since construction work is occurring anyway and established gardens and grounds are not being dug up.

However, as discussed above in Section 3.3.2.3, in the absence of other financial incentives for developers it is likely that at least some of the additional cost of microgeneration will fall onto home buyers. Therefore while the ‘hassle’ issue can be overcome in new homes, the issue of upfront cost remains. In a competitive market, despite the shortage of new homes in the UK, developers will seek to provide home owners with options that are perceived as most desirable. At present, there is much evidence to indicate that most prospective home buyers are largely indifferent to renewable energy features, tending to prioritise other features.

“There is no market demand. I can't imagine that there are many customers who walk into show houses and say, ‘ok, where's the PV panel, where's the heat pump?’ you know, ‘why haven't you put them in?’” (Consultant 1)

As discussed in Section 2.5.1.3 and 2.5.1.5, microgeneration can hold other appeals such as independence and environmental protection. However interviewees opined that even so financial concerns usually take precedence, and that prospective buyers would only choose microgeneration if they were convinced it would save them money.

“Trying to sell carbon [reduction] to people, it gives people like a fluffy feeling: a nice happy feeling… some people would be driven maybe to spend a bit more on their house because of that, but really what they'd be thinking about is reduced energy costs versus a conventional house, and that probably will always be the biggest driver.” (Consultant 2)

Many interviewees therefore believed that the majority of home buyers would only start to seek out microgeneration once electricity and gas prices reached an ‘uncomfortable’ level.

“Well the obvious thing [driving consumer demand] is energy costs. There's an inexorable upward trend. So the benefits will be self-evident I think. I don't think there's any more incentive required beyond that.” (Civil Servant 2)

"What will drive [mainstreaming of microgeneration] would be the rising energy costs. So we've had a 20% increase across the board in the last 12, 14 months in energy prices. Looking at the various reports, that's set to continue quite dramatically. That will have the same effect as petrol prices had on people. It's beginning to hurt. And the same thing will apply to people's homes." (Consultant 3)

It is reasonable to assume that the 'tipping point' will differ depending on occupants' socio-economic status and level of awareness regarding energy price trends and projections. As a result, the demographic stratifications in attitudes and likelihood of microgeneration adoption discussed in Section 2.5.1.9 may begin to change as energy prices rise.

3.3.3.2 Using microgeneration

Section 2.5.2 described the behavioural changes which may result from the adoption of microgeneration technologies: namely increased awareness of energy and environmental issues, increased adoption of efficiency measures, and even in some cases reductions in energy use. However, the evidence for these changes was mixed, and Dobbyn and Thomas (2005) noted that attitudinal changes were greatest in households which had actively decided to adopt the technology, rather than those who had passively accepted it by moving into social housing where microgeneration was present. Dobbyn and Thomas also observed that passive householders were more likely to lack understanding of how to operate the technologies and use them to the greatest advantage. This observation was corroborated by interviewees in this study commenting on microgeneration in social housing:

"The user interface is not that friendly… the installers set it up and they say 'don't touch it - just leave it, it's fine'. And then people [think] 'oh well I'd better not touch it' - they get frightened of touching it… not everyone was given an instruction manual so even people who wanted to interact with it in some cases weren't able to." (Researcher 2)

Householders for whom microgeneration is an incidental feature of a home they purchase may lack the interest or motivation to learn how to make the best use of it. In addition to lost opportunities for cost savings and carbon reduction, this poses the risk of eroding user confidence in the technologies, as negative word of mouth reports can have significant impacts on the reputation of innovations (see Section 2.5.1.7). Furthermore, home buyers are unlikely to meet the installer of the microgeneration, and are therefore reliant on the developer to act as a 'go-between' to provide the information. The repeal of the requirement for Home Information Packs in 2011 potentially compounds this risk.

However, despite the observation that behavioural effects were smaller in passive households, Dobbyn and Thomas did observe increases in awareness and efficacy for some of the passive households in their study. This suggests that including microgeneration in new homes has the potential benefit of reaching and effecting attitudinal changes in those who would otherwise not have adopted the technology.

3.3.4 **Business strategies**

3.3.4.1 The building industry

The nature of the building and construction industry itself can present barriers to the uptake of microgeneration in new buildings. In 2010, the top ten house builders in the UK completed 47,783 houses (Building.co.uk 2011), making up approximately 40% of the 124,200 new builds completed in England that year (DCLG 2011b). A small number of these companies hold a large share of the market, with the top three in the completion league table all building over twice as many houses as the company in fourth position (Building.co.uk 2011). This dominant role is important, because conservatism among these industry leaders has been identified as a barrier to innovation (Tassinari and LoCascio 2011; Watson et al. 2006). Indeed, many interviewees cited conservatism of the major builders as a factor which is stifling low carbon innovation in the housing sector:

"The building industry in Britain [is] very conservative; new build is mostly down to… a few dozen large companies which build similar homes over and over, which is completely different from retrofit which is literally tens of thousands of small [projects]." (Researcher 1)

"If the established [developers] were being smart, they would look to innovate and get into new markets, but that's not the way they work. There are very few of them, to my understanding, that are thinking that way." (Consultant 3)

These developers subcontract much of the actual building work out, and at this scale the construction industry is quite fragmented. In 2010 there were 256,441 private construction contracting companies registered in the UK, of which 78% employed fewer than four people (Office for National Statistics 2011f). Several interviewees reported that a lack of knowledge sharing prevailed in the industry, and information sharing and continuity were perceived to be a problem even among people working on the same project. The large number of people involved in construction of new homes can lead to discontinuity in design and execution, and disconnects between designers and sub-contractors were reported to lead to built products which differed from design.

"The way that the industry works, with a lot of sub-contracting and using different people on different projects, means that it's very difficult to take learning and good practice from one project and apply it to the next - even within the same company, never mind between companies." (Researcher 2)

"There is a disconnect between architects and installers and planners, and I'm aware that the heat pump industry, they complain that architects are not aware of this and do not design new build for heat pumps, which if they consulted installers they could do in the first place and make things more efficient." (Consultant 2)

The consensus from interviewees was that knowledge about the functioning and costs of technologies among developers was good, but that pricing and standards of workmanship from contractors were very variable. It was reported that prices for certain technology types did not appear to correlate consistently with the size of the installation, and that while accreditation schemes such as the MCS had gone some way towards standardising skill levels, accreditation was not always a guarantor of good workmanship while high financial pressures on contractors persisted. Problems with finding skilled installers were particularly apparent for newer and less common technologies such as micro-CHP, while more established technologies such as solar PV were less problematic.

"With solar thermal, prices [are] all over the place, with hardly any correlation to the size of your installation. With PV it's much better because it's much more easy to measure exactly what you're putting in and how much it generates." (Researcher 1)

"It's not just about the accreditation, it's about following it through. Accreditation's one thing, you can jump through the various hoops and get there, but once you're there, who's going to check you? Especially when you come back to the financial pressures that people are under, poor old contractor at the end of the day." (Consultant 3)

A distinction between technology types was also seen in terms of developer confidence in microgeneration. Solar PV technologies in particular were frequently mentioned as being more 'established' and therefore inspired more confidence than technologies which were perceived to be more novel and require more complex installation such as ground source heat pumps and micro CHP.

"Different sort of tiles on roofs or whatever is fairly straightforward; putting appliances into the ground and drilling deep holes is not something builders routinely do, so the skills that are needed and the systems that are needed I don't think are as well-developed and as pervasive." (Civil Servant 1)

All interviewees stressed the importance of knowledge sharing and skills among builders and installers and education for residents as a response to concerns over technological performance. Therefore a unique challenge for new build homes is to promote links between large numbers of different people and companies, within projects and between projects, and to facilitate knowledge sharing without stifling competition. Research into how these outcomes could be best delivered could strengthen the Zero Carbon Homes target, as well as other aspects of sustainable building.

3.3.4.2 Alternative business models

Several interviewees cited opportunities for expansion into new markets as a possible driver for developers to include microgeneration on new homes, specifically the opportunities for developers to act as ESCOs and recoup the cost of the technology by receiving FIT payments. Under an energy services contracting arrangement, an ESCO will own, operate and maintain the generating technology, which could take the form of microgeneration located on the client's house. The client pays a set monthly or annual fee for energy services, or depending on the arrangement may also buy electricity and heat from the ESCO at a competitive rate. A typical example of this type of arrangement was described by Developer 1. The developer sets up an ESCO for each new housing project, and then contracts out more and more of the maintenance work as time goes on, while still retaining overall control of the ESCO. The ESCO controls the microgeneration technologies on site (in this example, heat pumps and rooftop wind turbines) and provides a resident helpline. Residents pay for this service through a levy on their energy bills, and since they are unable to switch energy provider, the ESCO ensures that its prices are competitive compared with the 'Big Six' UK energy companies.

Expansion into energy service markets by developers was suggested by some interviewees as a solution to the financing issues around new build microgeneration described earlier. While switching existing private households to an ESCO arrangement is challenging since their energy delivery infrastructure is already in place, new build provides an opportunity to implement an energy services arrangement.

"[Developers] come up with a decentralised energy strategy for the site… and then maybe they retain ownership of anything that's installed on individual houses. And

then they sell energy, whether it be heat or electricity, to the homeowner. There are precedents for that, but if it's simply a developer building a hundred houses on a site and then selling each of those individual plots to a home-owner, there's no real benefit to him to install renewables is there?" (Consultant 2)

The ESCO model could also be applied to existing developments by retrofitting the necessary technology and putting control systems in place, but this would in most cases involve a large amount of infrastructural change, and also require commitment from all or most of the existing residents in a certain area. By contrast, a new development could be built with the necessary infrastructure, and essentially represents a guaranteed demand from residents if it is the only energy delivery option in place.

However, there were also suggestions from other interviewees that expanding into ESCO activities would not be attractive to developers, and that most would prefer to either contract out to a dedicated ESCO, or simply sell the technologies outright to home buyers rather than provide potentially costly and complex ongoing support and maintenance.

"Most contractors won't want to have that sword of Damocles hanging over their head once they've done the work. They'll want to pass on to somebody else." (Consultant 3)

"I don't think a lot of traditional developers would really feel it's their business necessarily to maintain a presence within a development once all the plots are sold on. You know - they'll be looking to hand it over to an energy supply company." (Researcher 1)

An important consideration in this case is the period for which the builder is likely to remain responsible for the microgeneration system under the terms of the new home warranty provided to the house buyer. Over 80% of new houses in the UK are registered with the National House Building Council (NHBC 2012), which requires the builder to accept liability for repairs for two years after completion (NHBC 2011).

3.3.4.3 Social housing

Social housing presents an opportunity for innovation in the new housing sector, since there is high and increasing demand for it (McManus et al. 2010). Microgeneration technologies may have a role to play in alleviating fuel poverty in lower-income areas. In cases where the housing provider has paid the capital cost, and particularly for heating technologies when homes are off the gas grid, microgeneration is expected to provide cost savings for householders (O'Flaherty and Pinder 2011; Walker 2008).

As a result, many social housing providers use ESCO-like arrangements when including microgeneration in their developments. Since the housing provider retains ownership of the properties, they can receive FIT payments to offset the cost of installation, while residents can benefit from lower energy bills. Broadly the same benefits and disadvantages apply as for the developer as ESCO model. However, this arrangement presents two issues which are unique to social housing. The first is that social housing residents may have no, or reduced, choice over where they are housed and what features are included. When energy technologies are in place that are less familiar, or are perceived to perform less reliably than conventional options, residents may feel that such technologies have been imposed upon them.

"There was an element of choice, but I think it may have been over-sold to some extent, and [the council] may have made slightly unrealistic claims about the sorts of savings [tenants] could expect. And therefore I think perhaps some people might feel put off by the systems for that reason." (Researcher 2)

The second issue is that the housing provider may be seen to have a duty to provide advice on energy saving for residents, but that a conflict of interest may arise when the council is receiving FIT or RHI payments.

"If the council wants the system and gets RHI payments, then there's no particular incentive to encourage the tenants to take other efficiency measures, because [the tenants are] paying the energy bills." (Researcher 2)

3.3.5 **Ecosystems**

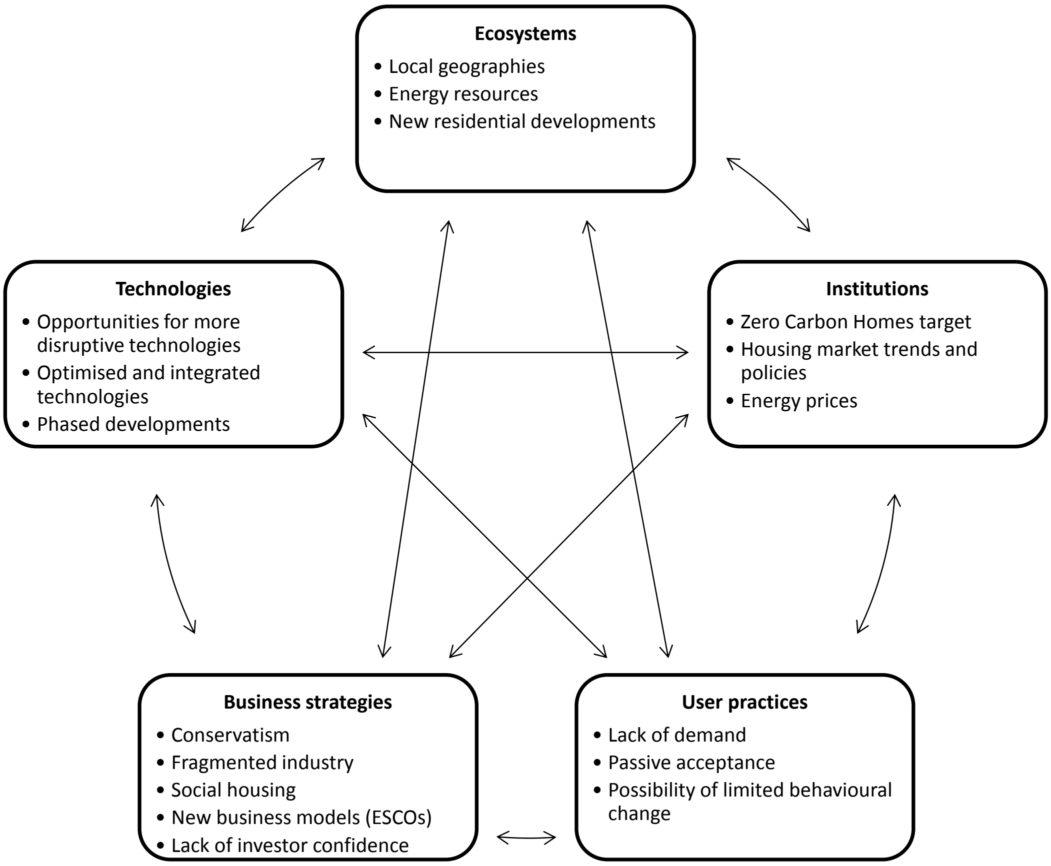
As discussed in Chapters 1 and 2, the motivations underlying many government and individual decisions on microgeneration are climate change and fossil fuel resource scarcity. In this sense then, ecosystem issues are exerting selection pressure on the chosen method of energy provision. With regards to new homes, population increase and changing demographics are the ecosystem issues driving the need for new homes.

On a smaller scale, the suitability of a particular new residential development for microgeneration will be a function of the local climate and geography. Local wind, solar, biomass and water resources will all impact on the feasibility and efficiency of the associated technologies. Given the low priority given to microgeneration by both developers and prospective buyers which has been discussed in this chapter, site selection for new homes on the basis of suitability for microgeneration seems unlikely in the near future. However, if energy prices or other external pressures were to rise to such an extent that microgeneration became increasingly desirable or even essential, this could start to be the case. In recent decades there has been increased attention to sustainability within urban planning research, with one facet being urban layouts which optimise renewable energy use (e.g. Droege (2006), Grosso (1998), Littlefair (1998), *inter alia*). If microgeneration attains dominance in the UK energy system, it may be therefore that aspects of local geographies relevant to energy resources assume greater importance in decisions around the location and design of new homes and cities.

3.4 Coevolutionary processes

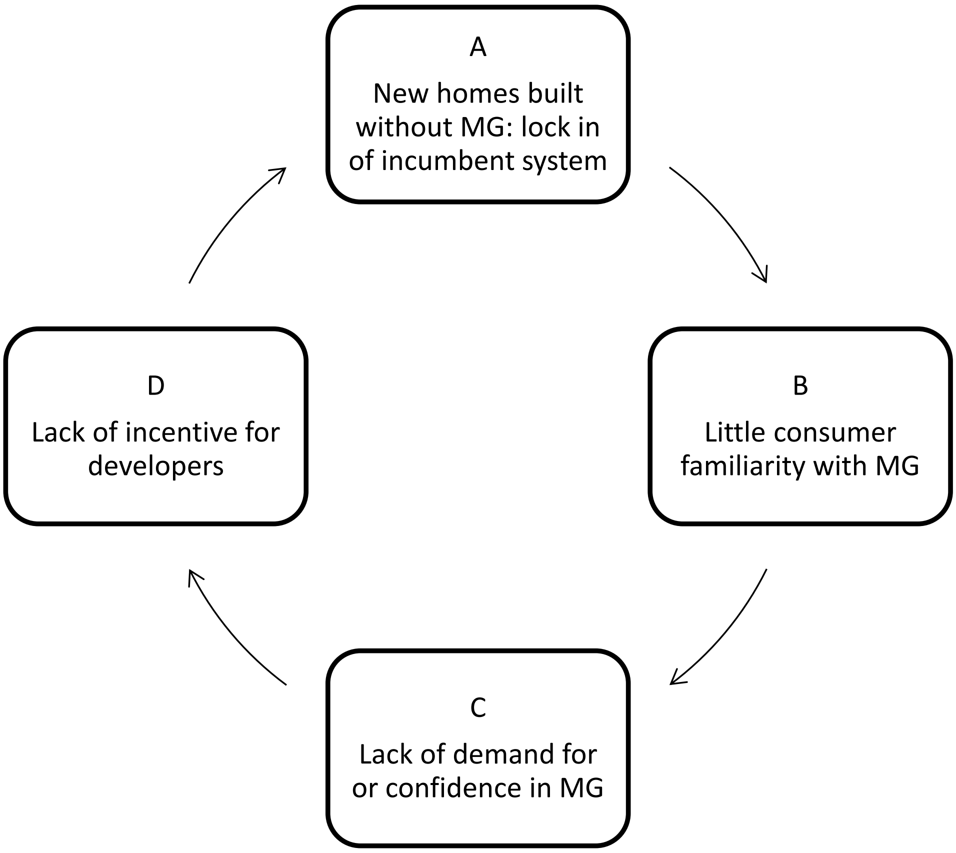
By analysing empirical data using the coevolutionary framework, the ways in which ecosystems, institutions, user practices, business strategies and technologies are mutually influencing each other to give rise to drivers and barriers for microgeneration in new homes have been identified. The key processes are summarised in Figure 8.

Figure 8. Key drivers and barriers for microgeneration in new homes



This analysis has identified a number of issues and processes which are influenced by each other in various ways. One particular ‘vicious circle’ of mutual causation has been identified, illustrated in Figure 9.

Figure 9. Coevolutionary 'vicious circle'



Since microgeneration still represents an innovation rather than a 'conventional' technology, consumer knowledge and awareness of it is lower than for conventional fossil fuel based centralised energy delivery system. User routines in home buying have not incorporated microgeneration, and it is not an 'expected' feature. Developers therefore expect little competitive advantage for incorporating microgeneration in their developments, and this is coupled with a regulatory framework that is uncertain and seemingly unlikely to be enforced. New homes are therefore built using conventional energy technologies, reinforcing lock-in of the incumbent system.

Several points in this 'vicious' circle present opportunities for it to be broken, and even to give rise to a 'virtuous circle' of development for microgeneration in new homes.

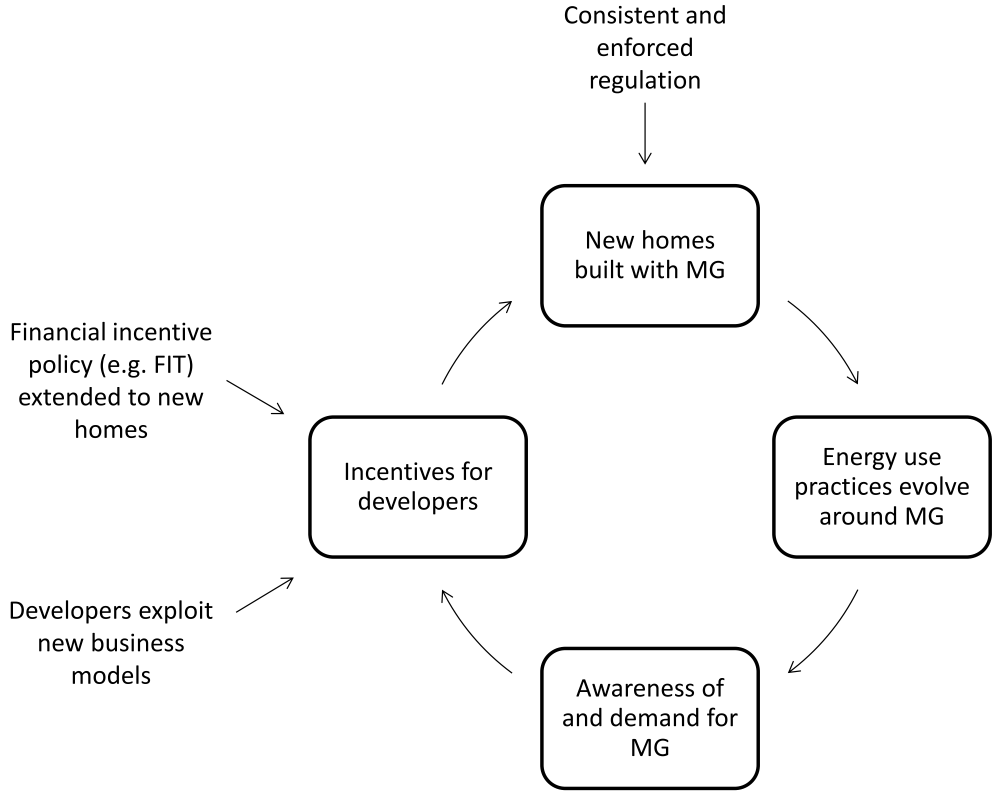
Point A in Figure 9 represents an opportunity for regulation, in particular the Zero Carbon Homes target. As discussed, regulation has the ability to 'force' developers to build to certain standards. As stated by interviewees, tightening the definitions of the policy such that allowable solutions are not favoured at the expense of on-site measures would likely give rise to need for microgeneration technologies on many new developments. This would contribute to the 'mainstreaming' of the technology, making it more visible to consumers and raising expectations about the technology through the normative mechanisms discussed in Section 2.5.1.7.

However, using policy as a 'blunt instrument' in this way is unlikely to be a strategy favoured by government as it would lead to significant opposition from industry lobby groups, and could potentially have negative impacts on the domestic construction industry. Introducing a financial incentive for developers to include microgeneration in developments (point D in Figure 9) may therefore be a more appropriate intervention. It is beyond the remit of this thesis to suggest detailed policy options, but one possibility which would fit within the existing regulatory framework would be to extend FIT payments to developers of new homes for a certain amount of time after occupancy of the house. The differential payments for different technology types offered also have the advantage of promoting diversity in technology options.

Another development which could break the vicious circle at point D is the expansion of developer activities into energy contracting, mentioned by several interviewees as a potential opportunity for the industry. This in turn has several potential impacts on user practices. Recouping costs through maintaining ownership of technologies and receiving FIT payments would allow developers to charge less for new homes incorporating microgeneration, and may increase consumer demand for them. However, relinquishing ownership and control of the technologies to an ESCO may mean that the changes in user routines and energy use behaviours predicted by many researchers do not come about. These issues are discussed in more detail in Chapter 4.

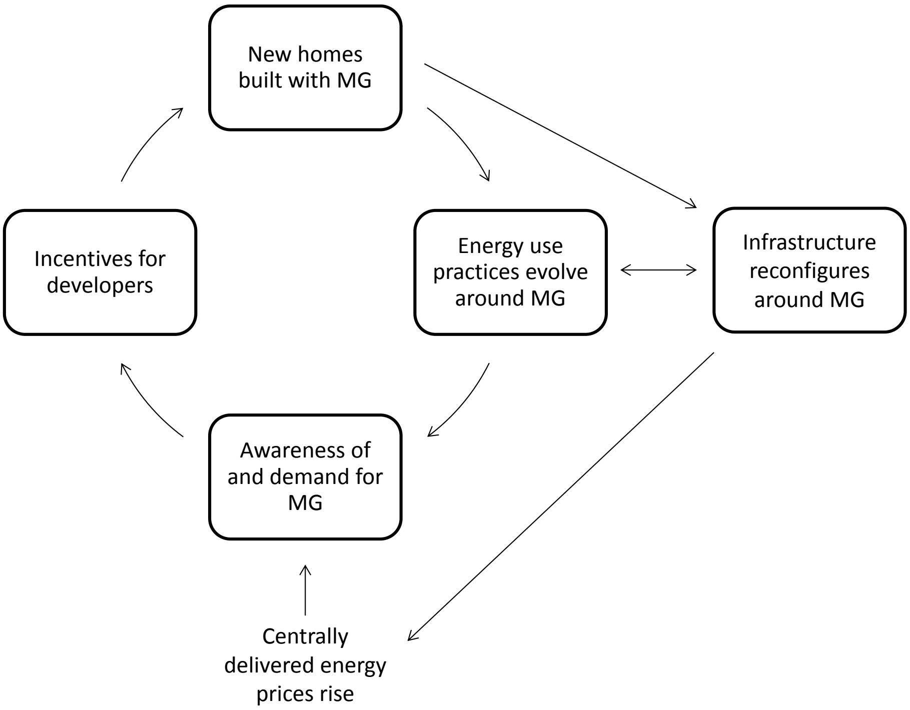
The potential for a virtuous circle of coevolution between business strategies and user practices as a result of these interventions is shown in Figure 10.

Figure 10. Virtuous circle of coevolution of business strategies and user practices



Another opportunity for breaking the vicious cycle shown in Figure 9 is the rising cost of electricity and fossil heating fuels. If the cost of centrally delivered electricity and heating fuels continues to rise, the vicious cycle in Figure 9 may be interrupted at point C. As discussed in Sections 2.5.1.2 and 2.5.1.5, independence from conventional fuels and savings on energy bills are already significant motivators for many who choose to retrofit microgeneration, and rising energy costs are likely to increase this interest and make new builds with microgeneration more desirable. This in turn will provide an incentive for developers to include it in their developments, providing returns in the form of infrastructure (or the lack of infrastructure for centralised energy delivery) and user and industry learning. This situation is illustrated in Figure 11.

Figure 11. Virtuous circle of coevolution of fuel prices, business strategies, user practices and infrastructure



It must be noted however that energy prices are a highly political issue. The rise in fuel poverty which may precede increased uptake of microgeneration technologies is socially and politically undesirable, and the government and industry would be likely to attempt to mitigate it. For example, in late 2013 and early 2014 the majority of the UK's 'Big Six' energy companies froze their prices for up to two years in response to political pressure, and at the time of writing a cap on energy prices is a planned part of the Labour party's election manifesto (Chazan and Pickard 2014).

There is also the problem that those with lower incomes who are worst affected by fuel prices are less likely to purchase their own homes. In the case of social housing in the UK however, there are already several examples of housing providers installing microgeneration to tackle fuel poverty, and rising fuel prices may encourage an increase in this practice.

3.5 Conclusions

As discussed in Chapter 2, the issue of microgeneration in new homes has been previously somewhat neglected despite a wealth of literature on the drivers and barriers for microgeneration. Previous analyses have either dealt with the issue briefly, or subsumed it into more general research on ‘eco homes’, despite the differences between microgeneration and energy efficiency measures. This chapter has used Foxon’s coevolutionary framework to analyse existing evidence in literature and new evidence from the semi-structured interviews to explore the drivers and barriers for microgeneration in new UK homes in greater depth. Important differences between retrofitting microgeneration and its inclusion in new homes have been characterised in terms of actors, barriers, drivers and opportunities; possible interventions to overcome barriers have been discussed; and areas for further research have been identified.

3.5.1 Differences between retrofit and new homes

The differences in actors, barriers, drivers and opportunities between retrofitting microgeneration and including it in new homes are summarised in Table 8. For retrofit, research has largely focused on householders as the key actors, as they make the decisions about whether to adopt microgeneration. Installers and Green Deal advisers may act as influencers of these decisions, through advice and sales pitches. For new homes, the number of decision makers is arguably much greater. Architects, building systems designers and developer project managers will decide on the inclusion and type of technology, and installers, builders and local authorities will also have input on design, planning and implementation. For new homes, the householders’ decisions are more passive than they are in the case of retrofit, though they may still be required to take on additional costs. In the case of social housing, the social housing provider will be the primary decision maker in both cases, but may have more freedom of choice regarding the technology configurations for new homes.

Table 8. Actors, barriers, drivers and opportunities for microgeneration retrofitting and microgeneration in new homes

	Retrofitting to existing homes	Incorporation in new build housing
Primary decision-makers (technology adoption, type, sizing etc.)	Home owners Social housing providers	Architects Building systems designers Developer project managers Social housing providers
Other decision-makers	Installers Green Deal advisers	Installers Builders Prospective home buyers Local authorities
Barriers	Capital cost of technology to home owners Inconvenience and disruption to home owners Normative influences on home owners Inadequate information on operation for home owners	Capital cost of technology to developers Capital cost of property to home owners (?) Development phasing (barrier to district scale solutions) Housing market (?) Inadequate information on operation for home owners
Drivers	Feed in Tariff RHPP/RHI Green Deal Building regulations (if extension/major retrofit) Financial motivations for home owners Environmental motivations for home owners Normative influences on home owners	Zero Carbon Homes target Code for Sustainable Homes Building regulations Opportunities for integrated, optimised and high involvement technologies Housing market (?)
Opportunities	Householder energy use behaviour change	Householder energy use behaviour change ESCO business models for developers

Some drivers and barriers are similar for retrofit and new homes, such as the opportunity for energy use behaviour change, and the capital cost of the technology. However even in these cases there are some differences in their impacts: for new developments, decisions around capital cost involve developers as well as householders, and the cost to householders is likely to be ‘bundled’ with the price of the house. Changes in energy use behaviour may also be different for passive adopters of the technology rather than active adopters. Other issues which are unique to new homes are the inconsistency and definition of the Zero Carbon Homes target, the nature and practices of the building industry, the options for optimised or integrated technologies in new builds and trends in the UK's housing market which affect the home-buying demographic.

It is clear therefore that overcoming barriers to microgeneration in new UK homes will require a different set of interventions than the barriers to retrofit. Analysis of the coevolutionary interactions in the relevant sociotechnical system has identified three such interventions, which may arise either 'organically' from developments in international markets, or as a result of deliberate actions by government or businesses. These are: rising energy costs, the strengthening and enforcement of the Zero Carbon Homes target, and the expansion of developer business strategies into ESCO activities.

3.5.2 **Opportunities for further research**

This research has also identified areas with the potential to impact upon the success or otherwise of microgeneration in new homes, but whose influence is currently unclear, and would benefit from further research.

Technology

Phased developments are likely to have an impact on the potential for district scale generation, due to the risks of oversizing systems, and technology advances during building leaving new developments with already obsolete generation systems. Technoeconomic modelling of different technology options, development sizes and phasing plans would allow quantification of the risks involved, and provide guidance for developers on how phasing and microgeneration or district scale technology could be managed.

Ecosystems

Mapping in-progress and planned developments along with available energy resources (wind speed, solar radiation, biomass sources) would allow an evaluation of the technical potential of microgeneration in planned UK developments. Similarly, mapping available energy resources and sites suitable for development would indicate where new developments could be sited to make the best use of local energy sources for microgeneration.

Policy

Two policy interventions have been recommended here: the strengthening of the Zero Carbon Homes target, and the extension of the FIT to developers of new homes incorporating microgeneration. Technoeconomic modelling of representative development-scale and national-scale scenarios regarding technology costs and uptake as a result of different policy options would indicate which policy measures would result in optimal environmental and economic outcomes. Similarly, a longitudinal study of the demographics of new home buyers would indicate what impact fluctuations in the housing market and policies such as Help to Buy have on the demographics of purchasers, and therefore the likelihood of acceptance of microgeneration on new homes.

Social

It was hypothesised in this chapter with evidence from Dobbyn and Thomas (2005), that an increase in the number of people passively adopting microgeneration through home purchase, as opposed to actively deciding to install, would reduce the potential benefits of microgeneration in making consumers more aware of energy use and its environmental impacts. As discussed in Section 2.5.2, evidence for changes in the amount and pattern of energy use by microgeneration adopters is currently limited and mixed. Longitudinal quantitative studies of energy use by active and passive adopters before and after adoption would strengthen the evidence base, and also provide information on whether the type of adoption is likely to make a significant difference.

Business strategies

Having concluded that the fragmented and 'top heavy' nature of the building industry is not conducive to knowledge-sharing and best practice, research into how this would be mitigated is now needed. Indeed, organisational psychology and project management researchers have long been aware of the traditionally adversarial and non-collaborative nature of the construction industry (see for example Bishop et al. (2009), Humphreys et al. (2003) and Wood and Ellis (2005) *inter alia*), and insights could therefore usefully be drawn from that area.

A significant area of opportunity for developers identified in this investigation is the possibility of expanding activities to include maintaining an on-site presence as an ESCO once building work has concluded. Theoretically, this could help developers to recoup some or all of the costs of including microgeneration in developments, ensure efficient use of the technology, and even overcome any consumer distrust of microgeneration. There are few precedents for this arrangement however, and therefore little is known about how widely this practice could be applied, or how potential home buyers might respond. The next chapter of this thesis therefore explores this area in more detail, considering whether different ownership and operation arrangements for microgeneration could help to overcome some of the barriers to its deployment in new homes identified in this chapter.

4 Can the appropriate deployment models overcome barriers to microgeneration in new homes?

4.1 Chapter overview

The previous chapter identified the unique barriers and opportunities for microgeneration in new homes in the UK. A major barrier identified was a perceived lack of demand for microgeneration technologies from consumers, who may be unwilling to pay more for new homes incorporating them. This feeds into another barrier: lack of financial incentives for home developers to incorporate microgeneration into developments. It was suggested that some developers might use the ESCO model to recover the additional costs of including microgeneration in their developments. While robust empirical evidence for the systematic failure of microgeneration technologies to increase home sale prices is lacking, the available evidence discussed in Section 2.5.3 strongly suggests that developers will not be able to count on recouping the additional costs of microgeneration through the sale price of homes. As discussed in Chapter 3, this currently means that most developers will choose the least cost options for meeting regulations, which usually excludes microgeneration. However if building regulations are enforced or tightened to the point that the inclusion of microgeneration is necessary to meet standards, increasing numbers of developers may choose to contract out to ESCOs or act as ESCOs themselves, if this is likely to help them to recoup the additional build costs.

In Chapter 3, evidence was also raised that certain features of ESCO arrangements could help to overcome consumer reluctance to adopt the technologies, and increase demand. Although there is a wealth of information available on the different models (described in Section 2.6), and on developer and consumer decisions relating to energy and homes, no studies explicitly considering how they intersect could be located in the open literature at the time of writing. This chapter therefore investigates more thoroughly the potential of different deployment models for increasing the desirability of microgeneration in new homes for both consumers and developers. The aim is to answer the third research question presented in Section 1.5: How can different deployment models for microgeneration be used to overcome barriers to the technology in new homes in the UK? One significant feature of a new development is that there are no residents prior to the energy infrastructure being installed. Unless the homes are being built by a co-operative therefore, the community microgeneration deployment model is unlikely to be used. As a result, this chapter does not consider community ownership models for decentralised energy generation.

Section 4.2 describes the methods used in this chapter. Section 4.3 discusses the technoeconomic feasibility of different microgeneration deployment models for new homes, and presents a technoeconomic analysis of the different models. Section 4.4 discusses potential householder attitudes towards the different deployment options, with Section 4.5 going into more detail on theories about innovativeness and how it might affect these attitudes. The conclusions from these analyses, and hypotheses which can be developed, are presented in Section 4.6, and topics for future work are discussed in Section 4.6.2.

4.2 Methods

4.2.1 **Literature synthesis**

Although there have been no studies making specific comparisons of microgeneration deployment options for new homes, analyses of various facets of the relevant issues have been conducted by researchers from several disciplines. A synthesis study was therefore conducted: analysing and linking previously disconnected evidence from different research disciplines in order to provide new insights into the question of how different deployment models for microgeneration could be used to overcome barriers to the technology in new homes in the UK. Given the constraints to community ownership models for new homes discussed in section 4.1 above, the analysis focused primarily on the ESCO and plug and play models.

The technique used was literature synthesis rather than meta-analysis, since statistical analysis was not used to analyse the results of previous studies. The aim was rather to explore linkages between disciplines, to conduct a 'boundary-breaking exercise' (Sherwood 1997) in order to generate new theories and understandings. In cases where there was not enough empirical evidence to draw conclusions, hypotheses were formulated on the basis of theoretical evidence.

A divergent, iterative search technique was used to identify sources for the literature synthesis. Review papers from each relevant field were used to identify key texts, which were used as starting points for further research, in order to identify the relevant strands and themes of each discipline. Literature searches focused on the central research question, exploring areas where evidence from different disciplined overlapped or were contradictory. Evidence from the following was used:

- Studies on the effects of policy and institutional conditions on ESCOs.
- Technoeconomic analyses of district heating and ESCOs.
- Statistics on residential construction in the UK.
- Academic literature on marketing, especially of 'green' products.
- Literature and theories on attitudes to different deployment models.
- Psychology literature on the construct of 'innovativeness'.

4.2.2 **Technoeconomic analysis**

A technoecomomic model was produced in Excel and used to investigate the question arising from the literature synthesis in Section 4.3 below: whether the proportion of on-site electricity generation consumed by a householder dictates which deployment model has the best economic outcome for them. The model was intended to be indicative of a 'typical' new home, rather than a detailed or specific feasibility assessment, therefore several assumptions were made and only certain technology types were modelled. The model calculated cashflow and a simple payback period using year timesteps, based on capital expenditure, feed in tariff income and savings on energy bills. A discount rate was not applied, due to the inconsistency in consumer discount rates (discussed in Section 4.4). Although this reduces the 'real life' representativeness of the results, the primary purpose of this model is to test payback period and deployment model sensitivity to variations in on-site electricity use, rather than calculate specific actual payback periods. A detailed description of data sources and calculations is provided in Appendix B. In summary, the parameters used for the model were as follows:

Household type and energy demand

Two house types were tested: detached and attached (encompassing semi-detached, end-terrace and mid-terrace). Houses rather than flats were used as the reference dwellings, since the nature of flats is such that individual-dwelling scale technologies are not always appropriate. Floor area and electricity consumption figures were taken from the Zero Carbon Hub (2009) report, *Defining a Fabric Energy Efficiency Standard*, shown in

Table 9 below (parameters for semi-detached and terraced houses are the same, hence the single category 'attached').

Table 9. House types, floor are and electricity consumption

House type	Total floor area m^2	Electricity consumption kWh/year
Detached	118	3300
Attached	76	3300

Technology choice

Solar PV was chosen as the electricity generating technology as it is more pervasive in the UK: solar PV currently accounts for over 74% of installed microgeneration capacity (AEA 2013), and is less site-specific than micro wind or micro hydro. It is also used by the Zero Carbon Hub as the basis for its calculations of an appropriate 'carbon compliance' limit for the Zero Carbon Homes target (Zero Carbon Hub 2011). The system's physical size was assumed to be 30% of the total floor area of the dwelling: the maximum considered feasible in the Zero Carbon Hub's (2011) calculations. Generating capacity was assumed to be 110W per m^2 (Ownergy 2013; SunRun Home 2012), and capital cost was calculated from the size using the Energy Saving Trust solar calculator (Energy Saving Trust 2013e). The solar calculator was also used to determine annual electricity generation, assuming a South-facing array, and using the postcode SW1 2AA (10 Downing Street in London).

Capital cost

For the ESCO scenario it was assumed that the ESCO would cover 100% of the marginal capital cost of including the generation technologies in a new home. This allows for a situation wherein the developer sets up its own ESCO operations, and there is therefore no cost sharing between developers and ESCOs. For the plug and play scenario it was assumed that the householder would cover 100% of the marginal capital cost.

Savings

For the ESCO scenario, it was assumed that energy efficiency savings accrued to the ESCO, since they are fully responsible for energy generation. However, to ensure some benefit to the householder, it was assumed that the ESCO would sell electricity to householders at 90% of the UK average direct debit tariff. The tariff information was taken from a website which aggregates price information from the major UK energy suppliers (Confusedaboutenergy.co.uk 2013). This is in line with the usual ESCO requirement to ensure competitive energy prices for their customers, discussed in Section 2.6.2, and follows Watson (2004) and Watson et al. (2006), who give 10% as an example of a typical discount.

The proportion of on-site generation consumed (at zero cost to the householder) was a variable in the model.

FIT income

For the ESCO scenario, it was assumed that the ESCO retained 100% of FIT income to offset the capital and operating costs of the technologies and transaction costs. For the plug and play model, it was assumed that the householder would receive 100% of the available FIT income. Tariff figures current at the time of analysis (2013) were used. These are shown in Table 1.

The use of a smart meter to monitor exports to the grid was assumed (rather than a deemed export tariff).

4.3 Technoeconomic feasibility of different deployment models under different conditions

This section considers the effect of the chosen deployment model on the technoeconomic feasibility of microgeneration on a new residential development. With a few exceptions (Provance et al. 2011; Watson 2004; Watson et al. 2008; Watson et al. 2006), different deployment models have rarely been compared directly in the literature. There are however a number of studies on the feasibility of ESCOs or district heating (and by extension ESCO control) under different conditions which provide insights into their applicability compared with plug and play arrangements.

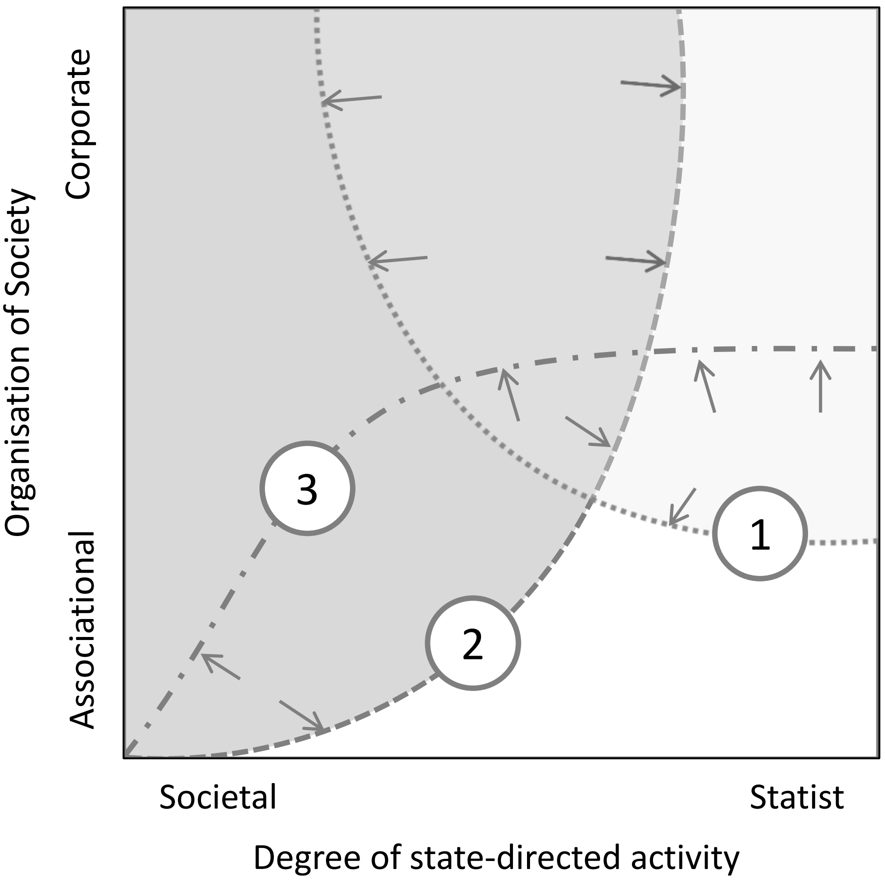
A number of interlinked factors have a bearing on the suitability of either the plug and play or ESCO model, which can be broadly categorised as institutional factors, technology choice, heat demand, type of development and electricity demand. These are discussed in turn in this section: in each case, evidence from studies which may not have explicitly compared deployment models is analysed, to either draw conclusions or develop hypotheses for future study. For electricity demand, the results of the technoeconomic modelling described above are presented and discussed. The implications of these insights for new developments in particular are considered.

4.3.1 **Institutional and political factors**

Provance et al. (2011) argue that the choice of business model for microgeneration is strongly driven by institutional factors operating at the national level. In their analysis they evaluate institutional conditions along two axes: 'statism' – the degree to which the government influences business activities; and 'corporatism' – the organisation of society with respect to property rights and power structures. Figure 12 illustrates the socio-political conditions which Provance et al. consider to favour the different business models. When corporatism and statism are high, political emphasis is on social welfare and public property rights (public rather than private ownership). Under such circumstances, government incentives such as feed in tariffs and grant programmes are likely to encourage investment in projects which increase social welfare. These conditions are considered by the authors to encourage the emergence of the community microgrid model. When corporatism is high but the degree of state-directed activity is lower, the company driven (ESCO) model will tend to emerge as free market competition allows competing service provision mechanisms to develop, while the means of generation remains publicly owned. The plug and play model is most likely to emerge where private property rights are emphasised (low corporatism) and competitive market dynamics are prevalent (low statism). In general, a more freely competitive market is found to encourage both the plug and play and the company driven model.

Provance et al. also contend that new microgeneration ventures are highly entrepreneurial and must seek 'legitimacy' within their institutional setting. They therefore name institutional and competitive isomorphism (mimicry of incumbents) as a driving factor in the formulation of microgeneration business models, particularly when free market competition dominates (when statism is low). This is closely related to ideas of lock in of suboptimal products and regimes by virtue of having developed first or gaining an early advantage by chance (Arthur 1989; Unruh 2000), discussed in Chapters 2 and 3. For the UK, whose political ideology is currently dominated by neo-liberal free market ideals, this suggests that competitive isomorphism could be an important factor in the development of business models for microgeneration. As the number of residential district scale generation schemes in the UK is currently very low (Energy Saving Trust 2011a), and most microgeneration systems are privately owned, competitive isomorphism would likely favour the plug and play model.

Figure 12. Institutional factors favouring different business models for microgeneration Reproduced from Provance et al. (2011)



1. Community microgrid
2. Company driven
3. Plug and play

Studies of ESCOs specifically have similarly found a set of external factors which are likely to encourage their formation, largely related to the formation of energy service contracts and access to compensation and financing. Vine (2005) observes that new ESCOs tend to be small start-up companies and therefore struggle to attract funding from financial institutions. Improving access to finance is therefore widely recommended (Bertoldi et al. 2006; Marino et al. 2011; Vine 2005), and some authors recommend the development of a European third party financing scheme for ESCO activities (Bertoldi et al. 2006; Marino et al. 2011). An institutional framework which is supportive of contracting (Provance et al. 2011; Sorrell 2007) and the development of national or international standardised 'off the shelf' customisable contracts are also recommended (Bertoldi et al. 2006; Marino et al. 2011; Vine 2005). Sorrell (Sorrell 2007) also hypothesised that a competitive energy market would favour the development of ESCOs. This suggests that the UK, with a centralised lending system and a privatised (though oligarchic) energy market, may provide an institutional environment appropriate for ESCO formation.

In their analyses of the economics of different deployment models in the UK, Watson et al. (2008; 2006) found that the current fiscal regime disadvantages corporate investors in domestic microgeneration. Companies can claim enhanced capital allowances (ECAs) on technologies for demand side reduction and some CHP technologies, but not microgeneration technologies such as PV and micro wind. Furthermore, ECAs are not applicable to any measures installed in homes: only ESCOs serving commercial buildings can benefit from them. Watson et al. find that allowing companies and individuals access to ECAs for domestic microgeneration would reduce payback times for both plug and play and company driven arrangements. They note however that a truly “level playing field” would also require that private individuals under a plug and play arrangement pay income tax on FIT revenue, whereas at present FIT income from systems installed by householders “to generate electricity mainly for their own home” is not taxable (HMRC 2009). In the same analysis the authors find that under both a baseline ‘business as usual’ scenario and ‘level playing field’ scenarios, payback periods for micro-wind and PV tend to be shorter for company driven models than plug and play, though the analysis is based on data from a small number of real-world sites and is therefore arguably quite site-specific.

In summary, it is unclear whether the current political and tax regimes in the UK favour the plug and play or ESCO model (or neither) more, though the fact that only 24% of PV installations (the most common microgeneration technology) are owned by ‘aggregators’ rather than individual householders (DECC 2012a) could be considered evidence in itself. Although Watson et al.’s modelling study suggested that the tax regime slightly favours the ESCO model, the UK’s political emphasis on free market operation, and competitive isomorphism/lock-in appear be giving the plug and play model an advantage at present. A useful avenue for further research in this area would be to investigate how much influence a country's political economy has on the development of different deployment models, compared with other factors such as public opinion.

4.3.2 Heat demand and district heating

Thus far, studies of the applicability of different deployment models to different developments have largely considered the choice of model as an emergent consequence of the choice of technology. In most cases district scale generation systems (which may use CHP, biomass or ground source heat pump systems) is considered almost inevitably to require an ESCO-type model due to their scale and the complexity of their operation (Boardman 2007; Faber Maunsell and Capener 2007). An exception to the need for ESCO operation would be a community-owned district scale project, of which there is a growing number in the UK (Willis and Willis 2012). However, since new build developments do not have an incumbent 'community' in place prior to their being built, this arrangement is highly unlikely to be suitable for new homes. As a result, the choice of ESCO management or private ownership for a new development may depend heavily on the economics of district heating, particularly CHP.

Heat demand is the most important 'internal' factor affecting the economics of distributed heat generation, in particular CHP. Higher and more sustained heat demand is desirable as it allows systems to run most efficiently, and in the case of CHP to generate enough electricity to be economical. The Energy Saving Trust states that as a general rule, district CHP systems should be able to run for 4,000 – 5,000 hours per annum (equating to 13 - 14 hours per day) for optimum efficiency (Energy Saving Trust 2011a).

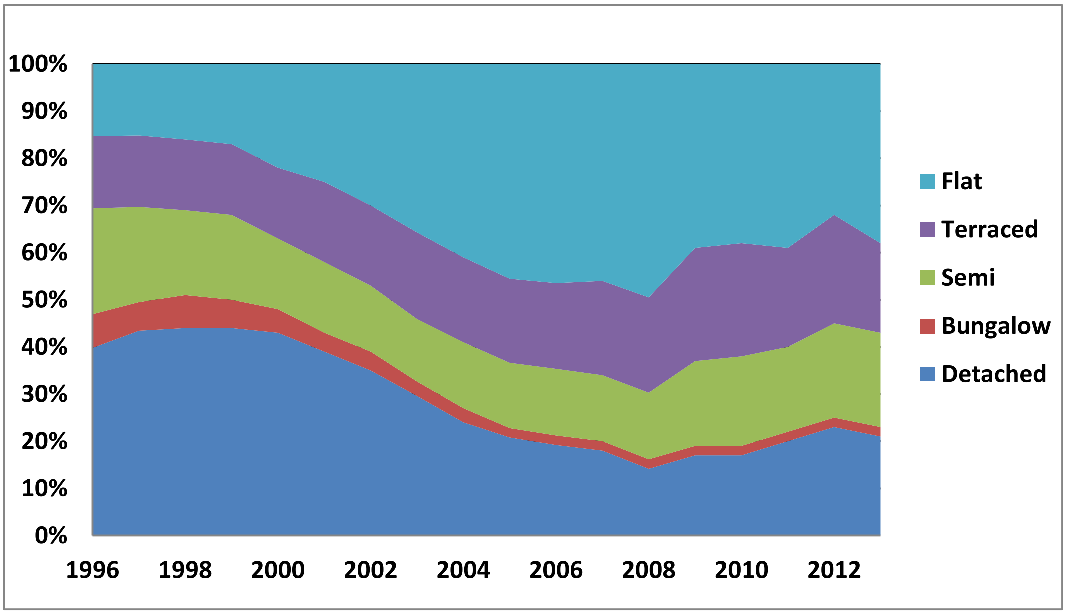
Given the importance of heat demand to the feasibility of an ESCO-run district heating system, trends in the characteristics of new homes in the UK will have a bearing on which deployment models for microgeneration are likely to be most suitable. These include the physical attributes of individual dwellings, such as fabric efficiency and size; trends in the attributes of developments as a whole, such as size and density; and other factors such as trends in the type of tenure and ownership.

4.3.2.1 Individual dwellings

As building regulations tighten progressively, new homes are built to higher standards of fabric efficiency which reduces their total heat demand. The Energy Saving Trust predicts that between 2006 and 2016 in the UK, space heating requirements will decrease by 64% for detached houses and 70% or more for flats (Energy Saving Trust 2011a). This also means that heat demand becomes increasingly driven by the demand for hot water, rather than space heating. Under Level 6 of the CSH, space heating accounts for only 30% of total heat demand for detached houses and 27% for flats; this may decline even further under future building regulations (Energy Saving Trust 2011a). Hot water driven demand profiles also tend to be much 'flatter', with a more consistent (lower) heat demand throughout the day as opposed to pronounced morning and evening peaks (Åberg et al. 2012). A more sustained demand profile with fewer peaks and troughs can be beneficial for district scale systems, due to the efficiency of continuous operation. However, reduced overall heat demand per dwelling may mean that increasing numbers of developments have insufficient total heat demand to make a district scale solution economical.

Additionally, data from the National House Building Council (NHBC) shown in Figure 13 illustrates the growing trend for new build homes to be flats, and the decreasing market share of detached houses. Since flats generally have the lowest heat demand of common dwelling types, and detached houses the largest, this trend will further reduce average heat demands for new developments.

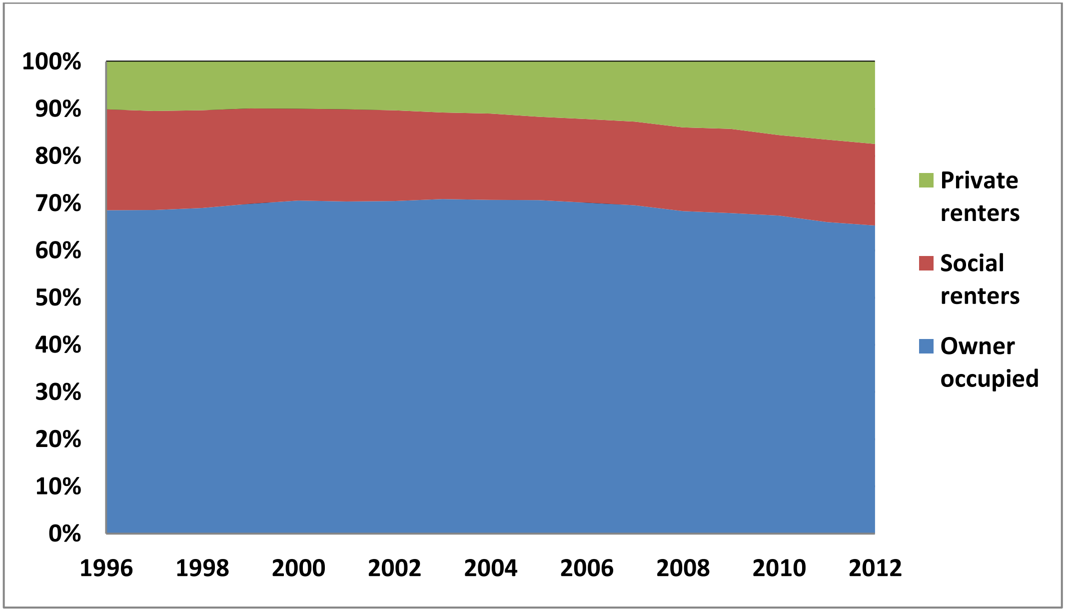
Figure 13. New homes by house type and year
Data from (NHBC 2013)



4.3.2.2 Tenure

Saxena and Hinnells (2006) state that flats represent a key market for ESCOs, as they facilitate the installation of communal generation systems. They also make the point that that flats tend to be rented, or owned under leasehold rather than freehold, with the mandatory provision of building services for a fee. This arrangement would lend itself well to provision of energy services, as any fees associated with the ESCO could be bundled with building services fees. Aside from this, the issue of tenure has been largely neglected in studies of deployment models, with most assuming owner occupation. This is often a justified assumption: in 2011 – 2012 65.3% of dwellings in England were owner occupied (DCLG 2013c). However as illustrated in Figure 14 there has been a slow but steady increase over the last decade in the proportion of private renters and a corresponding decline in the proportion of owner occupiers. Rented properties are likely to be more suited to ESCO arrangements, as the owner of the property would not directly benefit from any savings on energy bills brought about by paying upfront to install microgeneration, and may prefer to contract out any maintenance issues. Indeed, mismatched incentives between landlords and tenants are often cited as a barrier to the uptake of renewable energy and efficiency measures in rented properties (Bird and Hernández 2012; Gillingham et al. 2012).

Figure 14. Percentage of tenure types in the UK by year
Data from (DCLG 2013c)



4.3.2.3 *Dwelling density*

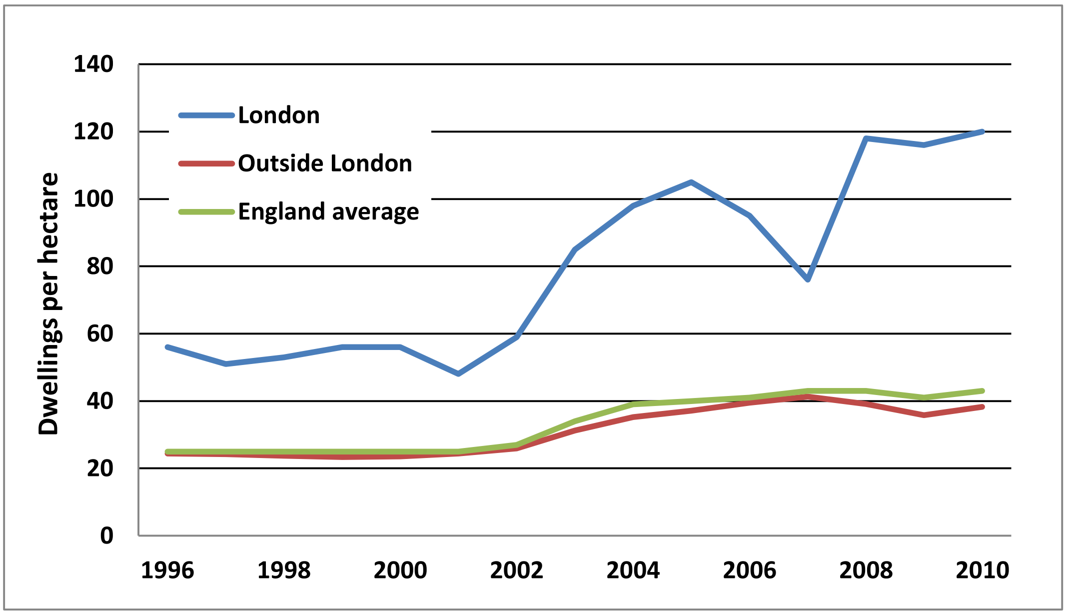
In addition to the importance of total heat demand, the high costs of heat distribution means that a key criterion for district scale heating schemes is the density of developments. The greater the dwelling density, the shorter the distance between the plant and the heat delivery points, and therefore the lower the capital and operational costs of setting up and maintaining a distribution network. The aforementioned study of district heat in Sweden found a representative minimum linear heat density requirement of 2GJ/m (Reidhav and Werner 2008). In the UK the minimum dwelling density generally considered feasible for district heating is over 50 dwellings per hectare (Boardman et al. 2005; Energy Saving Trust 2011a). This density requirement is a further reason that district heating schemes are often most suitable for blocks of flats as opposed to individual dwellings (Boait 2009; Pöyry 2009). In the UK, 89% of dwellings connected to domestic district heat schemes are flats (Energy Saving Trust 2011a) and in Sweden (where district heating is much more common) detached houses account for only 12% of the market share of district heat (Reidhav and Werner 2008).

In addition to the increasing proportion of flats being built discussed above, data for England from the DCLG (2011c), illustrated in Figure 15, show that since the turn of the millennium, average development density has been increasing steadily. This increase in average build density may counteract the effect of reduced per dwelling heat demand when district heat is considered for new developments.

Additionally the average density in London is much higher than the rest of the country. For the latter reason Saxena and Hinnells (2006) identified London as a key potential growth area for ESCOs.

Figure 15. Density of new residential developments by year

Data from (DCLG 2011c)



4.3.2.4 *Development characteristics*

As discussed thus far, heat demand is dictated in large part by the size and type of dwellings in a development, and the development's size and density. Despite new developments tending to have lower heat demand per home, a report by Pöyry (2009) suggested that large new developments could be targeted for district heating schemes as knowledge of the fabric efficiency and their size would mean a certain level of heat demand could be guaranteed. However, according to a report from 2007 by the Renewables Advisory Board[1] most new homes are built in small developments: 32% with fewer than ten dwellings, and only 15% with more than 500 dwellings. Many of these smaller developments will be likely be unsuitable for district heat: as discussed in Section 2.6.2, ESCOs can achieve economies of scale in production and transaction costs, and district heat has consistently been found to be more economical on larger sites (Energy Saving Trust 2011a; Faber Maunsell and Capener 2007). Two recent modelling studies showed a logarithmic relationship between the number of houses in a new development and the internal rate of return (IRR) of a district heating scheme (Halsey 2011; Saxena and Hinnells 2006). The Energy Saving Trust (2011a) states that at present for instance, biomass powered CHP is likely to be economical only on developments of over 1,000 dwellings.

Guaranteeing a high and sustained demand for district heat can alternatively be achieved by siting schemes on mixed-use sites which include both residential and commercial buildings which have a constant need for heat, such as swimming pools (Pöyry 2009). The UK's 2010 Community Infrastructure Levy Act allows local authorities to charge developers a fee for new developments, based on the size and nature of the developments. These fees are used for new local infrastructure, which means that new residential developments are often accompanied by new non-residential buildings. In addition, the 2012 National Planning Policy Framework (NPPF) allows local authorities to set out their own planning policies, within certain criteria identified by the NPPF. Many large sites identified by local authorities as being potential residential development sites will have planning conditions attached to them, enforced through local planning policy. These usually require developers to provide amenities such as shops, offices, leisure centres and schools, to ensure that such developments do not place a burden on existing local infrastructure. As a result of such policies, it is now common for new residential developments to be effectively mixed-use,

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[1] The report is no longer available, but is quoted in a report by the Energy Saving Trust (2011a).

increasing and flattening heat demand profiles, and making district heating a more likely option.

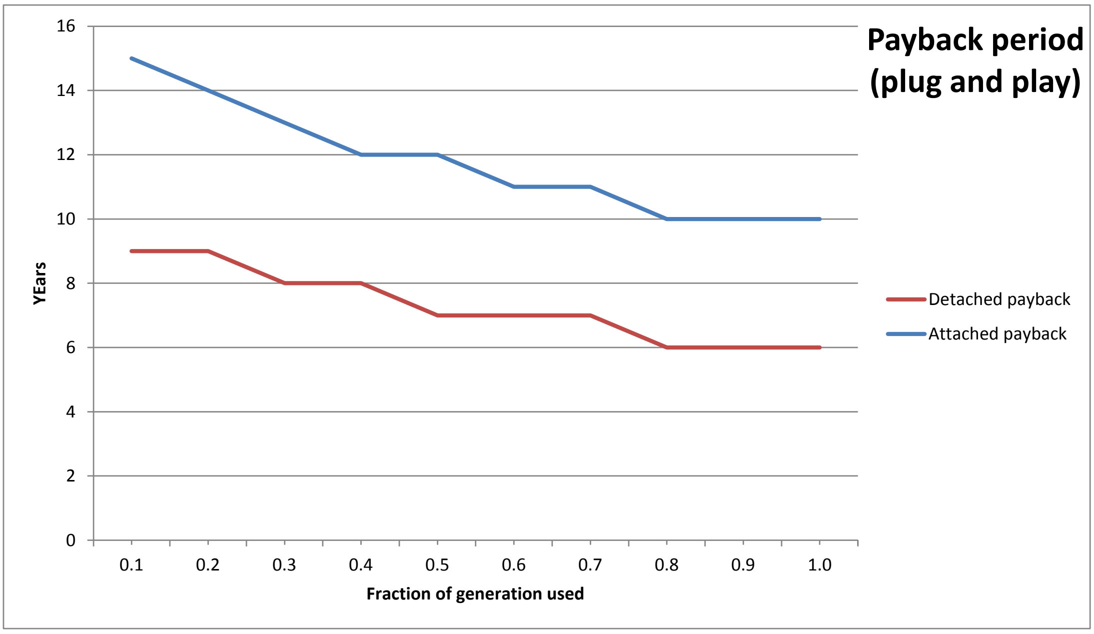
4.3.3 Electricity demand

Compared with studies of heat demand, there have been fewer analyses of the effects of electricity demand on the economics of microgeneration installations. Those that exist have either explicitly or implicitly used the plug and play model, and have shown that total household electricity demand can have a significant impact on the value of microgeneration installations to the householder. In a socio-economic analysis of PV installations in social housing schemes in South Yorkshire and the West Midlands, O'Flaherty and Pinder (2011) found that the proportion of electricity consumed on-site had a significant effect on payback periods and net present value of the installation for householders. The discrepancy was more pronounced for a scenario with no feed in tariff, but even with a modelled tariff, a 25% (absolute) reduction in the proportion of electricity consumed led to an approximately 30% decrease in net present value at every timestep. Watson et al.'s (2006) analysis of a site near Portsmouth found that one homeowner who consumed less than 50% of the electricity generated had a payback period 13 years longer than his neighbour who consumed 75%. The authors also noted that the same behaviour-induced discrepancies would occur for the electricity generated by micro CHP.

Although neither Watson et al. or O'Flaherty and Pinder discuss the implications for the choice of deployment model, it appears that householders who consume smaller proportions of on-site electricity could be better served by a contracting arrangement whereby they only pay for the electricity or energy services they use. As discussed in Section 2.6.2.3, under an EPC an ESCO could levy a monthly fee (less than the householder's previous average bill) and claim FIT payments to offset the capital cost of the microgeneration. Under an ESC, the householder could be charged at a competitive rate for the electricity they use. A development-scale microgrid arrangement whereby surplus electricity could be used by other households could also be appropriate where householder electricity demand is low. The capital and maintenance costs of the infrastructure would be higher, but more efficient use of generated electricity could mean that fewer generating systems were needed. There are however very few microgrids of this type operating in the UK: a review of the potential for microgrids in the UK found that they have significant potential to reduce emissions from the building sector, but that current regulatory frameworks are not supportive of them (Abu-Sharkh et al. 2006).

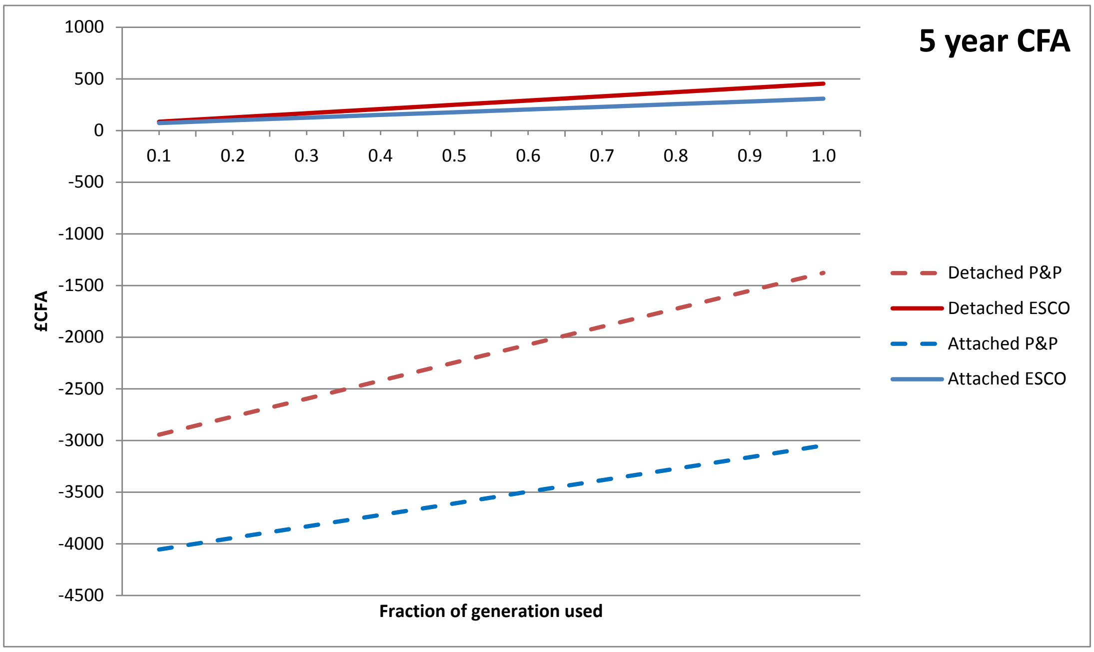
In order to quantitatively investigate the effect of differences in the proportion of on-site generation used on the payback period for householders, a technoeconomic analysis was carried out using the method described in Section 4.2.2. The results are presented below.

Figure 16. Effect of electricity consumption on payback periods for plug and play model



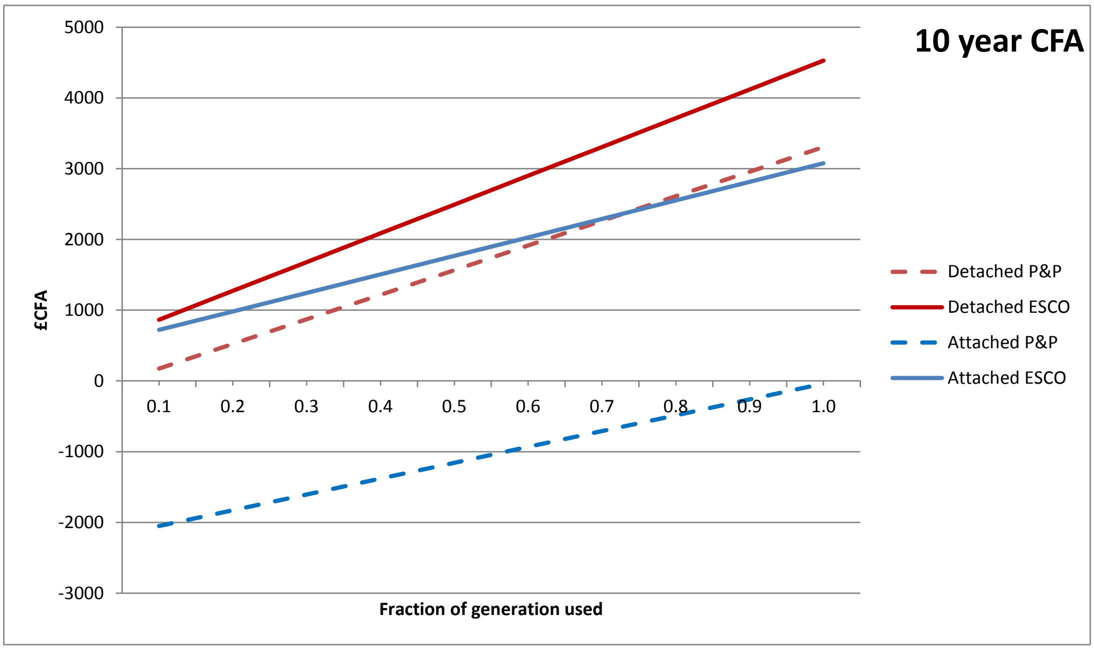
Unsurprisingly, since the export tariff for microgeneration is much lower than both the generation tariff and the average cost of electricity in the UK, consuming a greater proportion of the electricity generated on-site leads to a shorter payback period for the capital cost of a plug and play arrangement. The plateau at 80% consumption is due to the fact that this is the maximum proportion of household electricity demand that can be met by PV under the assumptions of the model. The shorter payback periods for detached houses are due to their larger size, which allows installation of a larger PV array.

Figure 17. Effects of electricity consumption on 5 year CFAs



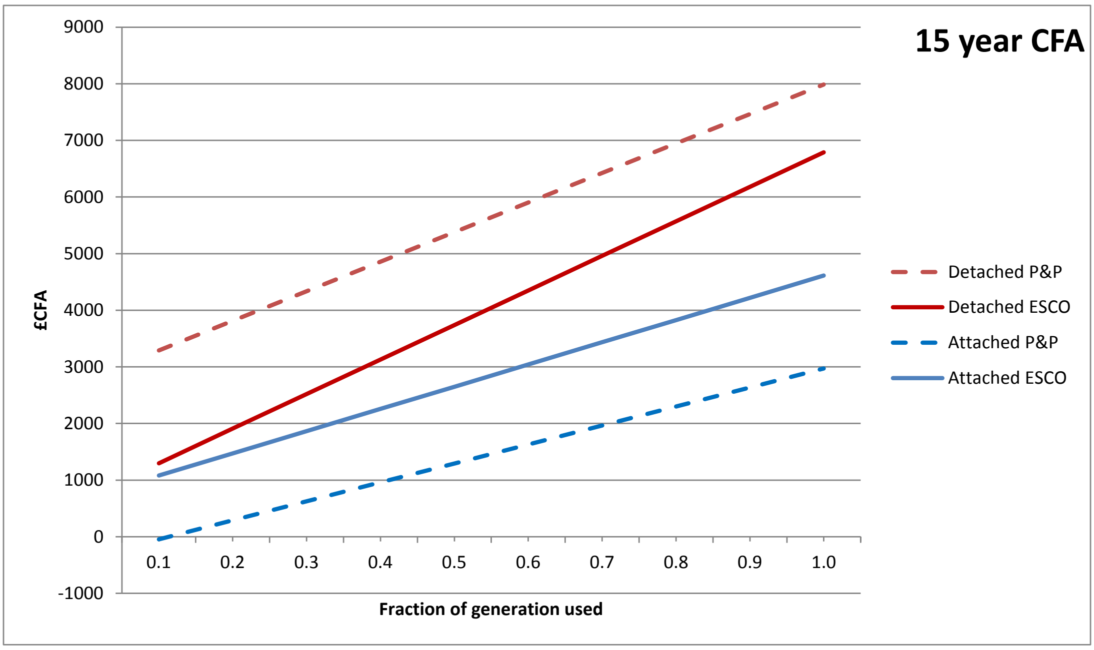
After 5 years, the initial capital cost of the PV system has not been paid back for either attached or detached houses, whereas savings made under the ESCO arrangement have accrued: with savings proportional to the amount of on-site electricity consumed.

Figure 18. Effects of electricity consumption on 10 year CFAs.



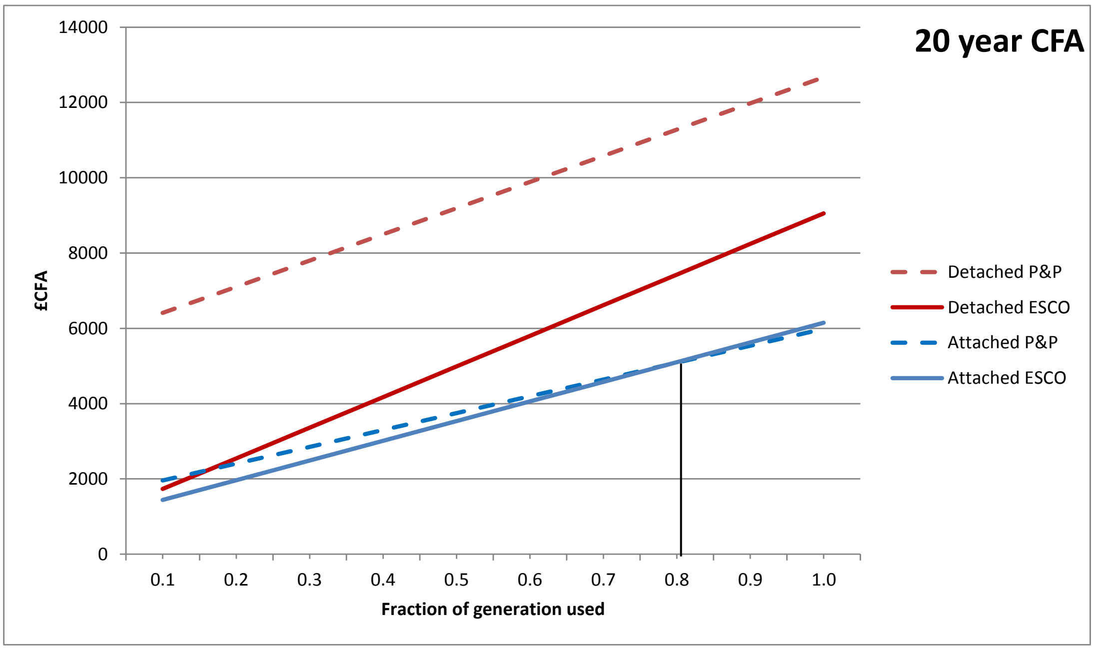
After 10 years, the initial capital cost for the detached house has been recovered and a profit is now being made, regardless of the proportion of on-site electricity consumption. For attached houses, the capital cost has not been recovered, regardless of the proportion of on-site electricity consumption. In all cases, the accumulated savings are higher under the ESCO arrangement (for a particular house type).

Figure 19. Effects of electricity consumption on 15 year CFAs



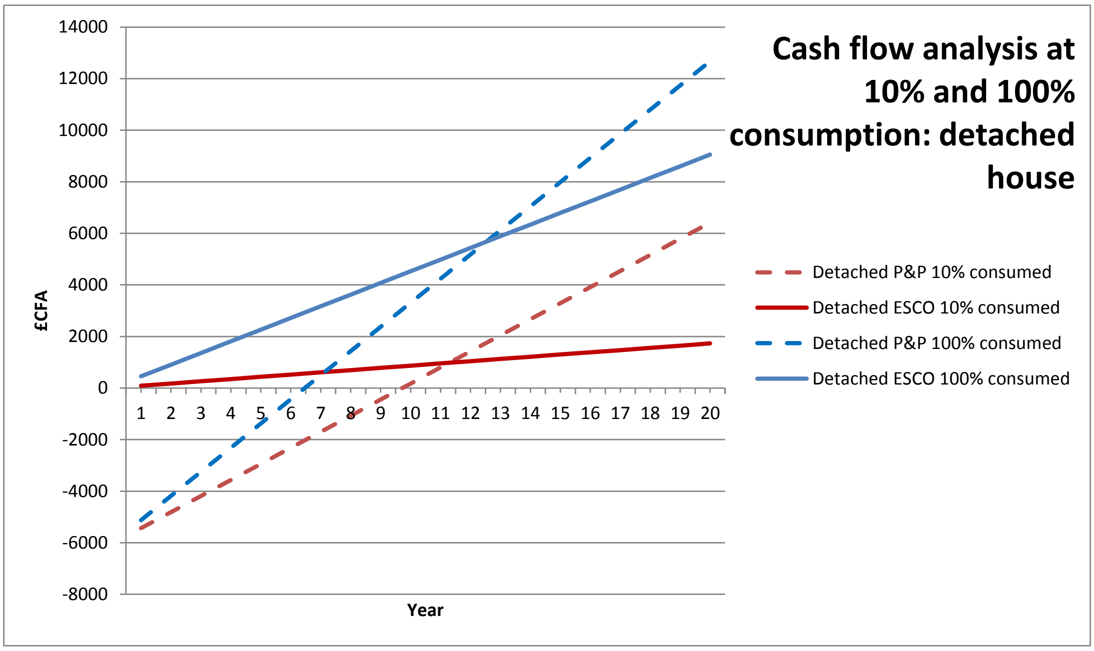
After 15 years, the capital cost of the plug and play arrangement has been paid back in all cases, except where on-site generation consumption in attached houses is less than 10%. For detached houses, the plug and play arrangement is more profitable regardless of the proportion of on-site electricity consumed. For attached houses, the ESCO arrangement is more profitable regardless of the proportion of on-site electricity consumed.

Figure 20. Effects of electricity consumption on 20 year CFAs.



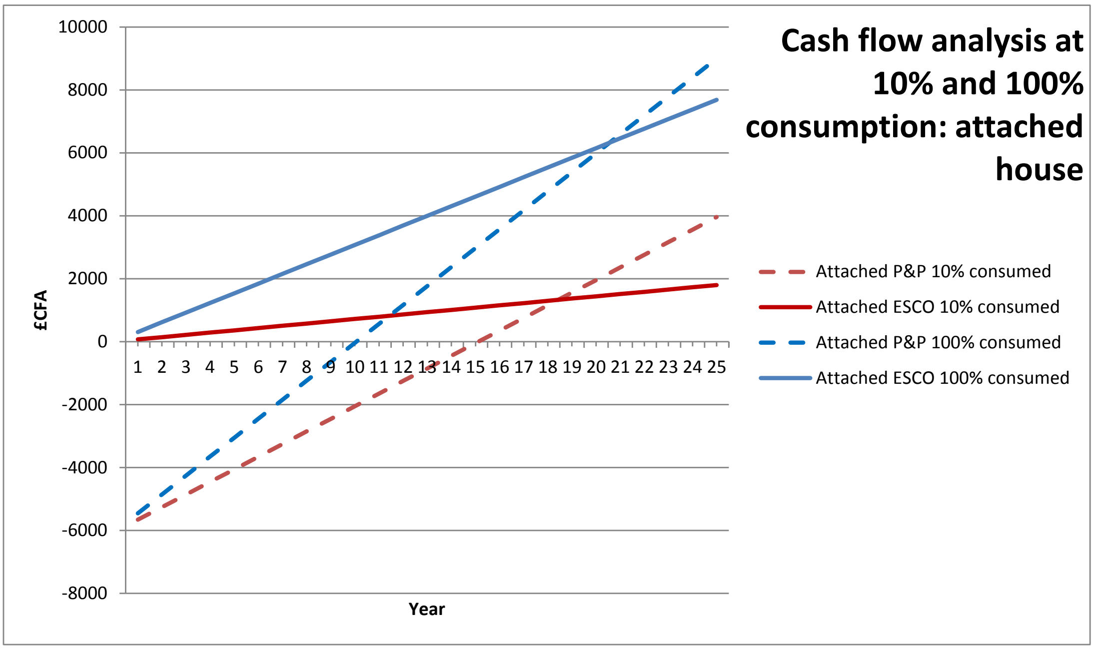
After 20 years, the plug and play model is more profitable for detached houses, regardless of the proportion of on-site electricity consumed. For attached houses, consuming over 80% of the electricity generated on site makes the ESCO model more profitable, whereas consuming less makes the plug and play model more profitable.

Figure 21. Effects of electricity consumption on cash flow for plug and play and ESCO models: detached houses



For detached houses, the point at which the accumulated savings for the plug and play model exceed those for the ESCO model varies between 11.5 and 12.5 years, depending on the proportion of on-site electricity generation used.

Figure 22. Effects of electricity consumption on cash flow for plug and play and ESCO models: attached houses



For attached houses, the point at which the accumulated savings for the plug and play model exceed those for the ESCO model varies between 18.5 and 20.5 years, depending on the proportion of on-site electricity generation used.

The proportion of electricity consumed had a smaller effect on payback periods for the plug and play model than those observed by O’Flaherty and Pinder (2011) and Watson et al. (2006). In the latter case, the introduction of the FIT in 2010 will have reduced the discrepancy, since savings and income are now driven by generation in addition to reduced imports. With regards to O’Flaherty and Pinder’s observation, the different characteristics of the dwelling compared with the modelled dwelling in this study, and the differences between their modelled tariff and current tariff rates are likely to have had an impact. Similarly, it should be noted that any future changes to the FIT, or other policy changes, would be likely to affect the outcome of the models used here. The results will also respond to differences in the capital costs of the technologies, the per unit costs of grid electricity, and different home specifications from those used here. For example, if the capital cost of PV fell, payback periods for the plug and play model would fall accordingly; and if per unit grid electricity prices fell, the ESCO scenario would become less profitable. Since the models were designed to measure the differences between plug and play and ESCO for different electricity consumption scenarios however, they can be used under current policy and tariff conditions to make some observations about the effects of different electricity consumption levels.

These results show that while electricity consumption has a significant effect on the profitability of microgeneration for householders, it has less effect on the (financially) optimal choice of deployment model. In this case, a difference was only seen after 20 years for attached houses, where consuming over 80% of the electricity generated by on-site PV yielded a greater return under the ESCO model than the plug and play, and vice versa. The main determining factor in selecting the financially optimal deployment option is the desired payback period, as the plug and play model ultimately yields more profit but returns do not exceed savings from the ESCO arrangement for 11.5 - 20.5 years, depending on house type and proportion of on-site generation consumed. These results have some significance for developers as well as householders. If a development is likely to be targeted at those who may not stay there long term (for example first time buyers, or elderly retirees), using an ESCO model would likely appeal more to prospective buyers, who could be assured of making savings regardless of their length of occupancy. For developments whose residents are likely to stay longer (for example, family homes), buyers may be willing to invest up front in a plug and play arrangement, with the assurance that their investment will yield returns in the long term. The likely levels of electricity consumption of prospective residents is less of a differentiating factor.

4.4 Householder attitudes

Thus far we have seen that the choice of deployment model for microgeneration can have a significant impact on the economic outcome of a project. However, economic feasibility alone will not be sufficient to ensure the successful deployment of microgeneration in new homes. Prospective buyers must be persuaded to choose new homes incorporating microgeneration over the alternatives available to them.

Classical economic theories assume that consumers in possession of sufficient information will make the choice which maximises their utility. Under this assumption, supplying prospective buyers with accurate information about expected savings from microgeneration would be sufficient to ensure that they chose to buy these homes (all other attributes being equal). However, there is a great deal of evidence to show that this is not the case. It is beyond the remit of this thesis to discuss theories of human economic behaviour in detail: for a detailed examination of consumers as non-rational agents see for example Sen (1977), Tversky and Kahneman (1981, 1986) and Stern (1992). In essence, it has been shown that in reality, humans do not behave as the 'rational agents' they are assumed to be in classical economic analyses. This is sometimes considered to be the result of 'incomplete information' leading to non-rational decisions (Kivetz and Simonson 2000), and sometimes other factors including social and cultural norms, moral values or individual differences (McKenzie-Mohr 1994).

In the field of energy efficiency, consumers' failure to invest in efficiency measures even when they lead to demonstrable savings is known as the 'energy paradox' (Deutsch 2010). There is limited but increasing evidence (Bull 2012) that this is due in part to the difficulty for consumers of calculating operating and lifecycle costs; a situation succinctly described by Kempton and Layne (Kempton and Layne 1994):

"Efficient market functioning requires that the consumer know the prices, quantity and quality of goods - and use that information to make purchase decisions. This may be a reasonable assumption in a retail store, where the price is marked on the shelf or directly on the product itself... retail energy purchases are very different, with price and consumption data difficult to acquire and expensive to analyse. The buyer receives energy services (light, heat etc.) but is billed via the easy to meter, but irrelevant to the buyer, measure of electron flow (kWh)."

An ethnographic study by Kempton and Montgomery (1982) found that when required to consider complex quantitative information in order to make a purchase decision, consumers rely on heuristics and informal measurements: a method the authors termed ‘folk quantification’. They found that this was the case even among consumers with a good understanding of technical energy measurement. Their interviewees consistently overestimated payback periods for energy investments, primarily as a result of failing to account for future increases in fuel prices. The smaller the initial outlay and the larger the energy reductions resulting from the investment, the less participants overestimated payback periods, suggesting that respondents were particularly averse to high upfront costs. This finding is borne out in many other studies such as Defra’s study of over 1,000 UK households (Oxera 2006) and Caird *et al*’s survey of over 500 UK households (Caird et al. 2008).

Individual consumers’ discount rates will also affect their willingness to pay upfront costs in return for profit over a period of time. Unlike company discount rates, which are usually calculated based on the cost of capital, individual discount rates have been found to be extremely variable, and may not conform to economic ‘rationality’. For example, one study of purchases of energy efficient fridges found that 60% of participants had an implied discount rate greater than 35%, which equates to a payback time of less than three years (Meier and Whittier 1983). A similar study on air-conditioning units found an average implied discount rate between 15% and 25% (Hausman 1979). Even when participants were provided with information on market interest rates and the annual interest rates associated with different payment options, in a study using monetary reward options, discount rates were calculated as 15% - 17.5%. These rates are much larger than those used by most institutions and companies: as a representative example, in 2012 Ofgem’s recommended weighted average cost of capital (WACC) for National Grid Energy Transmission was 4.55% (Ofgem 2012).

It is clearly insufficient therefore to present an economic argument for microgeneration and expect house buyers to spend extra to obtain it, especially if upfront costs are involved. While pointing out the financial benefits is vital, developers will also need to communicate the added value that microgeneration can provide for consumers, in a way that will overcome reluctance to invest upfront. The Zero Carbon Hub has recognised the importance of marketing with the publication of a strategy document for marketing zero carbon new homes, stating that "it is essential that early progress is made to understand the kinds of marketing approaches and strategies that will impact effectively on consumers" (Zero Carbon Hub 2010).

Different deployment models are starting to be recognised as potential marketing tools, adding to the perceived value of homes in various ways. As far back as 1996 Nakarado was advocating the use of ESCO-type business models as part of marketing strategies for renewable energy, predicting that "new contractual relationships and communication will be substituted for traditional uses of fuel and materials". He also urged utility companies to move beyond economic analyses, focus on the "language" they used, and conduct more sophisticated market research to identify specific consumer groups who would be most likely to pay for alternative energy sources (Nakarado 1996). More recently, Sauter and Watson (2007) suggested that "companies' marketing and involvement in the decision making process is considerably more important than mere financial incentives to attract households' investments", and advocated using the features of different deployment models as selling points for microgeneration.

It has been suggested that the ESCO model could overcome consumer reservations about using decentralised generation technologies by removing the 'hassle factor' of installation, operation and maintenance (Energy Saving Trust 2011b; Watson et al. 2008). Boait (2009) states that a service-oriented market promotes the uptake of innovations by allowing consumers to use new technologies without having to acquire significant knowledge or expertise. He draws a parallel with the telecommunications industry, which "sustains a ferocious pace of innovation by selling consumers an easy to use service that hide the extreme complexity needed in their realisation", arguing that ESCOs could promote adoption of decentralised generation in a similar fashion. Similarly, the ESCO model could overcome consumers' distrust of new technologies by protecting them from the financial risks of investment in them (Boait 2009; Sauter and Watson 2007; Watson et al. 2008).

Another potentially attractive feature of the ESCO model is the potential to increase living space by employing district heating, removing the need to have a boiler in the home (Energy Saving Trust 2011a). This could be of particular significance in new homes, since a common criticism is that new dwellings are becoming smaller and more cramped (Ipsos MORI 2012; RIBA 2013; Roberts-Hughes and RIBA 2011). Bertoldi et al. (2006) also suggested that an ESCO could represent a 'value-added' feature of energy distributors, differentiating them from an "otherwise homogeneous commodity such as electricity". And Sauter and Watson (2007) point to the ability of companies to supply upfront capital in an ESCO model, potentially overcoming the issues of high individual discount rates and consumer aversion to upfront costs discussed above.

The argument of 'function over ownership' has also been advanced as evidence for the appeal of the ESCO model. White et al. (1999) point out that in modern markets where speed, flexibility and mobility are highly valued, the function or utility of products is more important than the ownership of them; and that "the objective economic worth of products is based upon the function they deliver." A contemporary example of this can be seen in mobile phone contracts, under which the cost of the phone is bundled into monthly charges, with small or no upfront payments, and in 'car clubs' wherein people pay membership, and an hourly fee for the use of a car. However, a possible cultural preference for individual household ownership of heat generating technologies was identified in Chapter 3 of this thesis, and White et al. acknowledge that "consumer preference for ownership of certain products… is in fact deeply rooted in subjective needs for security, control, prestige and status", and that a functional view of product consumption is likely to gain more traction in business-to-business markets where financial factors outweigh considerations of prestige and status. This point is echoed by Steinberger et al. (2009) who suggest that the "high cultural value given to ownership and control of products" could discourage residential consumers from using energy service contracts. Indeed, the concepts of user control and autonomy often arise when the benefits of microgeneration are discussed. Dobbyn and Thomas (2005) described the "sheer pleasure of creation and of self-sufficiency" as a common householder response to microgeneration, and a 2006 UK study found that 22% of people who had seriously considered installing microgeneration cited self-sufficiency as a motivation (Energy Saving Trust 2007). A survey of Irish home owners found that those who believed that investing in microgeneration would make them independent from conventional fuels and energy suppliers were willing to pay more for biomass boilers and solar PV than those who did not (Claudy et al. 2011).

Despite the existence of a large body of literature on consumer attitudes towards microgeneration, much of which aims to identify the demographic and attitudinal factors affecting uptake; there have been few attempts to identify target demographics for the different deployment models available. Given the compelling – and sometimes contradictory – arguments for the features of the different models which may have a bearing on consumer attitudes, identifying which consumer groups are likely to prefer which model could prove extremely useful in marketing new homes incorporating microgeneration. For example, in his extensive study on the adoption of innovations, Rogers stated that:

"*Change agents should use a different approach with each adopter category, or audience segmentation… this strategy breaks down a heterophilous audience into a series of relatively more homophilous subaudiences. Thus, one might appeal to innovators who adopted an innovation because it was soundly tested and developed by credible scientists, but this approach would not be effective with the late majority and laggards, who have a less favourable attitude toward science.*"
(Rogers 1995/2003)

If different microgeneration deployment models are to be used to market homes to prospective buyers, the ability to predict how different consumer segments are likely to respond will be vital. While the specific 'client' for a new housing development is not known initially, developers have excellent knowledge of the local market and build according to their predictions of what local residents need and want (DCLG 2007b). If different consumer segments do differ significantly in their preferences, further questions may arise over whether consumers' preferences for a specific deployment model align with the physical suitability of the types of dwelling they are likely to buy. For example, we have seen that the ESCO model is likely to be more suitable for blocks of flats and large, dense developments, but will the target consumer segments for such developments tend towards a preference for that model?

Sauter and Watson (2007) gave significant consideration to consumer preference in a study on the plug and play and 'Company Driven' (ESCO) models. By reviewing existing surveys of consumer attitudes to microgeneration, they formulated hypotheses about which deployment models would foster the greatest acceptance of microgeneration amongst different consumer segments. Since acceptance of renewables was linked to knowledge about them, they concluded that the plug and play model was most likely to appeal to 'innovators' who have sufficient assets to invest in new technologies and who have high levels of technical knowledge. In the related *Powerhouse* study, Watson et al. (2006) stated that "[innovators and early adopters] are generally characterised by an interest in new technologies, understanding of these technologies and sufficient capital available. They will therefore tend towards the more independent Plug and Play model."

In their discussion, Sauter and Watson drew on some observations by Fischer about early adopters of microCHP in Germany. Fischer rejects the term 'innovators' in favour of 'pioneers' because: "'innovators' evokes the association of the entrepreneur and in fact denotes the inventor of some novelty [rather] than its first user" (Fischer 2004). Nonetheless, the 'pioneers' she describes are analogous to Rogers' 'innovators' in that they are among the first to have adopted microCHP. While Fischer did not explicitly consider deployment models for microgeneration, many of her observations about the motives of early adopters seem to support the theory that innovators would prefer a plug and play model. The pioneers were described as having a desire for autonomy and a high level of interest in the new technology, and as home owners who wish to express their ideas and values visibly in their homes (Fischer 2004). A later paper also described them as having high levels of perceived self-efficacy, strongly rejecting the statement that "people like me cannot do much for the environment" (Fischer 2006).

The majority of respondents in the surveys examined by Sauter and Watson believed that responsibility for decarbonisation lies with the Government and/or energy companies. As a result, Sauter and Watson hypothesised that the company driven model would appeal to the wider public (the early adopters and later adopters as opposed to innovators) by overcoming an absence of personal commitment and technical knowledge in this group. Watson et al. (2006) also considered that later adopters would be less informed about microgeneration technologies, and that they would seek to avoid 'hassle', prioritising value for money . Watson (2004) also considered energy service contracting arrangements to be generally less innovative and disruptive than the plug and play model, stating that, "micro-generation could be seen by energy companies as an extension of the status quo, with large numbers of units installed in the homes of passive consumers."

Section 2.5 of this thesis reviewed a number of quantitative studies on householders' attitudes towards the adoption of microgeneration technologies, and the links between householder characteristics and likelihood of adoption. However, no quantitative analyses of householder attitudes to different deployment models, or relationships between householder characteristics and attitudes, have been conducted thus far. This section of the thesis has discussed the importance of non-financial factors and marketing to the adoption of microgeneration technologies in new homes. Empirical evidence regarding the type and nature of relationships between householder attributes and attitudes and their choice of deployment model would therefore be valuable in inform developer decisions regarding arrangements for microgeneration in new homes, and would help to identify methods for overcoming the consumer reluctance (perceived and actual) identified as a significant barrier in Chapter 3.

Given the theoretical and qualitative evidence for the significance of 'innovativeness' as a determinant, a more specific quantitative investigation into the link between householder innovativeness and choice of microgeneration deployment model would also be of value. As discussed above (and considered in more detail in Section 4.5 which follows), likely ‘innovators’ are often identified by other demographic and personality traits, which could allow developers and marketers to predict whether prospective buyers for a development were likely to be innovators. If a link between innovativeness and deployment model preference is quantitatively measured, this would further inform marketing and communication strategies for new developments incorporating microgeneration technologies.

There is little precedent for quantitative analysis of the relationship between innovativeness and attitudes to microgeneration deployment models. While the researchers whose work informs the proposed quantitative analysis linked their definition of ‘innovators’ to Rogers’ work in many cases, a formal definition or scale for ‘innovativeness’ has not been adopted for use in this area of research. The following section therefore considers how innovativeness is measured in Rogers’ studies and in psychological research, to inform the method and develop hypotheses for the quantitative analysis described in Chapter 5.

4.5 What is an innovator?

In order to consider whether householders’ innovativeness will impact on their preference for different deployment models, it is necessary to consider what is meant by ‘innovativeness’. Innovativeness is not a simple measurable attribute such as age or income, but rather a complex abstract construct. Indeed, the research community appears to be coming towards a consensus that ‘innovativeness’ can actually be separated into three discrete constructs: a personality trait (‘innate innovativeness’), a set of behaviours (‘actualised innovativeness’, or ‘innovative behaviour’), and a construct encompassing both within a particular product domain (‘domain-specific innovativeness’). Debates and research on the nature and antecedents of the constructs and their interactions with each other and other factors are ongoing.

4.5.1 **Innovative behaviour**

Midgley and Dowling (1978) were among the first to explicitly define innovative behaviour, which they termed ‘actualised innovativeness’. Also called ‘adoptive innovativeness’ (Hirschman 1980) and ‘new product adoption behaviour’ (Rogers and Shoemaker 1971), innovative behaviour is not a personality trait, but an observable behaviour or set of behaviours. In general, innovative behaviour refers to the act of adopting new products, services or behaviours. Various operational definitions of innovative behaviour have been proposed. It has been considered in terms of new products: ownership (Im et al. 2003), purchase (Bartels and Reinders 2010; Cestre 1996; Goldsmith and Hofacker 1991) and use (Cotte and Wood 2004; Rogers 1995/2003); and in terms of the search for ‘variety’ (Steenkamp and Baumgartner 1992) or ‘novelty’ (Hirschman 1980).

A number of methods for measuring innovative behaviour have been used. In a meta-analysis of consumer innovativeness studies, Im et al. (2003) identified four main measurements: number of products owned, ownership of a particular product, purchase intentions and relative time of adoption for a particular product. The first two are known as cross-sectional methods, as they involve observation of one ‘snapshot’ of time. By contrast, the relative time of adoption method involves a time dimension and was used by Rogers (1995/2003) in what remains one of the most frequently-cited and influential characterisations of the adopters of innovations, particularly in the eco-innovation and systems innovation domains. In a study of the diffusion of innovations among Andean farmers, Deutschmann and Fals-Borda (1962b) defined five innovator categories: ‘innovators’ (highest innovativeness score), ‘early adopters’, ‘early majority’, ‘late majority’ and ‘laggards’ (lowest innovativeness score). By examining a large number of empirical studies of relative time of adoption of innovations covering a range of products, services, populations and locations, Rogers expanded the descriptions of these innovator categories, and produced an inventory of the characteristics which predict innovative behaviour. His work is notable for the number of empirical studies analysed, and the number of product, service, cultural and geographical domains it covers. His conclusions about the characteristics of the different adopter categories can therefore be considered to be highly generalisable. Sauter and Watson (2007) and Watson et al.'s (2006) propositions about the relationship between innovativeness and preference for particular microgeneration deployment models are frequently couched in terms of Rogers' innovator categories.

4.5.2 **Innate innovativeness**

Innate innovativeness, also known as 'dispositional innovativeness' (Steenkamp et al. 1999; Steenkamp and Gielens 2003) and 'open-processing innovativeness' (Joseph and Vyas 1984) is a personality trait. Unlike innovative behaviour, it is not directly observable, but is as Midgley and Dowling (1978) described it, "a function of dimensions of the human personality". Innate innovativeness is generally considered to be a predisposition that all humans possess to a greater or lesser extent.

In a review of studies and theories of innate innovativeness, Roehrich (2004) identified the four main "forces" which have been put proposed as antecedents to innate innovativeness: need for stimulation, need for novelty, need for uniqueness and independence towards others' communicated experience. All have been supported empirically with the exception of the latter (Roehrich 2004). Venkatraman and Price (1990) decomposed innate innovativeness into cognitive and sensory components: the propensity for engaging in thought, and the propensity to seek or avoid arousal based on change. Similarly, Wood and Swait (2002) developed two subscales: one measuring the need for cognition, and one measuring the need for change. They found that both factors influence innate innovativeness, but that the two subscales are not always positively correlated, suggesting that innate innovativeness may be an emergent property of multiple personality traits.

4.5.3 **Domain-specific innovativeness**

Building on research into innovative behaviour and innate innovativeness, a more recently proposed concept is that of 'domain-specific innovativeness' (DSI).

Goldsmith and Hofacker (1991) were among the first to propose the need for a new method of consumer classification that would allow the measurement of innovativeness within a specific product/service category. DSI does not explicitly describe either innate innovativeness or innovative behaviour, it is "a less abstract construct than the personality trait of innate innovativeness, but less observable than the purchase of new products" (Nyeck et al. 1996)[2]. As described by Bartels and Reinders (2011), DSI in fact attempts to capture both innate innovativeness and innovative behaviour: it "captures an individual's *predisposition* toward a product class and reflects *the tendency to learn about and adopt new products* within a specific domain of interest" (emphasis added).

Theories around DSI arose in response to criticism of the idea that innovativeness is generalisable across domains (Gatignon and Robertson 1985; Nyeck et al. 1996; Robertson and Gatignon 1986). Bemmaor (1994) stated that the fact that innovators tend to adopt new innovations in an unpredictable fashion whereas 'imitators' are more deliberate in their adoption, means that people cannot be 'innovators' across all product categories. Empirical evidence from a number of studies has borne out this theory (Gatignon and Robertson 1985), and it has therefore been suggested that DSI is a more useful measure of innovativeness for companies and researchers investigating a particular product category (Goldsmith and Hofacker 1991; Nyeck et al. 1996).

4.5.4 Interactions between personal characteristics and innovativeness

Much of the research into innovativeness has investigated the interaction between the different types of innovativeness, and other factors such as demographics. Given that the goal of many researchers is to predict behavioural outcomes, there is often an emphasis on identifying the processes which lead to innovative behaviour. For example, Midgley and Dowling (1978) proposed that new product adoption behaviour arises from the interactions between innate innovativeness, personal characteristics, social communication networks and

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[2] Translated from French by the present author.

sociodemographic variables. Similarly Spence (1994) described innovative behaviour as the result of predispositional variables (internal individual characteristics such as innate innovativeness), personal variables (demographics) and situational variables (external influences such as dissatisfaction with current products). In order to better understand the householder characteristics likely to affect choice of microgeneration deployment model, the theoretical and empirical evidence for these processes will now be discussed.

4.5.4.1 Demographic factors as predictors of innovativeness

A number of studies into the link between demographics and innate innovativeness have been carried out, with somewhat ambiguous results (Bartels and Reinders 2011). Some studies have found a negative correlation between age and innate innovativeness (i.e. innate innovativeness is lower in older people) which is not statistically significant (Clark and Goldsmith 2006; Goldsmith et al. 2006; Im et al. 2003), with one study in South Africa finding a statistically significant negative correlation (Steenkamp and Burgess 2002). Similarly, a non-significant positive correlation between income and innate innovativeness has been found in some cases (Im et al. 2003; Lennon et al. 2007), with Steenkamp and Burgess' (2002) South African study finding a significant positive correlation. Level of education has been found to have a significant positive correlation with innate innovativeness (Lennon et al. 2007; Steenkamp and Burgess 2002).

The link between demographics and DSI is also somewhat ambiguous (Bartels and Reinders 2011). The nature of DSI means that the results of a study can only be considered to apply to the domain of interest. Age has been found to correlate negatively with DSI, significantly in two studies by Goldsmith and colleagues (Goldsmith et al. 2003; Goldsmith et al. 2005) and non-significantly in another study by Goldsmith, Moore and Beaudoin (1999), all in the fashion domain. In a study of internet shopping habits in Michigan, Blake et al. (2003) found a statistically significant positive correlation between education level and DSI, while in the fashion domain Goldsmith et al. (1999) found a non-significant positive correlation. The study by Blake et al. (2003) also found a significant positive correlation between income and DSI.

The relationships between demographics and innovative behaviour are less ambiguous. Age has been found (with statistical significance) to negatively correlate with innovative behaviour in Rogers' (1995/2003) meta-analysis, a study spanning 11 European countries and 50 products (Steenkamp et al. 1999), in a study spanning 4 European countries and 301 products (Gielens and Steenkamp 2007), in Finland in the mobile telecommunications domain (Munnukka 2007), and in the USA in the consumer electronics domain (Hirunyawipada and Paswan 2006; Im et al. 2003). Many of the same studies found that income is positively correlated with innovative behaviour (Hirunyawipada and Paswan 2006; Im et al. 2003; Im et al. 2007; Munnukka 2007; Rogers 1995/2003). A study investigating the behaviour of extreme sports participants in several countries found that both age and income were positively correlated with innovative behaviour, though neither was statistically significant (Schreier and Prügl 2008). Finally, level of formal education has been found to positively correlate with innovative behaviour: by Deutschmann and Fals-Borda (1962a; 1962b) in their detailed study of Andean villagers, and by Im, Bayus and Mason (Im et al. 2003) in their study on the adoption of consumer electronics in the US.

4.5.4.2 Personality traits as predictors of innovativeness

Personality traits that have been empirically identified as antecedents of innate innovativeness include need for stimulation, propensity for novelty (Roehrich 2004; Vishwanath 2005), desire for uniqueness (Roehrich 2004) (Venkatraman and Price 1990; Wood and Swait 2002) , low risk aversion (Shannon and Mandhachirara 2008) and market 'mavenism' (Goldsmith et al. 2006) – itself a construct describing involvement, expertise and information sharing in a particular market (Clark et al. 2008). In general, personality traits have been shown to be stronger predictors of innate innovativeness than of DSI or innovative behaviour (Bartels and Reinders 2011; Vishwanath 2005). However, market mavenism has also been shown to correlate with DSI (Goldsmith et al.

2003) and innovative behaviour (Feick and Price 1987; Ruvio and Shoham 2007); and need for uniqueness has been shown to correlate with DSI (Roehrich 2004).

In his meta-analysis, Rogers (1995/2003) produced a large inventory of personality traits which correlated with earlier adoption, i.e. innovative behaviour. The inventory is shown in Table 10.

Table 10. Rogers' inventory of the personality traits of earlier adopters

Trait described by Rogers	Direction of relationship with innovative behaviour
Empathy	Positive
Dogmatism	Negative
Ability to deal with abstraction (“ability to adopt new ideas on the basis of abstract stimuli e.g. media messages”)	Positive
Rationality	Positive
Intelligence	Positive
Favourable attitude to change	Positive
Ability to cope with uncertainty and risk	Positive
Favourable attitude towards science/technology	Positive
Fatalism/low self-efficacy	Negative
Aspiration “with respect to education, status and occupation.”	Positive
Technical knowledge/skill	Positive

4.5.4.3 Social circumstances and communication behaviour as predictors of innovativeness

Much of Rogers’ work on the factors affecting relative time of adoption focused on social and communication behaviours. Two aspects of an individual’s social and communication behaviour have been consistently found to correlate with innovativeness: opinion leadership and independence from interpersonal influence. A large number of studies have empirically linked opinion leadership to innate innovativeness (Munnukka 2007); and to DSI in the computing/consumer electronics domain (Girardi et al. 2005; Goldsmith and Hofacker 1991; Shoham and Ruvio 2008; Sun et al. 2006), the fashion domain (Goldsmith and Hofacker 1991; Goldsmith et al. 2005; Jordaan and Simpson 2006), the scent/cologne domain (Goldsmith and Hofacker 1991), and in a study on DSI which allowed respondents to choose their domain of interest (Ruvio and Shoham 2007). Opinion leadership has also been identified as a correlate of innovative behaviour in several studies (Deutschmann and Fals Borda 1962a; Deutschmann and Fals Borda 1962b; Girardi et al. 2005; Hirunyawipada and Paswan 2006; Rogers 1995/2003).

The attribute of independence from interpersonal influence has been described in terms of low conformity: being "free from the constraints of the local system" and having a greater tendency to reject social norms and prejudices (Rogers 1995/2003), "[low] susceptibility to interpersonal influence (Bartels and Reinders 2011), "autonomy in innovative decisions" (Le Louarn 1997)[3] and "[low] susceptibility to normative influence" (Steenkamp and Gielens 2003). In many of these studies independence from interpersonal influence has been shown to correlate with innovative behaviour (Bartels and Reinders 2011; Rogers 1995/2003; Steenkamp and Gielens 2003), and it was also found by Clark and Goldsmith (2006) to correlate with innate innovativeness. However, this lack of 'conformity' does not mean that innovators are disconnected from their social systems. Rather, Rogers (Rogers 1995/2003) found that earlier adopters tended to be highly socially active and interconnected, but that they were more likely to have interpersonal networks outside their local social system, as well as within it. They are also more likely to engage in information-seeking behaviour and to make more use of mass media and interpersonal communication channels: considered by some researchers to be driven by the aforementioned tendency to seek novelty (Roehrich 2004; Venkatraman and Price 1990).

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[3] Translated from French by the present author.

4.5.4.4 Innate innovativeness as a predictor of DSI and innovative behaviour

Innate innovativeness has been shown to have a positive correlation with DSI (Goldsmith et al. 1995; Hirunyawipada and Paswan 2006). Its relationship with innovative behaviour is more ambiguous: while it is positively correlated with intention to purchase or use products, it has not been found to have a significant influence on actual purchase or use (Bartels and Reinders 2011; Im et al. 2003).

4.5.4.5 DSI as a predictor of innovative behaviour

DSI has been shown to positively correlate with innovative behaviour with statistical significance in a number of studies in different locations and domains including internet shopping (Citrin et al. 2000; Hui and Wan 2004), cars (Grewal et al. 2000), computers (Grewal et al. 2000), consumer electronics (Hirunyawipada and Paswan 2006; Vishwanath 2005) and food (Huotilainen et al. 2006).

4.5.5 **Summary**

The evidence considered here demonstrates the complexity of 'innovativeness' as a construct. Innovative behaviour, or relative time of adoption, is an emergent property of a host of personality traits, demographic factors and social influences; the relative importance of which may differ according to the product or service domain considered, or even the study in question.

However, some facets of the nature of innovativeness have been observed empirically across a number of domains and studies, and may therefore be stated with a degree of confidence. Some key processes are:

- Innate innovativeness predicts DSI (particular evidence for the computing/consumer electronics domain).
- DSI predicts innovative behaviour (particular evidence for the computing/consumer electronics domain).
- Age is negatively correlated with innovative behaviour.

- Income and level of education are positively correlated with innovative behaviour.

This is not an exhaustive list: as discussed there are also a number of other personality traits, social behaviours and demographic variables which interact to a greater or lesser extent with innovative behaviour as predictors, mediators, moderators or antecedents.

4.5.6 **Implications for deployment model preferences**

Returning to the predictions made by Sauter and Watson (2007) and Fischer (2004, 2006), early adoption of microgeneration can be classed either as a manifestation of generalised innovative behaviour, or of DSI in the specific domain of energy generation technology, or technologies for domestic use. Sauter and Watson state that "innovators in the field of micro-generation technologies represent a particular group of consumers with high incomes and high levels of environmental awareness." As discussed above, income has been shown to correlate with innovative behaviour, while 'environmental awareness' in this context could refer to DSI in the environmental domain, or a separate construct entirely. Fischer also describes a high level of technological interest in early adopters of CHP, which could be interpreted as DSI in the technology domain.

Neither Sauter and Watson nor Fischer explicitly mention innate innovativeness, but they do describe traits which have been shown in other studies to form part of the construct: high perceived self-efficacy, and a desire for autonomy (independence from interpersonal influence). However, the weak link between innate innovativeness and innovative behaviour discussed above suggests that DSI is likely to be a more appropriate measure of innovativeness for predicting the early adoption of microgeneration. If 'innovators' do prefer the plug and play model, as Sauter and Watson predict, some predictions about the demographic characteristics of people who would likely prefer this model can be made. Given the correlations summarised above, they would likely be younger, have higher incomes, be more highly educated, be highly autonomous and be 'opinion leaders'. With the exception of age, these are similar to those attributes found to predict adoption of microgeneration discussed in Section 2.5. The complex relationships between age, attitude, income and microgeneration adoption were also discussed in that section.

An additional issue here is that certain types of householder are also more likely to buy certain types of home, and live on certain types of development. The significant impact of dwelling and development characteristics on the economic feasibility of the different deployment models has been discussed in this chapter, and it would be valuable to identify whether any deployment model preferences by certain groups of householders align with their likely choice of home.

4.6 Conclusions and future work

4.6.1 **Conclusions**

This chapter has used technoeconomic analysis and a literature synthesis to investigate how different microgeneration deployment models – ESCO or plug and play – could be applied under different circumstances to overcome householders' reluctance to adopt the technologies on new homes, and improve economic outcomes for householders, developers and investors in ESCOs. New insights have been gained into the potential role of deployment models in increasing the adoption of microgeneration, and opportunities for further study have been identified.

The evidence considered here suggests that the judicious use of different deployment models has the potential to overcome many of the barriers to microgeneration faced by developers and prospective home buyers. However, whether a particular deployment model will be suitable for a specific new residential development will be determined by a number of interlinked forces, some of which may not be in alignment. These are summarised inFigure 23.

Figure 23. Summary of factors affecting optimal deployment model for a new development.

<table>
<tr><th></th><th>ESCO ←</th><th>→ Plug and play</th></tr>
<tr><td>Political/ institutional factors</td><td colspan="2">Centralised lending system
Competitive energy market
Competitive isomorphism</td></tr>
<tr><td>Trends in new development</td><td>Denser developments
Increasing proportion of flats
'Flatter' heat demand profiles
Increasing proportion of renters
Requirements for mixed use developments</td><td>Smaller developments
Lower per-dwelling heat demand</td></tr>
<tr><td>Householder characteristics</td><td>Short term occupation
Desire for short payback period
Less innovative
Lower income</td><td>Willingness to accept longer payback period
Long term occupation
More innovative
Higher income</td></tr>
</table>

At this stage, with deployment of microgeneration still relatively low, it is difficult to predict whether one deployment model will ultimately become more prevalent, or whether both will become more mainstream. From the analysis of the factors summarised above, it appears that current trends in new residential developments are largely likely to favour the ESCO model. It is predicted therefore that if these trends continue (along with developers' difficulties in recouping upfront costs of microgeneration through home prices) ESCO arrangements will become increasingly prevalent in new residential developments in the UK. This is not certain however, as factors such as reduced heat demand on an individual home basis and the current prevalence of the plug and play model (particularly for retrofit) are less favourable to the ESCO model.

On sites where it is economically viable, an ESCO arrangement may overcome developers' reluctance to pay for the inclusion of microgeneration on new homes, as it provides an income from the sale of energy. If theories around microgeneration adoption and innovativeness are correct, the ESCO model may also go some way towards overcoming householders' reluctance to adopt the technologies. Conversely for innovators, the plug and play model may prove more appealing.

4.6.2 **Future work**

The purpose of this chapter was to investigate further the ideas introduced in Chapter 3 about how different deployment models could overcome some of the barriers to the inclusion of microgeneration in new homes. This chapter has considered a number of different aspects in order to identify areas where more detailed study would be beneficial. As a result, some of the themes have not been explored in as much detail as possible, and some of the conclusions drawn, while supported by existing evidence, would still benefit from more detailed study.

One such topic is the 'external' factors affecting deployment models, discussed in section 4.3.1 Since the main focus of this chapter and the subsequent one is 'internal' factors, the consideration here was brief, and served mainly to provide context for the more detailed discussions which followed. Given that in the time elapsed since Provance et al.'s and Watson et al.'s study, the incumbent Government has changed, and policies have been introduced or retired, this topic would benefit from a more detailed analysis than that contained within this thesis. This would likely take the form of policy analysis, technoeconomic analysis, and stakeholder interviews, particularly with those involved in setting up and running ESCOs in the residential market.

Another area likely to benefit from further study is the prediction that new residential developments in the UK will increasingly be suitable for ESCO arrangements, due to trends identified in the characteristics of new developments and householder tenure. Further study here could focus on the details of physical characteristics (such as size, density, mix of dwelling types and location) of recent and planned residential developments, to assess the technical and economic potential for ESCO arrangements and plug and play arrangements in the near future. While this would provide valuable information for stakeholders such as DNOs, new and established microgeneration manufacturers and installers, and ESCOs, accessing data on upcoming developments may prove difficult as developers are unlikely to share economically sensitive details of their operations.

This chapter has outlined the importance of effective marketing to the uptake of microgeneration, and the role which different deployment models could play in overcoming non-financial consumer concerns about it. The issue of householder innovativeness and deployment model preference has therefore been selected as an area for further analysis in this thesis. From the analysis of existing studies in this chapter, the following research questions and hypotheses have been produced, and will be tested in the following chapter.

Which attributes of the different deployment models have the greatest effect on householders' attitudes, and which deployment model (if either) is likely to be more popular with people in the UK?

> *Hypothesis 1: The following factors will cause householders to prefer the plug and play model:*
>
> - *A desire for autonomy and control*
> - *Interest in technology*
>
> *Hypothesis 2: The following factors will cause householders to prefer the ESCO model:*
>
> - *The high upfront cost associated with the plug and play model*
> - *The 'hassle factor' of using and maintaining unfamiliar technology*
> - *Scepticism about renewable energy*
> - *Increased availability of living space in the absence of a boiler*

Do people's demographic characteristics or personal attributes affect their preferred choice of deployment model, and if so – how?

> *Hypothesis 3: DSI will positively correlate with a preference for the plug and play model over the ESCO model.*
>
> *Hypothesis4: Income will positively correlate with a preference for the plug and play model over the ESCO model.*

> *Hypothesis 5: Age will negatively correlate with a preference for the plug and play model over the ESCO model.*
> *Hypothesis 7: Level of education will positively correlate with a preference for the plug and play model over the ESCO model.*

Do consumer groups' preferences for a specific deployment model align with the physical suitability of the types of dwelling they are likely to buy?

In the next chapter of this thesis therefore, a strategy for quantitatively assessing the relationships between householder attributes, attitudes and choice of deployment model is developed, and the results reported and discussed.

5 The effects of householder characteristics and attitudes on deployment model preference

5.1 Chapter overview

All of the questions identified in Chapter 4 would benefit from further investigation. The focus will now be turned to three particular questions:

Which attributes of the different deployment models have the greatest effect on householders' attitudes, and which deployment model (if either) is likely to be more popular with people in the UK?

Do people's demographic characteristics or personal attributes affect their preferred choice of deployment model, and if so – how?

Do consumer groups' preferences for a specific deployment model align with the physical suitability of the types of dwelling they are likely to buy?

These questions have been chosen for investigation because, given the potential role of the deployment model in marketing microgeneration to prospective home buyers, an empirical investigation of the factors affecting people's preferences will provide valuable information for developers. Knowing how local markets are likely to respond to the different models would allow developers to either use this feature of a development as a selling point, or identify areas where marketing strategies will need to overcome particular reservations. Policy-makers wishing to encourage the uptake of microgeneration in new homes will also be able to use this information to inform the design of any fiscal incentives or campaigns on this issue. This chapter describes the investigation of the questions above. The methods used to collect and analyse data are presented in Section 5.2, the results of analysis are presented in Section 5.3, and Section 5.4 comprises a discussion of the results. The conclusions drawn, and potential for future work identified, are presented in Section 5.5.

5.2 Method

5.2.1 **Data collection**

In order to draw robust conclusions, an adequate sample size is required. The ideal minimum sample size (ss) for this study was calculated using a power calculation:

<u>For 95% confidence interval</u>

Confidence interval (c) = 0.05
Z score[1] = 1.96
p = 0.5 (binary choice, even spread assumption)

$$ss = \frac{Z^2 \times p \times (1-p)}{c^2}$$

$$ss = 384.16$$

<u>For 90% confidence interval</u>

Confidence interval (c) = 0.1
Z score = 1.645
p = 0.5 (binary choice, even spread assumption)

$$ss = \frac{Z^2 \times p \times (1-p)}{c^2}$$

$$ss = 67.65$$

A questionnaire, rather than focus groups or direct observation, was therefore deemed to be the most appropriate data collection method. Questionnaires allow the collection of quantitative data, and can be completed by respondents in the absence of the researcher, increasing the amount of data that can be collected in

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[1] Number of standard deviations above the mean.

a limited time frame. To ensure an adequate questionnaire response and completion rate, a balance had to be struck between parsimony and sufficient detail to make results meaningful. This was particularly challenging in light of the explanations of microgeneration and the different deployment models required for respondents to understand the questions. As a result, decisions had to be made regarding which demographic and attitudinal attributes to address in this study, as including every dimension of interest would result in an overlong questionnaire.

5.2.2 **Pilot**

The questionnaire was piloted prior to dissemination. Pilot respondents were chosen for their ability to provide detailed feedback. Five females and six males of various ages were selected. Half had previous experience with renewable energy or renewable energy research, so were able to check technical details. Half had no prior experience with renewable energy, so were able to provide feedback on whether questions could be understood by non-experts. The pilot respondents' characteristics are shown in
Table 11.

Table 11. Pilot questionnaire respondent characteristics

Age range	Gender	Familiar with renewable energy technologies/research
20 – 30	Female	No, but expert in personality testing and questionnaire design.
20 – 30	Female	No
20 – 30	Male	No
30 – 40	Female	Yes
30 – 40	Female	Yes
30 - 40	Male	Yes
30 – 40	Male	No
40 – 50	Male	Yes
40 - 50	Male	Yes
50 – 60	Female	No
50 - 60	Male	No

The pilot respondents were asked to fill in the questionnaire and answer the following questions:

- How long did it take you to complete the questionnaire?
- Were all the questions easy to understand?
- Was it obvious how to answer the questions?
- Do the choices presented make sense? Was there enough information to allow you to choose between them?
- Were you upset or annoyed by any of the questions?

Changes to the questionnaire script in light of comments from the pilot respondents are detailed in the relevant sections below. The full final questionnaire script is reproduced in Appendix B.

5.2.3 **Capturing demographic information**

As discussed in Section 4.4, the interactions between demographic variables, personality traits and social context which give rise to innovative behaviour are extremely complex, and in some cases ambiguous. In the interest of parsimony, it was decided that demographic factors which have been reliably shown to correlate with innovative behaviour would be included: age, level of education and income. These have all previously correlated with innovative behaviour individually and collectively in previous studies. A question on gender was included to assess the representativeness of the sample.

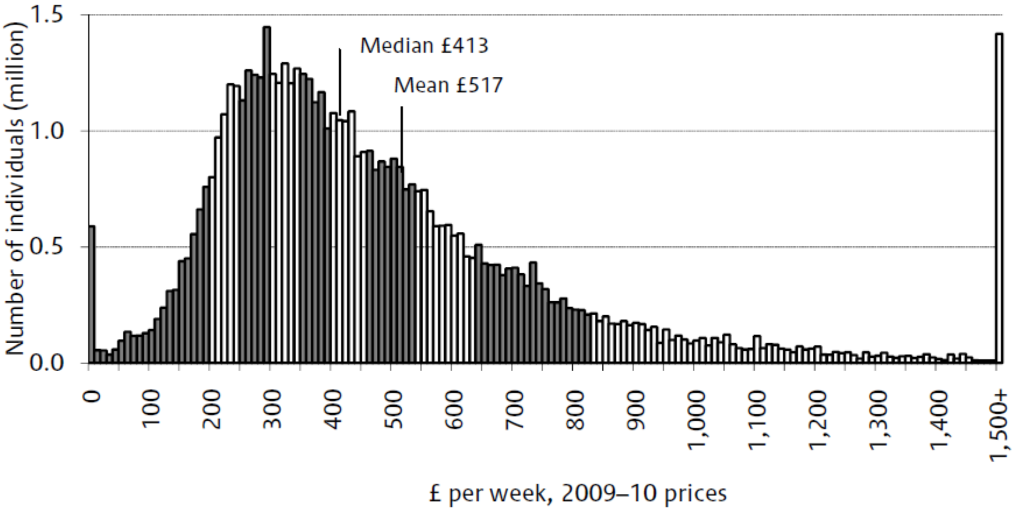
Since income is often considered a sensitive subject in the UK, many questionnaires allow respondents to choose from a list of income bands rather than entering their exact income. However, in this instance respondents were asked for the exact figure. As shown in Figure 24, the distribution of incomes in the UK has a positive skew with a long tail. A large percentage of UK incomes fall within a fairly narrow range. As a result, banding incomes would result in a very large margin of error and excessive 'smoothing' of the variation in incomes. Since income is one of the research variables, this would negatively affect the usefulness of the results. Having bands small enough to reduce this error significantly would entail the use of ranges so small as to render the point of them obsolete. In addition, the long tail on the distribution means that a very large number of options would then be required to capture the true range of incomes, making this question very long and potentially irritating or confusing for participants.

A question on other household members was included, asking respondents to indicate whether they lived with a partner, other non-spousal adults, children over 14 or children under 14. This stratification was intended to provide the means for calculating a measure of equivalised income, based on household composition. However, after the dissemination of the questionnaire it became apparent that the question on income did not capture total household income in cases where occupants did not share finances. The equivalised measure was therefore invalid, and was not used in the final analysis.

In order to address the question of how householder preferences for different deployment models align with their dwellings' suitability, a measure of urbanisation was desired. This could be achieved using postcodes and a mapping tool, but this method would be labour intensive and also highly subjective since assessments would need to be made visually. An existing open-source consumer segmentation system was therefore used: the MOSAIC UK tool published by Experian. MOSAIC UK was selected because it assigns an urbanisation ranking (from 1 – 15) using only a postcode (requiring only one question) and is free to use, subject to the disclaimer detailed in Appendix C. A drawback of this method is that the resolution of the data used by Experian is not specified. However since GIS resources were not available, this method was judged to be the most suitable alternative.

Figure 24. Distribution of equivalised net incomes in the UK, 2009 – 2010

Source: Institute for Fiscal Studies (2011)



5.2.4 Capturing deployment model preferences

To elicit a stated preference from respondents for either the ESCO model or the plug and play model, two hypothetical scenarios were presented. Respondents indicated their choice of deployment model using a five point Likert scale. This allowed measurement of the direction and strength of preference, and included an option for no preference. To avoid any premature judgements by respondents, the scenarios were not given descriptive names, but called 'Option 1' (the plug and play option) and 'Option 2' (the ESCO option).

The scenarios were constructed to be as representative as possible of a 'real world' choice. This meant that judgements had to be made about how much information prospective homes buyers would receive, and what a 'typical' arrangement would include in terms of technology, contract scope and financing. The two scenarios also had to adequately represent the significant differences between the two types of deployment model. As a result, the scenarios represented opposite ends of a spectrum of choices, rather than every possible option available.

5.2.4.1 Technology

An explanation for the choice of CHP and solar PV as the generating technologies is given in Section 4.2.2. For the ESCO model, a district heating scenario was described (as opposed to household level CHP units in a microgrid), with the plug and play model described as having an individually operated unit in each household. These are not the only arrangements available, but represent the two ‘extremes’ of the options, making the choice between the two more explicit. It also allowed assessment of respondents’ attitudes to sharing energy generation technologies.

5.2.4.2 Contract scope

The aforementioned strategy of creating scenarios which emphasised the differences between the two types of deployment model extended to the description of the contract scope. For the ESCO scenario, an ESC arrangement was described, with the ESCO owning the microgeneration, and having full control over operation and maintenance as long as they provided the contractually agreed service to the householder. The householder would not be able to switch contracts. The only involvement by the householder was in having solar panels on the roof, and a thermostat in their home. In the plug and play scenario, the householder was described as taking full responsibility for the operation and maintenance of the technologies.

5.2.4.3 Financing

Costs, savings and income for the scenarios were calculated as follows. Only costs and benefits for the householder(s) were stated, as costs to the developers and the ESCO would not factor into a home buyer’s decision.

FIT income

For the ESCO scenario, it was assumed that the ESCO retained 100% of FIT income to offset the capital and operating costs of the technologies and transaction costs. For the plug and play model, it was assumed that the householder would receive 100% of the available FIT income. Annual householder income for the plug and play scenario for both technologies was calculated as £1043 using figures from the Energy Saving Trust's 'Cashback Calculator' tool (Energy Saving Trust 2013b). The parameters entered into the tool are the same as those used by the Zero Carbon Hub for a 'reference' semi-detached or end terrace house (Zero Carbon Hub 2011), assuming a build date in 2013. Parameters for a semi-detached house were used as approximately equal numbers of terraced, semi-detached and detached houses are built each year (see Figure 13) and semi-detached therefore represents the 'midpoint' for energy consumption, efficiency and size. The Energy Saving Trust tool was used as it is freely available, and is the type of source which prospective buyers may be directed to if seeking information on energy. This therefore helps to fulfil the aim of presenting a plausible choice for respondents.

Bill savings

For the ESCO scenario, it was assumed that energy efficiency savings accrued to the ESCO, since they are fully responsible for energy generation. However, to ensure some benefit to the householder, it was assumed that the ESCO would sell gas and electricity to householders at 90% of the UK average direct debit tariff. The tariff information was taken from a website which aggregates price information from the major UK energy suppliers (Confusedaboutenergy.co.uk 2013). This is in line with the usual ESCO requirement to ensure competitive energy prices for their customers, discussed in Section 2.6.2. Using the fuel consumption figures from the Zero Carbon Hub for a semi-detached or end terrace house resulted in an annual saving of £145. The bill savings for the plug and play model were included in the FIT income figures obtained from the Energy Saving Trust tool stated above.

Capital costs

For the ESCO scenario it was assumed that the ESCO would cover 100% of the marginal capital cost of including the generation technologies in a new home. This allows for a situation wherein the developer sets up its own ESCO operations, and there is therefore no cost sharing between developers and ESCOs. For householders under the plug and play scenario, installed costs tend to be very variable, but reported average marginal costs of the technologies and their installation were found to be £7,000 for a solar PV installation (Energy Saving Trust 2013f) and £3,000 for CHP (Baxi 2012), for a total marginal capital cost of £10,000.

Operating costs

For the ESCO scenario it was assumed that the ESCO would cover the operating costs of the technologies. For the plug and play scenario, it was stated that the technologies would need to be serviced, but costs were not specified. CHP units cost roughly the same to service as conventional condensing boilers (Baxi 2012), therefore the marginal cost should be close to zero. Solar panels require cleaning only, and respondents were informed that they could undertake this task themselves, or pay someone to do it. Since the cost of commercial cleaning is so variable, a representative cost was not included as the risk of inaccuracy biasing results was too high.

ESCO fee

With the exception of 'rent a roof' schemes, which do not fall under the ESC arrangement assumed here, there are currently very few ESCOs in the UK which serve domestic properties, and prices are variable depending on the level of service agreed upon in the contract. There was therefore insufficient information available to calculate a 'typical' ESCO fee which might be levied on homeowners. Given the modest annual savings calculated for the ESCO scenario, a heuristic value of £10 per month was included to represent the situation of paying monthly for ESCO services. There is no ESCO involvement in the plug and play scenario therefore no fee.

The calculated costs and savings for the two scenarios are summarised in Table 12. In summary, Option 1 requires the householder to pay the upfront cost of the technology, which they then recoup through the use of free electricity from the PV (saving on energy bills) and FIT payments. There is no ESCO involvement. Option 2 requires no upfront payment from the householder: they do not receive FIT payments and pay a monthly fee, but do benefit from a 10% discount on their energy bills. The ESCO pays the upfront cost of the technology, which they then recoup through FIT payments and the monthly fees paid by householders.

Table 12. Summary of scenario options

Option	Cost	Savings
1	£10,000 one off capital cost	£1043 per year
2	£10 per month	£145 per year

The scenarios and the Likert scale were presented twice. The first time, no financial information was included, and respondents were told to assume that the cost was exactly the same as buying a new house with conventional energy technologies. The second time, cost, savings and income figures were included and respondents were asked to make the choice again in light of the additional information. The aim of this was to gauge the importance of economic factors in people's decision, relative to other factors.

5.2.5 Characterising the factors influencing preferences

Potentially attractive or unattractive features of the different deployment models for householders were discussed in Section 4.4. From the review there, the main features were identified and statements formulated to describe them. Questionnaire respondents were asked to choose a number from one to five (1 = very important, 5 = very unimportant) to show how important each statement was when making their choice between the two options. The statements and the reasons for their inclusion are shown in Table 13.

An optional textbox was provided in the questionnaire for respondents to add any other factors they had considered which may have been omitted.

Table 13. Questionnaire statements on reasons for deployment model preference.

Feature	Sources	Statement(s)
ESCO model could overcome consumer distrust of new technologies by protecting them from the financial risks of investment.	Boait (2009) Sauter and Watson (2007) Watson et al. (2008)	"I'm sceptical about newer energy technologies: I'd prefer not to invest my own money in them"
Ability of companies to supply upfront capital in an ESCO model could overcome consumer aversion to upfront cost.	Sauter and Watson (2007)	"I would prefer to spread the cost of the energy technologies over monthly payments rather than pay the full cost upfront"
ESCO model could overcome consumer reservations about using decentralised generation technologies by removing the 'hassle factor' of installation, operation and maintenance.	Energy Saving Trust (Energy Saving Trust 2011b) Watson et al. (2008)	"I would prefer not to have the effort involved in maintaining my own energy generation technologies"
Potential to increase living space by employing district heating, removing the need to have a boiler in the home.	Caird and Roy (2010), Energy Saving Trust (2011a)	"Not having a boiler in the home increases the space available for me to use (e.g. more kitchen cabinet space)"
Desire for ownership/reluctance to relinquish control.	Steinberger et al. (2009) White et al. (1999)	"I would prefer to own my own energy generation technologies rather than have a company own them" "I don't like the idea of sharing my boiler with other people" "I would prefer to own my own energy generation technologies rather than have a company own them"
Lack of information and understanding about the technologies, or conversely technological interest.	Fischer (2004, 2006) Watson et al. (2006)	"I'd be worried about using newer energy technologies myself: I'd rather have an expert do it"

5.2.6 Measuring innovativeness

A measure of innovative behaviour was not included in the questionnaire for two reasons. Firstly, the aim is not to investigate whether innovative behaviour predicts preference for one deployment model over another, but rather whether a preference for the plug and play model can be considered a form of innovative behaviour: seen in those whose traits predispose them towards innovativeness, and who may have engaged in innovative behaviour in other areas. Secondly, the techniques available to measure innovative behaviour are not suitable in this case. The cross-sectional methods described in Section 4.5.1 have been criticised for relying on sometimes arbitrary lists of items which are formulated by individual researchers (Goldsmith and Hofacker 1991). The unique nature of microgeneration – it does not easily fit into a genre such as 'consumer electronics' – would also make producing a list of products prohibitively difficult. The relative time of adoption technique is a post hoc method and is only effective when an innovation has been widely adopted within a social system, which is not the case for microgeneration.

Instead therefore, a measure of DSI was included. As discussed in Section 4.5.3, DSI can describe innovativeness in a particular domain more effectively than global measures of innate innovativeness or innovative behaviour. It has also been shown to be a strong predictor of innovative behaviour (stronger than innate innovativeness), both individually and collectively along with the demographic factors also measured in this questionnaire. DSI was measured using Goldsmith and Hofacker's scale, developed in 1991. The scale consists of the six items shown in Figure 25, with respondents choosing from a five point agree/disagree Likert scale for each.

Figure 25. Goldsmith and Hofacker's Domain Specific Innovativeness Scale

1. In general, I am among the first (last) in my circle of friends to buy a new _________ when it appears.
2. If I heard that a new ___________ was available in the store, I would (not) be interested enough to buy it.
3. Compared to my friends I own a few of (a lot of) _________.
4. In general, I am the last (first) in my circle of friends to know the titles/brands of the latest _________.
5. I will not (I will) buy a new _________ if I haven't heard/tried it yet.
6. I (do not) like to buy _________ before other people do.

Two versions of the scale were validated by Goldsmith and Hofacker (Goldsmith and Hofacker 1991): version one in which items 1, 3 and 4 are negatively worded and scored, and version two in which items 2, 5 and 6 are negatively worded and scored. Version two was used for this questionnaire. For item 5, the 'tried' wording option was used rather than 'heard', as the latter applies to questionnaires on music. Feedback from several pilot respondents was that item 5 would be more easily understood if worded as "I will not buy a new _________ if I haven't been able to try it first". As this does not change the meaning of the item, the scale used in the questionnaire used the new suggested wording. The order of the items was randomised for each respondent to avoid question order bias.

Goldsmith and Hofacker's scale was chosen for reasons of parsimony and validity. Comprising only six items, the scale is considerably shorter than other similar scales, such as Manning, Bearden and Madden's 1995 Consumer Innovativeness scale which has 14 items and two dimensions, or Leavitt and Walton's 1975 Openness of Information Processing scale which has 24 items. A shorter scale was preferred to reduce respondent fatigue and attrition rates.

Construct validity has been demonstrated, and the chosen scale has been found to be reliable, unidimensional, and to have nomological validity in several studies, as shown in Table 14. International validity has been shown in the US, Canada and France, though internal reliability failed in Israel (Nyeck et al. 1996). The scale had not previously been used in the UK, therefore this study incidentally serves as an internal validity test for Goldsmith and Hofacker's scale in the UK. However, validation in other Western countries suggested that the scale would also be suitable for use in the UK.

The only validated way to measure opinion leadership is by using a construct scale consisting of several questions. Since two versions of the DSI scale were included in the questionnaire, it was judged that adding another scale would increase respondent fatigue and attrition, so opinion leadership was not measured in this study.

Table 14. Validation of Goldsmith and Hofacker's (1991) measure of DSI

Study	Sample(s)	Country	Domain	Reliability	Construct validity	Nomological validity	Unidimensional
Goldsmith & Hofacker (1991)	146 men, 129 women, mean age = 21.5 years (students)	US	Rock music	Yes Alpha coefficient = 0.83 Correlation between positively and negatively scored items = -0.67 (p<0.001)	Scale positively correlated (p=0.001) with six criterion measures: • Awareness of eight selected records. • Purchase of eight selected records. • Reading and subscribing to rock music magazines. • Number of record store visits. • Listening to rock music 'Top 40' chart. • Watching MTV.	Scale positively correlated (p=0.001) with King and Summers (1970) opinion leadership scale.	Yes

	97 women, mean age = 22.1 (students)	US	Fashion	Yes Alpha coefficient = 0.82 Correlation between positively and negatively scored items = -0.70 (p<0.001)	Scale positively correlated (p=0.001) with the six criterion measures above.	Scale positively correlated (p=0.001) with King and Summers (1970) opinion leadership scale.	Yes
	225 men, 237 women,(age range 24 – 60	US	Fashion	Yes Alpha	Correlation with sum of new fashions owned = 0.41 (p=0.001)	-	Yes

				coefficient = 0.79			
	225 men, 237 women, age range 24 – 60	US	Electronic equipment	Yes Alpha coefficient = 0.81	Correlation with sum of new electronic products owned = 0.46 (p not given)	-	Yes
Goldsmith & Flynn (1992)	135 women, age range 20 – 77, mean age = 39.1	US	Fashion	Yes Alpha coefficient = 0.73	-	-	-
Flynn & Goldsmith (1993a)	98 women, 82 men, age range 21 – 80,	US	Holidays	Yes Alpha	-	-	Yes

	mean age = 48.3			coefficient = 0.79			
Flynn & Goldsmith (1993b)	129 men, 118 women, age range 19 – 27, mean age = 21 (business undergraduate students)	US	Rock music	Yes Alpha coefficient = 0.84 Correlation between positively and negatively scored items = -0.72 (p not given)	Scale positively correlated with a three item perceived product knowledge scale adapted from Beatty and Smith (1987) and Ventakraman (1990), two item-matching tests measuring actual product knowledge, a generalised measure of item search behaviour adapted from Beatty and Smith (1987), monthly amount spent on rock records and estimated weekly time spent listening to rock music.	Scale positively correlated with purified (three item) King and Summers (1970) opinion leadership scale as revised by Childers (1986) and Zaichowsky's (1987) revised Personal Involvement Inventory.	Yes

Nyeck et al. (1996)	275 university students: 53% male, mean age 21.5	France	Cinema	Yes Alpha coefficient = 0.7	Correlation with measure of frequency of cinema visits = 0.427 (p<0.0001)-	Strong positive correlation between scale and measures of: • Tendency to seek out new and unknown sensations. • Variety seeking. Weak positive correlation between scale and measure of 'openness'.	Yes
	268 university students: 51% male, mean age 24	Canada	Cinema	Yes Alpha coefficient = 0.77	Correlation with measure of frequency of cinema visits = 0.375 (p<0.0001)	Strong positive correlation between scale and measures of tendency to seek out new and unknown sensations.	Yes

						Weak positive correlation between scale and measure of ‘openness’. Correlation between scale and measure of variety seeking was not significant.	
	296 university students: 60% male, mean age 23.8	Israel	Cinema	No Alpha coefficient = 0.634	-	-	Unconfirmed

An additional consideration in using the DSI scale was the chosen domain of interest. Since the questionnaire is about hypothetical decisions to do with microgeneration, and few if any of the respondents were likely to already own or use microgeneration technologies, applying to the scale specifically to microgeneration was inappropriate. A judgement therefore had to be made about the domain in which consumer innovativeness was likely to have an impact on attitudes to microgeneration. From a review of existing literature, it is apparent that microgeneration is nearly always framed in terms of a 'technological innovation', a 'green innovation' or both – the two are not mutually exclusive. In an investigation into resistance to innovation in Northern Ireland, Claudy et al. (2010b; 2010c) describe microgeneration as a green innovation and "[an] innovation which help[s] promote 'green values'". Similarly, Watson et al. (2006) and Fischer (2004) suggest that early adopters of microgeneration technologies may do so as an outward expression of green values. The Zero Carbon Hub's (Zero Carbon Hub) document on marketing strategy also focuses heavily on perceptions of microgeneration as sustainable 'green' technologies. Elsewhere, microgeneration is framed more as a cluster of complex technologies: Boait (2009) for example, emphasises consumer distrust of 'new technologies' in general as a possible reason for resistance to adoption; and Watson (2004) characterises likely early adopters as people with high levels of technical knowledge.

In light of this, two versions of Goldsmith and Hofacker's scale were included in the questionnaire: one measuring innovativeness in the consumer electronics domain and one measuring it in the 'green products' domain. Consumer electronics was chosen as a proxy for 'technology' as it provided a sufficiently narrow focus, and met the criteria of being available and not prohibitively expensive for the majority of consumers (Flynn and Goldsmith 1993b). When completing the DSI scale, respondents were told to "think about products that are relevant to YOU and your interests". This was included to ensure that participants did not have difficulty generalising about what could be two very wide ranges of products, and that they responded according to their preferences rather than their financial means: one of the conditions for the use of the scale as recommended by Flynn and Goldsmith (1993b).

5.2.7 Dissemination

Two versions of the questionnaire were disseminated: a web-based version and a hard copy. The web version was initially sent to appropriate professional and personal contacts, along with a request to pass the link onto anyone who might be willing to complete it – a form of 'snowball' sampling. Colleagues in the field of renewable energy were asked to pass on the link without completing the questionnaire themselves, to avoid gaining a sample with unusually high technical and environmental knowledge. The link was also displayed on posters around the university, and disseminated to a patient focus group affiliated with the university. The group has a diverse membership, with the only common characteristics being chronic illness and residence in or near Leeds.

Hard copies were also produced to avoid excluding people without access to a computer or the internet: people who may well represent the less 'innovative' portion of the sample in some cases. Hard copies were given to members of three groups: an art club in North London (primarily adult female membership, resident in or near North London), a walking group in rural Bedfordshire (primarily elderly village residents) and a freemasonry group in Central London (all male membership, most over 35).

5.2.8 **Statistical analysis**

Table 15 shows the variables used in the analysis and their descriptions.

Table 15. List of variable names and descriptions

Variable name	Description	Format/coding
Age	Age in years	Positive integer
Gender	Gender	1 = Female 0 = Male Missing = Other/Prefer not to say
Income	Net monthly income in British Pounds Sterling (£).	Positive integer
Education	Highest level of respondent's education.	1 = School to age 16 or younger 2 = GCSEs or equivalent 3 = A levels or equivalent 4 = Bachelor's degree 5 = Master's degree 6 = Doctoral degree
Urbanisation	Ranked variable computed using Experian Mosaic urbanisation ranking for postcode given by respondent	1 = Most urbanised 15 = Least urbanised
NC Choice	Choice made between Option 1 and Option 2 on five point scale in the absence of cost information.	1 = Strongly prefer Option 1 2 = Slightly prefer Option 1 3 = No preference either way 4 = Slightly prefer Option 2 5 = Strongly prefer Option 2
C Choice	Choice made between Option 1 and Option 2 on five point scale with cost information.	1 = Strongly prefer Option 1 2 = Slightly prefer Option 1 3 = No preference either way 4 = Slightly prefer Option 2 5 = Strongly prefer Option 2
Dichotomised NC Choice	NC Choice recoded as a dichotomous categorical variable	0 = Either strongly or slightly prefer Option 1 1 = Either strongly or slightly prefer Option 2 Missing = No preference either way
Dichotomised C Choice	C Choice recoded as a dichotomous categorical	0 = Either strongly or slightly prefer Option 1

	variable	1 = Either strongly or slightly prefer Option 2 Missing = No preference either way
Sceptic*	“I'm sceptical about newer energy technologies: I'd prefer not to invest my own money in them”	1 = Extremely unimportant 5 = Extremely important
Own*	“I would prefer to own my own energy generation technologies rather than have a company own them”	1 = Extremely unimportant 5 = Extremely important
Effort*	“I would prefer not to have the effort involved in maintaining my own energy generation technologies”	1 = Extremely unimportant 5 = Extremely important
Using*	“I'd be worried about using newer energy technologies myself: I'd rather have an expert do it”	1 = Extremely unimportant 5 = Extremely important
Spread*	“I would prefer to spread the cost of the energy technologies over monthly payments rather than pay the full cost upfront”	1 = Extremely unimportant 5 = Extremely important
Control*	“I want to have control over how my energy generation technologies operate”	1 = Extremely unimportant 5 = Extremely important
Space*	“Not having a boiler in the home increases the space available for me to use (e.g. more kitchen cabinet space)”	1 = Extremely unimportant 5 = Extremely important
Share*	“I don't like the idea of sharing my boiler with other people”	1 = Extremely unimportant 5 = Extremely important
GreenDSI	Sum of the six items on the DSI scale for ‘Green Products’	Min = 6 Max = 30
TechDSI	Sum of the six items on the DSI scale for ‘Household Technologies’	Min = 6 Max = 30
Demographic variables	Collective term for Income, Age, Gender, Education,	

	Urbanisation and Children.
Reason variables	Collective term for Sceptic, Own, Effort, Using, Spread, Control, Space and Share.
DSI scores	Collective term for GreenDSI and TechDSI.
Choices	Collective term for Dichotomised NC Choice and Dichotomised C Choice

* All Reason variables were recoded to be negatively scored for the analysis.

Asterisks next to test statistics:
* = Significant at $p < 0.05$ (i.e. less than 5% probability of the result occurring when the null hypothesis is true)
** = Significant at $p < 0.01$ (i.e. less than 1% probability of the result occurring when the null hypothesis is true)

*** = Significant at $p < 0.001$ (i.e. less than 0.1% probability of the result occurring when the null hypothesis is true)

Significance values in *italics* refer to one-tailed significance. All other significance values are two-tailed[1].

The statistical analysis presented here was carried out using IBM SPSS Version 21. Where manual calculations were used, this is indicated in the text. The parametric statistical tests used in this analysis assume a normal distribution of sample means. This can be assumed if the collected data are normally distributed, and some of the variables in this dataset are not. However for sample sizes over 200, the consensus is that parametric tests are robust even if the data are not normally distributed, and a normal sampling distribution can be assumed in these cases (Fagerland 2012; Field 2009a). In addition, Central Limit Theorem states that when group (bin) size exceeds 10 (as it does in cases here

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[1] One-tailed significance is used when there is a directional hypothesis in place (i.e. the ‘direction’ of the effect has been predicted).

where the data are not normally distributed), the means will be approximately normally distributed regardless of the distribution of the data. As a result, a normal sampling distribution was assumed for all variables in this dataset.

The treatment of Likert scales as interval data for the purposes of statistical analysis is contentious, with ongoing debate and arguments made both for and against. The issues relevant to this dataset are:

- Debate is ongoing over whether Likert scales should be treated as ordinal or interval: see for example Jamieson (2004) and the response from Carifio and Perla (2007).
- However, Norman (2010) *inter alia* states that although a Likert *question* is ordinal, Likert *scales*, consisting of sums across items, are interval.
- Parametric tests that compare means and central tendency (e.g. the t-test) are sufficiently robust to be effective even when the assumption of interval data is violated (Norman 2010).
- Using non-parametric tests reduces statistical power in some cases, increasing the risk of overlooking significant results.

Given the arguments outlined above regarding assumptions of normality and the use of Likert scales as interval data, the following decisions were made regarding their use:

- The two DSI scales were treated as interval data for the purposes of statistical analysis.
- The five point preference scales could not be treated as interval data as they do not measure ‘most to least’, but rather a dichotomous choice (Option 1 or Option 1). The five point scales were reported descriptively. For the purpose of correlations and regression analysis they were recoded into the dichotomous categorical variables ‘Dichotomised NC Choice’ and ‘Dichotomised C Choice’. Only 8.9% of the sample for NC Choice and 4.8% of the sample for C Choice expressed no preference, and were recoded as missing values.

However, it is argued that the difference between the two preference scales can be treated as interval, as it is a measure of change and arguably qualifies as a 'sum of ranks' measure (c.f. Norman, 2010). The t-test, which as discussed is robust for large samples even when the interval assumption is violated, was therefore used to assess the difference in responses using the five point scales. However as this is a contentious area, in the interest of thoroughness a non-parametric test (Wilcoxon signed-rank) was also conducted.

5.3 Results

5.3.1 **Data quality control**

5.3.1.1 Sample characteristics, validity and quality control

316 questionnaire responses were returned, 280 online and 36 by post. Incomplete online responses were automatically rejected by the collection system. One postal response was unusable as the respondent had not ticked to consent to the use of their data, bringing the total number of responses to 315. This exceeded the minimum of 68 responses for a 90% confidence interval calculated in Section 5.2.1.

Prior to statistical analysis, boxplots were produced to check for outlying data points. In one case, a single item from the TechDSI scale was missing, and the scale is not valid with missing items. Since the sample size was sufficiently large, the TechDSI score was deleted from this case, rather than imputed (which can introduce inaccuracy).

Sample characteristics compared with the reference population are shown in Table 16. Where available, the most relevant table from the 2011 Census was used as the reference. Gender balance and mean income were fairly well matched with the reference population, but the sample population was younger, less likely to have children at home, and more highly educated than the reference population. These differences must be borne in mind when interpreting the results: if demographic factors have a significant effect on preferences, then the percentage of respondents preferring a particular deployment model is likely to differ somewhat from the population as a whole.

Table 16. Descriptive statistics on sample and reference population

Variable	Sample	Reference population
Age[1]	$\bar{x}$ 37.87 SD 16.3	$\bar{\mu}$ 47.7 SD 18.7
Income[2]	$\bar{x}$ £2,123.68 SD £1,477.82	$\bar{\mu}$ £2,608 SD not available
Gender[3]	Male 44.3% Female 55.7%	Male 49.1% Female 50.9%
Education[4]	No qualifications 5.1% GCSEs or A levels 25.2% BSc or higher 69.7%	No qualifications 2.01% GCSEs or A levels 47.14% BSc or higher 28.85%
Presence of children in household[5]	14.0%	29.1%

[1] Reference population = population of England and Wales aged 18 – 99 (inclusive) on census day 27th March 2011 (Office for National Statistics)

[2] Reference population = all UK households, 2011/2012 (Office for National Statistics 2013)

[3] Reference population = entire population of UK on census day 27th March 2011 (Office for National Statistics)

[4] Reference population = population of England and Wales aged 16 or over on census day 27th March 2011 (Office for National Statistics)

[5] Reference population = all households in England and Wales on census day 27th March 2011 (Office for National Statistics)

5.3.1.2 Validity of DSI scales

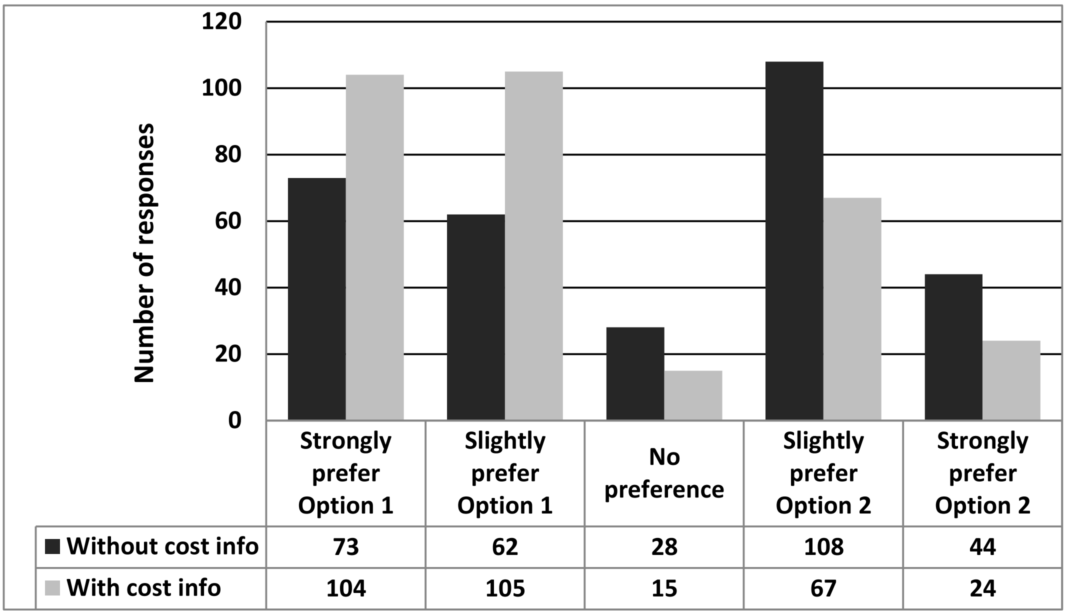
As previously discussed, the internal validity of the DSI scale can be measured using Cronbach's α. This is a measure of internal consistency of the items in a scale, to check that they are all measuring the same construct. Cronbach's α scores greater than 0.70 are considered to show good internal validity. Cronbach's α was 0.71 for GreenDSI and 0.78 for TechDSI.

This is the first demonstration of the internal validity of this scale in this domain in the UK, adding to the evidence base for its use as discussed in Section 5.2.6.

5.3.2 **Descriptive statistics**

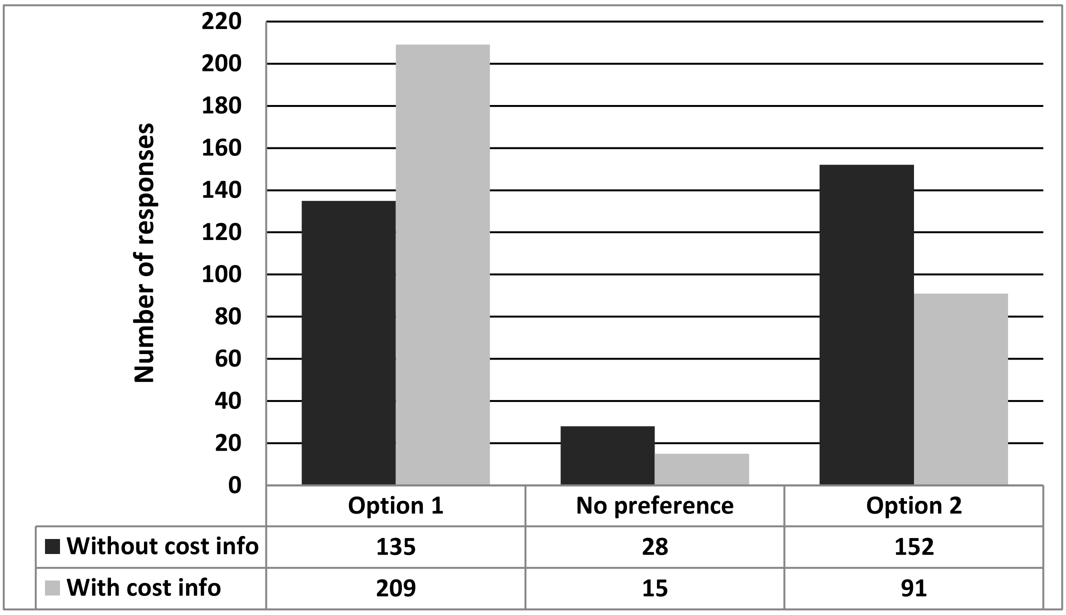
5.3.2.1 Choice of deployment model

Figure 26. Frequency of choices (five point scale)



	Strongly prefer Option 1	Slightly prefer Option 1	No preference	Slightly prefer Option 2	Strongly prefer Option 2
■ Without cost info	73	62	28	108	44
□ With cost info	104	105	15	67	24

Figure 27. Frequency of choices (three point scale)



	Option 1	No preference	Option 2
■ Without cost info	135	28	152
□ With cost info	209	15	91

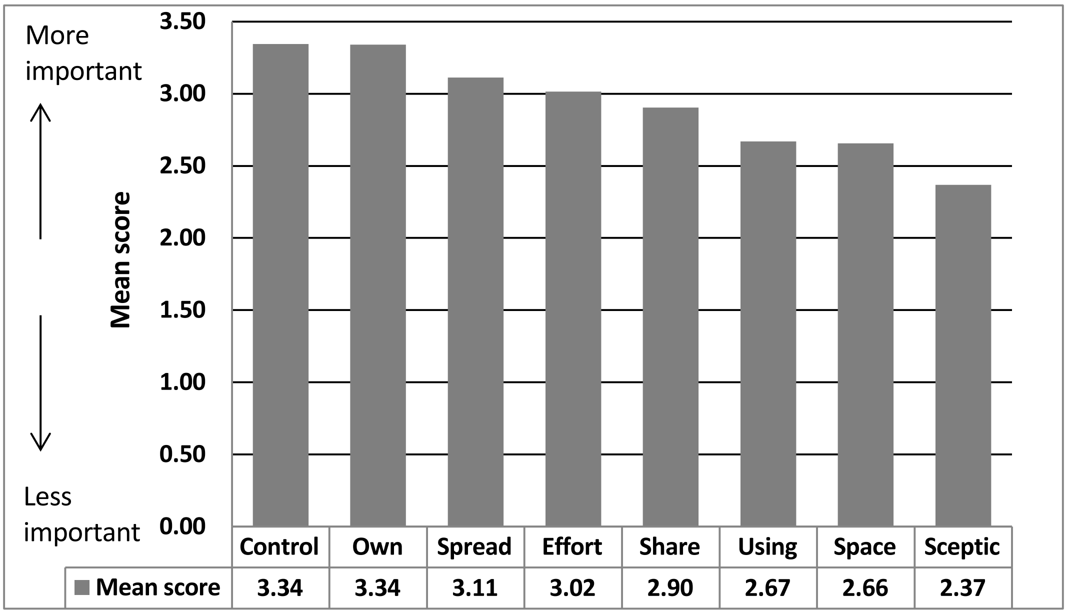
In both cases, people's choices were split between the two deployment options. If cost were not an issue, 48% of the sample would prefer Option 2, 43% would prefer Option 1, and 9% had no preference. More strong preferences were expressed about Option 1, with 54% of those choosing Option 1 'strongly' preferring Option 1, while 29% of those choosing Option 2 'strongly' preferred it.

When the cost information was presented, there was still a split but the majority – 66% of the sample - now preferred Option 1, 29% preferred Option 2, and 5% had no preference. There was an almost even split for Option 1 between those 'strongly' preferring it and those 'slightly' preferring it. For Option 2, 74% 'slightly' preferred it.

5.3.2.2 Attitudes affecting the choice

Respondents reported the importance of different reasons for their choices on a five point Likert scale. In the questionnaire, 1 = very important and 5 = very unimportant. For the analysis, the scores were inverted so that 5 = very important and 1 = very unimportant, i.e. the higher the score, the greater the importance. The mean score for each reason is shown in Figure 28.

Figure 28. Mean scores of factors considered in respondent choice



	Control	Own	Spread	Effort	Share	Using	Space	Sceptic
■ Mean score	3.34	3.34	3.11	3.02	2.90	2.67	2.66	2.37

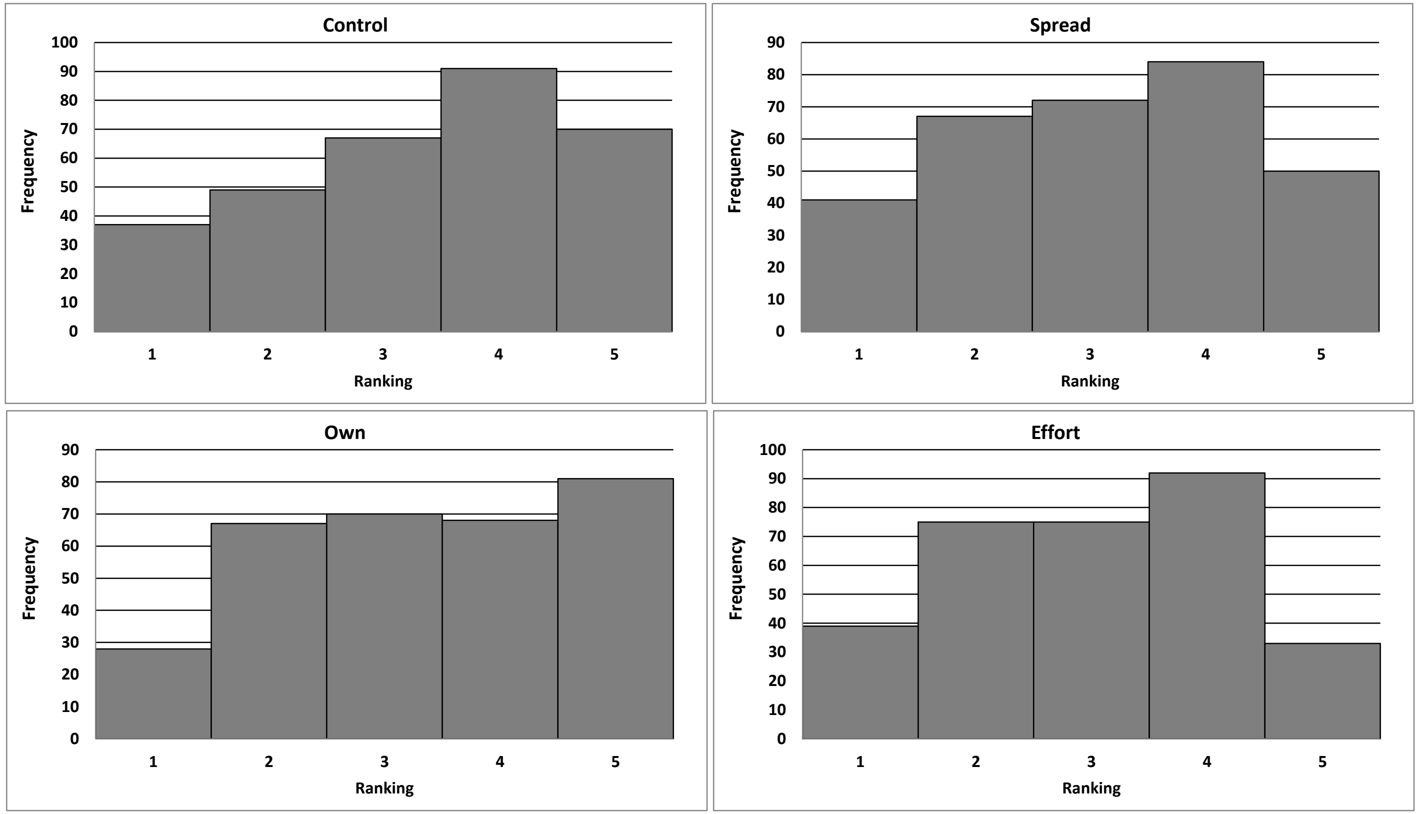
The Control and Own reasons ranked highest on average, and the Sceptic reason ranked lowest on average. In particular, Sceptic scored lower than the 2.5 out of 5, showing that on average respondents considered it to be unimportant. A clearer picture of the variation within and between the scores can be seen in Figure 29.

5.3.2.3 Additional reasons given

61 respondents (19% of the sample) gave additional reasons for their choices in the optional text box in the survey. The responses are shown in Table 17. Some of the responses were already covered by the rating scale: for example, "…due to the current economic situation, I cannot afford a large upfront fee", is arguably covered by the Spread variable. However, the additional detail provided by respondents shows some of the nuances of their decision making processes, and it may be that the choice to repeat or expand upon a reason already given reveals its importance in the mind of the respondent.

Since the question was optional, the responses come from a self-selected sample within the wider sample; and the answer format was not standardised. As a result, the responses should not be generalised to the population as a whole, or even to this sample as a whole. However, to provide some qualitative insights into the responses, the answers were analysed using the same inductive thematic approach used in Chapter 3. The results of this analysis are shown in Table 18. The frequencies in Table 18 do not add up to 61, as some responses contained more than one statement or reason.

Figure 29. Histograms of scores for each Reason variable

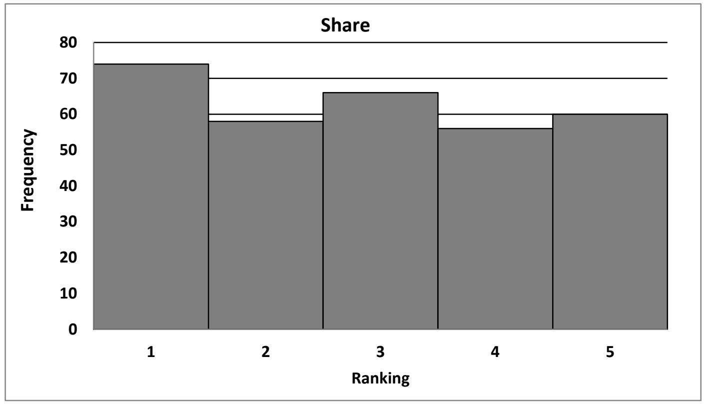


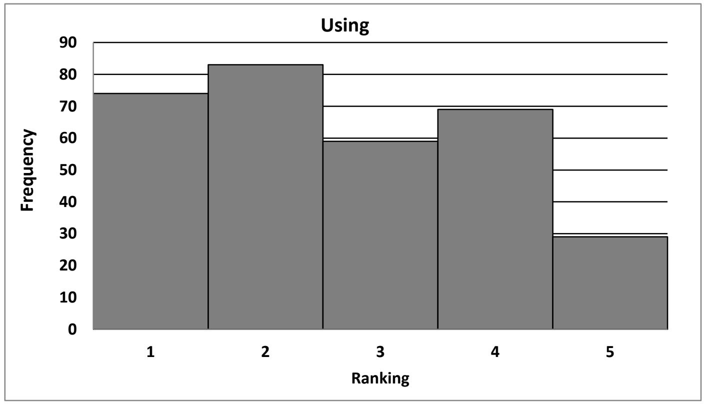
Control

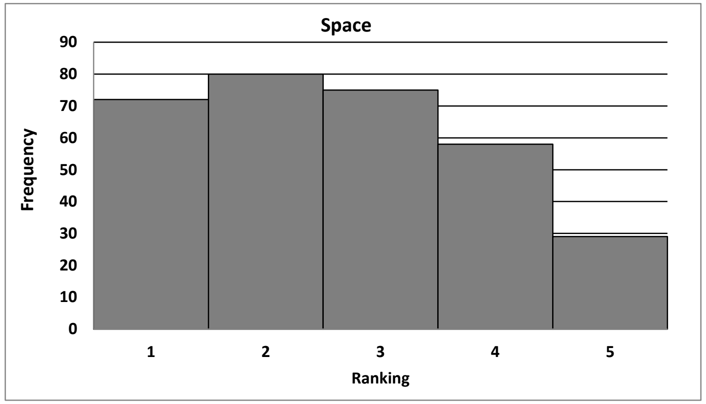
Spread

Own

Effort


Share
80
70
60
50
40
30
20
10
0
Frequency
1
2
3
4
5
Ranking


Using
90
80
70
60
50
40
30
20
10
0
Frequency
1
2
3
4
5
Ranking


Space
90
80
70
60
50
40
30
20
10
0
Frequency
1
2
3
4
5
Ranking

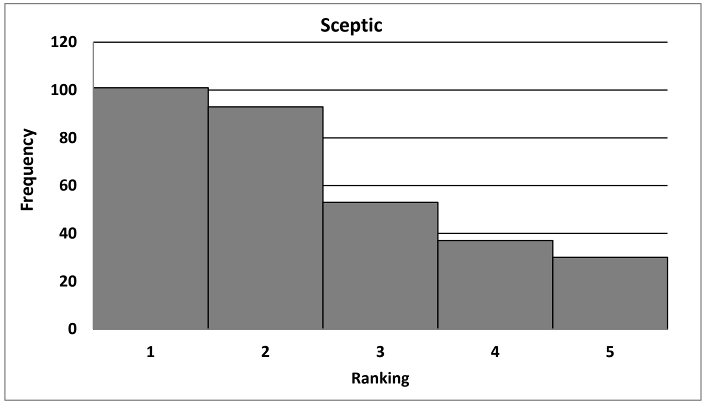

Sceptic
120
100
80
60
40
20
0
Frequency
1
2
3
4
5
Ranking

Table 17. Text entered in the 'other reasons' box

Age	Gender	NC Choice	C Choice	Reason given (verbatim)
21	Female	1	1	If there's any outage for the company I have to wait for them to dispatch somebody and everybody is without heating/electricity. I'd rather not be too dependent on them. Furthermore, in the long term I'd make the investment back more easily whereas I'd cost me more to pay the company to service it.
21	Not given	1	2	If the grid goes down, I still have my own means of power generation
22	Female	2	2	More efficient to have a larger system shared between a community.
22	Male	2	2	If there are more people using a CHP the system will have to be large resulting in a better efficiency of equipment
22	Male	2	1	I like the idea of sharing energy needs across a neighbourhood community
23	Female	2	1	Maintenance quality and frequency provided by the company plays into account. If they are good and efficient then everything would run smoothly and a shared unit would be fine. However, if there was a problem, then someone needs to call the services and who then takes responsibility?
23	Female	2	1	Cost vs. return over time (if it is generating money rather than costing it)
24	Female	2	1	The savings don't seem as good in option 2
24	Male	2	2	Insurance purposes (e.g. breakdowns)
24	Female	1	2	For the own your own technology option, it would make the deposit required & overall mortgage amount

				needed to buy a house more expensive as the price would increase for the house. If money were no object, I would find the owning your own option & getting more revenue back a year more appealing, but due to the current economic situation, I cannot afford a large upfront fee
24	Female	2	1	Energy savings/income generated from energy created when owning this technology is very attractive to me.
25	Male	1	1	Work for *[redacted: one of the 'Big Six' energy companies]* in their CHP and renewable division. Strongly believe that power should be generated and held on a micro site level, owned and operated by individual operators. benefits would be greater than stated.
25	Male	1	1	Not wanting to work with a private company. Co-operatively owned/organised/maintained I would much prefer the more community based approach.
25	Male	1	1	Not being able to control prices set by external company, and not being able to switch, puts me off an external company running the boiler.
25	Male	No preference	1	In the long term you make significantly more savings by owning the system.
25	Male	1	1	If the price of my home would be higher this will also boost its resale value AND the increased mortgage cost would be offset by the extra money from the feed-in tariff.
25	Female	1	1	If I was to sell the house it would be easier to take them off/upgrade them etc. if I wished
25	Female	1	1	I wouldn't trust the stability of prices if an energy company operated the renewable energy units. At the moment I live in an unconventional home, where renewable energy through solar panels is something I already have, the

				prospect of cleaning and maintain renewable energy units, therefore doesn't worry me. I have more faith in my ability to maintain the systems and make repairs quickly than a larger corporation operating a system for a neighbourhood.
25	Not given	2	1	After ten years, I'll have paid off the extra costs for having the boiler in my house and will make an extra 1000/month for at least another 10 years. In comparison to that, a company owned boiler hardly gives me any financial benefit.
26	Male	2	1	Option 2 only saved £25 per year, option 1 pays back in less than 10 years then savings of £1000+ thereafter.
26	Female	1	1	If everyone shared a boiler then perhaps less people would be cold in the winter as there would always be heat. My sister living in Sweden has a similar set up with communal heating and hot water. there is a maximum temperature for each individual flat but everyone has the heat. I know this isn’t exactly the point of the survey but it is an interesting point?!
26	Female	2	2	Currently buying first home, and the extra 10 grand to start with would make getting onto the housing ladder even harder than it already is. I imagine my parents, to whom 10 grand is not nearly as significant a chunk of their budget, would be keener on Option 1, but that extra 10 grand would seriously limit the sort of property I could buy.
26	Female	2	2	Collective resources allow more people to benefit, and as a collective, people have power to make sure energy companies do what they have promised re maintenance/price
27	Male	2	2	Strongly in favour of district-level systems - much more cost and energy efficient to have larger CHP and heat

				network
27	Female	2	2	It seemed more energy efficient to share the boiler
28	Female	2	No preference	The savings made in the second option are not as much as you think considering the monthly payment to the energy company. Although I like the idea of sharing energy, I'm also quite sceptical it would work OK. I don't know…
28	Male	1	1	People are less responsible with communal technology
28	Female	1	1	Over time option 1 is more financially profitable
28	Male	2	2	I like the idea of them being shared among the community
28	Female	2	2	I don't the house to cost more.
28	Male	1	2	Although long-term the £10k is a better bet, I want to buy a house and can't afford the extra
29	Male	1	2	If the system breaks I would like to be able to fix it, or pay to have it fixed, rather than rely on a service provider.
29	Male	2	1	I would expect greater efficiency from a large central operation.
29	Female	2	1	I like the idea of shared community energy generation
29	Female	No preference	1	Financial savings compared to conventional fuel. A guarantee that it could be less than or equal to could mean I pay the same AND a maintenance fee.
30	Male	2	1	After 10 years I would be making money
31	Male	2	2	I'm not confident in making a large investment which takes over 10 years to pay back
31	Male	1	1	I don't trust energy companies, before you know it the buggers are dictating terms and they've got you over a

				barrel because they know there's not much you can do.
32	Female	2	1	It's a better investment having your own boiler as the yearly income means you would pay off the extra cost of your home within 10 years and then would be making money. However, I do like the idea of energy being shared
33	Male	2	2	Sharing and making use of what's available is better than wasting unused energy
33	Female	1	1	I am sceptical of a company responsible for maintenance of equipment and the impact of selling a property on when a third party owns fixtures on the building.
34	Male	2	No preference	You didn't detail any information about maintenance costs. It's impossible to make an informed decision without that.
35	Male	1	1	Unsure whether option 2 provides enough of a significant departure from the current model, but also sceptical of the benefits of CHP compared with other generation or energy saving alternatives.
35	Female	2	2	The lack of ability to switch between service companies makes option 2 less attractive, rather than cost issues.
35	Not given	1	1	An outage or service interruption in a neighbourhood-centred Combined Heat and Power system would be more disruptive to remedy.
37	Female	1	1	The upfront costs are prohibitive but if I had the money I would spend it on sourcing my own renewable energy (option 1)
39	Female	2	1	Maintenance:- unsure due to lack of workable knowledge in maintaining equipment
40	Female	2	2	Sharing is good
49	Female	1	1	Do not trust the company not to share profits with shareholders

50	Male	1	1	The monthly benefit from government can be reinvested on inverter energy.
50	Female	1	1	Prefer to have personal control of energy technology as service provider could delay in response to energy service interruption
55	Female	1	1	The house would have extra value if I sold the house rather than just paying out £10 a month forever
59	Male	1	1	Assuming this technology will improve significantly in the next few years, having control of it would be better than having to negotiate with a company about any changes.
62	Male	2	2	£10,000 is a lot of upfront cost compared with interest considerations over say 10 years comparison.
65	Male	2	1	Sharing energy would help people on lower income
65	Male	1	1	I'll never trust any energy company; all rogues.
66	Female	1	1	You may benefit by managing your own usage against what is generated by having control of your own boiler.
67	Male	1	1	Do not trust energy companies
67	Female	1	1	Distrust of large energy companies, which tend to be in private and foreign ownership. Energy service would focus on shareholder investments and profits.
68	Male	1	1	If the energy company goes bust who owns the solar panels if I wanted to remove them?
70	Male	1	1	I prefer to be totally independent and self-sufficient.

Table 18. Categorisation of additional reason responses

Category	Number of responses in this (sub)category
Desire for independence or individual control	**23**
Concern about quality/timeliness of service from ESCO	(7)
General distrust or dislike of energy companies	(6)
Concern about inability to switch company and/or terms of contract changing	(4)
Desire for self-sufficiency	(2)
Concern over inability to remove or change installed technologies	(2)
Lack of trust in other users to use communal resources responsibly	(1)
Specific reason not stated	(1)
Favourable opinion of sharing energy	**17**
Ideological reasons or belief in social benefits	(10)
Belief that neighbourhood scale systems are more efficient	(7)
Option 1 makes or saves more money over time	**15**
Aversion to upfront cost	**7**
Miscellaneous concerns about Option 2	**3**
Concern that it would be more difficult to sell the house	(1)
Option 2 is too similar to the 'status quo'	(1)
Specific reason not stated	(1)
Prior positive experiences with or knowledge of microgeneration	**3**
Favourable opinion of having company deal with costs, maintenance or insurance	**2**
Belief that resale value of home would increase with presence of microgeneration	**2**
Sceptical about CHP specifically compared with other renewables	**1**
Not enough financial information provided to make a decision	**1**

5.3.3 **Mean comparison tests**

Figure 26 and Figure 27 seem to indicate that the provision of cost information has an effect on people's preferences, with more people preferring Option 2 in the absence of cost information, and more people preferring Option 1 when it is provided. The significance of this effect was tested using a dependent means (repeated measures) t-test and the Wilcoxon signed-rank test, based on the five point choice scale, where 1 = strong preference for Option 1, and 5 = strong preference for Option 2. Effect size (*r*) for the t-test was calculated manually using the following formula:

$$r = \sqrt{\frac{t^2}{t^2 + df}}$$

Effect size for the Wilcoxon signed-rank test was calculated using the following formula:

$$r = \frac{z}{\sqrt{N}}$$

From the t-test: on average, respondents had a greater preference for Option 1 when cost information was presented (*M* = 2.37, *SE* = 0.75) than when no cost information was presented (*M* = 2.96, *SE* = 0.8), *t(314)* = 7.506, *p* < .001, *r* = 0.39). The result was statistically significant.

The Wilcoxon signed-rank test gave the same result: on average, respondents had a greater preference for Option 1 when cost information was presented (*Mdn* = 2) than when no cost information was presented (*Mdn* = 3), *z* = -6.837, *p* < .001, *r* = -0.39. The result was statistically significant.

5.3.4 **Associations**

Correlation analyses were conducted to test the associations between selected respondent characteristics, choice of microgeneration deployment model and stated importance of the Reason variables.

The parametric test for bivariate correlation, Pearson correlation, assumes a normal sample distribution and that all variables are measured at the interval level. As discussed in Section 5.2.8, all ordinal and interval data in this sample can be assumed to have normal sampling distributions for the purpose of statistical analysis. If some variables are not measured at the interval level, but are dichotomous and have an underlying continuum (the C Choice and NC Choice variables), biserial correlation can be used. Biserial correlation was calculated manually by conducting a point-biserial correlation in SPSS then applying the formula:

$$r_b = \frac{r_{pb}\sqrt{pq}}{y}$$

Where r_b is the biserial correlation coefficient, r_{pb} is the point-biserial correlation coefficient, p is the proportion of cases in the larger of the two categories, q is the proportion of cases in the smaller category, and y is the ordinate of the normal distribution at point at which $X = p$ (fromn a reference table of values for the normal distribution).

The significance of r_b was identified from its Z score using a reference table of values for the normal distribution. The Z score was calculated from the standard error using the formulae:

$$SE_{rb} = \frac{\sqrt{pq}}{y\sqrt{N}}$$

$$Z_{rb} = \frac{r_b - \overline{r_b}}{SE_{r_b}}$$

Where $\overline{r_b} = 0$ assuming the null hypothesis that there is no correlation.

The Education and Urbanisation variables are ranked (ordinal) variables and violate the assumptions of the Pearson correlation and biserial correlation tests. Non-parametric tests were therefore selected for use with these variables. For association tests between the ranked variables and continuous (interval) variables, Kendall’s tau was used as it gives a better estimate of correlation than Spearman’s rho when data include a large number of tied ranks, as is the case here. However for the association tests between ranked variables and categorical variables, Spearman’s rho was used, as the biserial correction described above can be applied to Spearman’s rho but not Kendall’s tau.

For ease of interpretation, the test outcomes have been tabulated in Excel. Correlation coefficients shown in bold have been manually corrected for biserial correlation using the method described above. Significance values shown in italics have been measured at the one-tailed level, all others at the two-tailed level.

5.3.4.1 Relationships between reason variables and choices

Figure 30 and Figure 31 present the results of biserial correlation calculations testing the relationships between the Reason variables and the two choices (without cost information and with cost information).

Figure 30. Results of biserial correlation calculations for Dichotomised NC Choice and Reason variables

		Sceptic	Own	Effort	Using	Control	Space	Share
Dichotomised NC Choice	Correlation coefficient	**.048**	**-.413*****	**.387*****	**.130***	**-.401*****	**.224****	**-.432*****
	Sig.	*.261*	*.000*	*.000*	*.041*	*.000*	*.001*	*.000*
	N	286	286	286	286	286	286	286

Figure 31. Results of biserial correlation calculations for Dichotomised C Choice and Reason variables

		Sceptic	Own	Effort	Using	Spread	Control	Space	Share
Dichotomised C Choice	Correlation coefficient	**.176***	**-.306*****	**.269*****	**.236****	**.180****	**-.274*****	**.143***	**-.261*****
	Sig.	*.010*	*.000*	*.000*	*.001*	*.009*	*.000*	*.030*	*.000*
	N	299	299	299	299	299	299	299	299

NC Choice was significantly correlated with (order of effect size) Share (r_b = -.43, p < .001), Own (r_b = -.41, p < .001), Control (r_b = -.40, p < .001), Effort (r_b = .39, p < .001), Space (r_b = .22, p < .01) and Using (r_b = .13, p < .05). With no cost information, a tendency towards Option 1 was associated with higher desire to own the microgeneration, higher desire to control the microgeneration, and a higher aversion to sharing the technology. A tendency towards Option 2 was associated with higher aversion to the effort involved in using the microgeneration, higher concern over using microgeneration and higher approval of the space provided by not having a boiler in the household.

C Choice was significantly correlated with Own (r_b = -.31, p < .001), Control (r_b = -.27, p < .001), Effort (r_b = .27, p < .001), Share (r_b = -.26, p < .001), Using (r_b = .24, p < .01), Spread (r_b = .18, p < .01), Sceptic (r_b = .18, p = .01) and Space (r_b = .14, p < .05). With cost information, a tendency towards Option 1 was associated with higher desire to own the microgeneration, higher desire to control the microgeneration, and higher aversion to sharing the technology. A tendency towards Option 2 was associated with higher scepticism about renewable energy, higher aversion to the effort involved in using the microgeneration, higher concern over using microgeneration, higher desire to spread out the cost of the technology, and higher approval of the space provided by not having a boiler in the household.

5.3.4.2 Relationships between demographic variables and choices

Figure 32 and Figure 33 present the results of correlation calculations (biserial correlation or Spearman's rho) testing the relationships between the choices and demographic factors.

Figure 32. Results of biserial correlation calculations for age, income and choices

		Dichotomised NC Choice	Dichotomised C Choice
Age	Correlation coefficient	**-.254*****	**-.144***
	Sig.	*.000*	*.029*
	N	287	300
Income	Correlation coefficient	**.124**	**.044**
	Sig.	*.051*	*.288*
	N	274	286

Figure 33. Results of Spearman's rho calculations for choices and demographic variables

		Dichotomised NC Choice	Dichotomised C Choice
Education	Spearman's rho	**.12***	**.16***
	Sig.	*.048*	*.020*
	N	286	299
Urbanisation	Spearman's rho	**.22****	**.20***
	Sig.	*.006*	*.014*
	N	205	213

NC Choice was significantly correlated with age (r_b = -.25, $p < .001$), education (r_s = .12, $p < .05$), and urbanisation (r_s = .22, $p < .01$). Higher age, lower level of education and lower urbanisation ranking were associated with a tendency towards Option 1.

C Choice was significantly correlated with age (r_b = -.14, $p < .05$) level of education (r_s = .16, $p < .05$) and urbanisation (r_s = .20, $p < .05$). Higher age, lower level of education and lower urbanisation were associated with a tendency towards Option 1.

5.3.4.3 Relationships between DSI scores and Choices

Figure 34 presents the results of correlation calculations testing the relationships between the choices and domain specific innovativeness.

Figure 34. Results of biserial correlation calculations for Choice and DSI variables

		GreenDSI	TechDSI
Dichotomised NC Choice	Correlation coefficient	**.020**	**.025**
	Sig.	*.366*	*.337*
	N	287	283
Dichotomised C Choice	Correlation coefficient	**-.052**	**-.056**
	Sig.	*.184*	*.169*
	N	300	296

There were no significant correlations between DSI and choice, with or without cost information.

5.3.4.4 Relationships between demographic variables and reason variables

Figure 35 and Figure 36 present the results of correlation calculations (Pearson correlation or Kendall's tau) testing the relationships between demographic factors and the Reason variables.

Figure 35. Results of Pearson correlation calculations for Age, Income and Reason variables

		Sceptic	Own	Effort	Using	Spread	Control	Space	Share
Age	Correlation coefficient	.092	.174**	.038	.007	-.036	.190**	.014	.156**
	Sig.	.104	.002	.498	.905	.522	.001	.804	.006
	N	314	314	314	314	314	314	314	314
Income	Correlation coefficient	-.019	-.047	-.028	-.075	-.033	-.025	-.036	-.084
	Sig.	.749	.415	.625	.198	.566	.669	.536	.148
	N	300	300	300	300	300	300	300	300

Figure 36. Results of Kendall's tau calculations for Demographic and Reason variables

			Sceptic	Own	Effort	Using	Spread	Control	Space	Share
Kendall's tau	Education	Correlation Coefficient	-.084	-.141**	-.014	-.016	-.009	-.165***	.026	-.112*
		Sig.	.069	.002	.762	.727	.836	.000	.571	.014
		N	313	313	313	313	313	313	313	313
	Urbanisation	Correlation Coefficient	-.037	-.140**	.013	.028	.020	-.140**	.062	-.126*
		Sig.	.485	.007	.803	.595	.701	.007	.235	.016
		N	224	224	224	224	224	224	224	224

Age was significantly correlated with Control ($r = .19$, $p < .05$), Own ($r = .17$, $p < .01$) and Share ($r = .16$, $p < .01$). Higher age was associated with greater desire to own and control the microgeneration and a greater aversion to sharing the technology.

Education was significantly correlated with Control ($\tau = -.17$, $p < .001$), Own ($\tau = -.14$, $p < .01$) and Share ($\tau = -.11$, $p < .05$). More highly educated respondents tended to have less desire to own and control the microgeneration and less of an aversion to sharing the technology.

Urbanisation was significantly correlated with Own ($\tau = -.14$, $p < .01$), Control ($\tau = -.14$, $p < .01$) and Share ($\tau = -.13$, $p < .05$). Less urban respondents tended to have a greater desire to own and control the microgeneration and a greater aversion to sharing the technology.

Income was not significantly correlated with any of the Reason variables.

5.3.4.5 Relationships between DSI scores and reason variables

Figure 34 presents the results of Pearson correlation calculations testing the relationships between the Reason variables and domain specific innovativeness.

Figure 37. Results of Pearson correlation calculations for DSI and Reason variables

		Sceptic	Own	Effort	Using	Spread	Control	Space	Share
GreenDSI	Correlation coefficient	-0.135*	-.072	.088	.026	-.033	-.098	.054	-.065
	Sig.	.017	.205	.122	.648	.557	.082	.336	.250
	N	314	314	314	314	314	314	314	314
TechDSI	Correlation coefficient	-0.118*	.084	-.077	-0.142*	-.020	.013	.030	-.055
	Sig.	.038	.138	.174	.012	.727	.815	.599	.334
	N	310	310	310	310	310	310	310	310

GreenDSI was correlated with Sceptic (r = -.14, p < .05). Higher scores on the GreenDSI scale were associated with lower scepticism about renewable energy technologies. The effect size was small: r^2 = 0.02.

TechDSI was correlated with Sceptic (r = -.12, p < .05) and Using (r = -.14, p < .05). Higher scores on the TechDSI scale were associated with lower scepticism about renewable energy technologies and lower concern about using microgeneration.

5.3.4.6 Relationships between demographic variables and DSI scores

Figure 38 and Figure 39 present the results of correlation calculations (Pearson correlation or Kendall's tau) testing the relationships between demographic factors and domain specific innovativeness.

Figure 38. Results of Pearson and point-biserial correlation calculations for Demographic and DSI variables

		GreenDSI	TechDSI
Age	Correlation coefficient	-.063	-.099*
	Sig.	*.133*	*.041*
	N	315	311
Gender	Correlation coefficient	-.145*	.192*
	Sig.	.011	.001
	N	307	303
Income	Correlation coefficient	-.073	.099*
	Sig.	*.102*	*.045*
	N	301	297
Children	Correlation coefficient	-.015	.045
	Sig.	.787	.427
	N	315	311

Figure 39. Results of Kendall's tau correlation calculations for Demographic and DSI variables

			GreenDSI	TechDSI
Kendall's tau_b	Education	Correlation Coefficient	.100*	.000
		Sig.	*.010*	*.498*
		N	314	310
	Urbanisation	Correlation Coefficient	.078	-.025
		Sig.	.114	.608
		N	225	222

GreenDSI was significantly correlated with Gender (r_{pb} = -.15, p < .05) and level of education (τ = .10, p < .05). Female respondents tended to score more highly on the GreenDSI scale than male respondents. Higher levels of education were associated with higher scores on the GreenDSI scale.

TechDSI was significantly correlated with Age, (r = -.10, p *one-tailed* < .05), Gender (r_{pb} = .19, p < .01) and Income (r = .10, p < .05). Male respondents tended to score more highly on the TechDSI scale than female respondents. Higher scores on the TechDSI scale were associated with higher income and lower age.

5.3.5 **Regression analysis**

The correlations reported in Section 5.3.4 shed some light on the interrelationships between householder characteristics and their chosen deployment models in this sample. However, correlation coefficients alone do not tell us whether accurate predictions of people's deployment model choices can be made from demographic information. Having identified the characteristics which correlate with deployment model choice, logistic regression analysis was conducted to find out whether the choice between Option 1 and Option 2 could be predicted using these characteristics. A forced entry regression method was used, as stepwise methods are less likely to give replicable results.

5.3.5.1 NC Choice

5.3.5.1.1 Model 1: all attributes

Respondent characteristics were entered into the logistic regression model in two blocks. Block 1 contained attributes which correlated with NC Choice in this sample: age, education and urbanisation. Block 2 contained those which didn't: GreenDSI and TechDSI. Income was excluded as no cost information was presented in this scenario.

After Block 1 the model predicted 62.2% of cases correctly compared with 52.7% for the baseline model. Block 1 $\chi^2 = 13.65$ (3) $p < .01$, indicating that including age, education and urbanisation in the model improved its predictive power at a statistically significant level.

After Block 2 the model predicted 62.2% of cases correctly compared with 52.7% for the baseline model[1]. Block 2 $\chi^2 = .624$ (2) $p = .73$, indicating that

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[1] Identical percentages to Block 1 are coincidental.

including GreenDSI and TechDSI did not improve the predictive power of the model at a statistically significant level.

Diagnostics for the model are shown in Table 19. Eight cases had a leverage value more than three times the expected value (0.02), but in all these cases Cook's distance was well under 1 and the standardised residuals were within one standard deviation, so none was considered to be exerting undue influence on the model.

Table 19. Diagnostics for NC Choice logistic regression Model 1

Item	**Expected value(s)**	**Notes**
Cook's distance	< 1	Maximum in sample = 0.20
Leverage	≤0.06	8 cases > 0.06 Cook's distance for these cases all ≤0.11 Standardised residuals all within |1.96|
Standardised residual	95% within |1.96| 99% within |2.58|	All cases within |1.96|
DFbeta for constant	<1	Maximum in sample = 0.25
DFbeta for age	<1	Maximum in sample = 0.003
Tolerance	>0.1	Minimum = 0.644
VIF	<10	Maximum = 1.553

As shown in Table 20, age was the only variable significant at the individual level. None of the other variables was a statistically significant predictor. Additionally, all variables except age had 95% confidence interval ranges for odds ratios which crossed the boundary between <1 and >1. This means that their direction of influence cannot be predicted with confidence.

Table 20. Results of NC Choice logistic regression Model 1

	95% Confidence interval for odds ratio						
	B	S.E.	Wald	Sig.	Odds ratio	Lower	Upper
Constant	0.678	1.274	0.283	.595	1.969		
Age	-0.031	0.011	7.149**	.008	0.970	0.948	0.992
Education	-0.082	0.130	0.395	.530	0.922	0.714	1.189
Urbanisation	0.020	0.036	0.318	.573	1.020	0.951	1.095
GreenDSI	0.029	0.039	0.533	.465	1.029	0.953	1.112
TechDSI	0.008	0.031	0.070	.792	1.008	0.949	1.071

5.3.5.1.2 Model 2: age only

A second logistic regression model was run, including only the Age variable. Diagnostics for the model are shown in Table 21. 35 cases had a leverage value more than three times the expected value (0.01), but again in all cases Cook's distance was well under 1 and the standardised residuals were within one standard deviation, so none was considered to be exerting undue influence on the model.

Table 21. Diagnostics for NC Choice logistic regression Model 2

Item	**Expected value(s)**	**Notes**
Cook's distance	< 1	Maximum in sample = 0.09
Leverage	≤0.03	35 cases > 0.03 Cook's distance for these cases all ≤0.09 Standardised residuals all within |1.96|
Standardised residual	95% within |1.96| 99% within |2.58|	All cases within |1.96|
DFbeta for constant	<1	Maximum in sample = 0.16
DFbeta for age	<1	Maximum in sample = 0.002

Model 2 predicted 63.2% of cases correctly compared with 52.7% for the baseline model. Model χ^2 = 14.05 (1) $p < .001$, indicating that including age improved the predictive power of the model at a statistically significant level.

Table 22. Results of NC Choice logistic regression Model 2

	95% Confidence interval for odds ratio						
	B	S.E.	Wald	Sig.	Odds ratio	Lower	Upper
Constant	1.366	0.376	13.171	.000	3.918		
Age	-0.033	0.009	13.171***	.000	0.968	0.950	0.985

As age increases, the likelihood of a respondent choosing Option 2 decreases (conversely, the likelihood of them choosing Option 1 increases). 9% of the variance in choice is accounted for by the age of the respondent ($R^2_N = .089$).

Adjusted R^2, calculated using the formula below, takes account of shrinkage and provides an indicator of how well the model can be generalised to the population as a whole.

$$adjusted\ R^2 = 1 - \left[\left(\frac{n-1}{n-k-1}\right)\left(\frac{n-2}{n-k-2}\right)\left(\frac{n+1}{n}\right)\right](1 - R_N^2)$$

Where k = the number of predictors.

Adjusted $R^2_N = 0.075$. In the UK population, it is estimated that 7.5% of the variance in choice will be accounted for by age (compared with 9% for this sample).

5.3.5.2 C Choice: Model 3

Respondent characteristics were entered into the logistic regression model in two blocks. Block 1 contained attributes which correlated with C Choice in this sample: age, education and urbanisation. Block 2 contained those which didn't: income, greenDSI and techDSI.

After Block 1 the model predicted 66.8% of cases correctly compared with 67.8% for the baseline model. Block 1 $\chi^2 = 8.714$ (3) $p < .05$, indicating that including age, education and urbanisation in the model actually reduced its predictive power at a statistically significant level.

After Block 2 the model predicted 68.8% of cases correctly compared with 66.8% for the baseline model. Block 2 $\chi^2 = 1.410$ (3) $p = .70$, indicating that including income, greenDSI and techDSI did not improve the predictive power of the model at a statistically significant level.

Table 23. Results of logistic regression model for C Choice

	95% Confidence interval for odds ratio						
	B	S.E.	Wald	Sig.	Odds ratio	Lower	Upper
Constant	-1.587	1.410	1.266	.26	0.205		
Age	-0.001	0.013	0.006	.94	0.999	0.975	1.024
Education	0.269	0.149	3.276	.07	1.309	0.978	1.751
Urbanisation	0.067	0.040	2.763	.10	1.069	0.988	1.175
Income	0.000	0.000	0.159	.69	1.000	1.000	1.000
Green DSI	-0.019	0.042	0.201	.65	0.981	0.903	1.066
TechDSI	-0.033	0.033	0.994	.32	0.968	0.907	1.032

As shown in Table 23, no variables were statistically significant predictors of choice at the individual level. The variables were not significant predictors collectively. Additionally, all variables except income (which had an odds ratio of 1.000: no influence on preference) had 95% confidence interval ranges for odds ratios which crossed the boundary between <1 and >1. This means that their direction of influence cannot be predicted with confidence.

Diagnostics for the model are shown in Table 24. Three cases had a leverage value more than three times the expected value (0.035), but in all these cases Cook’s distance was well under 1 and the standardised residuals were within one standard deviation, so none was considered to be exerting undue influence on the model.

Table 24. Diagnostics for C Choice logistic regression model

Item	Expected value(s)	Notes
Cook's distance	< 1	Maximum in sample = .33
Leverage	≤0.11	3 cases >0.11 Cook's distance for these cases all ≤.28 Standardised residuals all within |1.96|
Standardised residual	95% within |1.96| 99% within |2.58|	All cases within |1.96|
DFbeta for constant	<1	Maximum in sample = 0.43
DFbeta for age	<1	Maximum in sample = 0.003
Tolerance	>0.1	Minimum = 0.633
VIF	<10	Maximum = 1.579

5.4 Discussion

5.4.1 **Overall choice split**

One of the questions investigated in this chapter was whether one particular deployment model was likely to prove more popular with UK residents. Assuming equal costs, while the ESCO model was preferred by the largest proportion of people (48%), the proportion preferring plug and play was not much smaller (43%), indicating that neither option can be assumed to be the 'favourite' in the majority of cases. The relatively even split was not an indicator of overwhelming ambivalence, as 91% of respondents had a clear preference one way or the other. This result alone shows that people are not indifferent to the features of different deployment models, and that these features should form part of a developer's marketing strategy.

5.4.2 Effect of price and contract information

It was hypothesised in Chapter 4 that the higher upfront cost associated with the plug and play model would induce a preference for the ESCO model. However, when respondents were presented with cost and contract information, the proportion of respondents choosing the ESCO model decreased from 48% to 29% (statistically significant at $p < .001$, medium effect size), suggesting that for most people the considerations of higher revenues over time outweighed the issue of upfront costs. This is somewhat surprising in light of the evidence for hyperbolic discounting discussed in Section 4.4. This result may be due to the fact that participants in this study considered the cost in the context of a house purchase, rather than as a standalone expense. The phenomenon of proportion dominance, whereby people tend to base purchase decisions on relative rather than absolute costs (Azar 2011; Bartels 2006), could therefore cause the upfront cost of £10,000 to be perceived less unfavourably when compared to the total cost of a house. Some respondents also stated as an additional reason for their choice that they believed that the presence of microgeneration would add to the resale value of a house, which would provide an additional perceived financial incentive.

However, this result does not mean that none of the respondents were averse to the upfront costs. Indeed, 12 respondents specifically mentioned this issue when volunteering additional reasons for their choice, and a significant t-test statistic could still occur even if a minority of respondents switched their choice from plug and play to ESCO. Additionally, the ability to spread the cost of microgeneration technologies over monthly payments to an ESCO (rather than paying upfront) was ranked the second most important consideration by respondents when asked what factored into their choice. The importance ascribed to this by respondents is perhaps surprising given that the majority of respondents opted for a plug and play scenario when cost information was presented. It may be that, while people favour the option of spreading the cost, other considerations were collectively more important. Acquiescence bias – the tendency of survey respondents to agree with a statement, regardless of its sentiment (Messick and Jackson 1961) – may also have been a factor.

It is also important to note that since contract information was included in the second scenario, it cannot be determined whether the change in preferences was primarily due to financial considerations or a desire not to be bound by a contract. There is some evidence for the latter in a recent study by Upham and Jones (2012): a questionnaire on waste heat district heating completed by 323 residents of Neath Port Talbot (Wales) showed that 32% of respondents viewed being tied into a heating/hot water contract for 12 months unfavourably, rising to 59% for a 24 month contract. In the present study, four respondents indicated that they did not like the idea of not being able to switch contracts when giving additional reasons for their choice. If this desire for flexibility in suppliers or contracts outweighs other considerations, it could be a significant obstacle to the acceptability of ESCOs for UK consumers. Any future studies should differentiate between attitudes towards upfront costs and attitudes towards contracts to gain a clearer picture of their relative importance.

Another factor that could have affected this result is hypothetical bias: respondents stating that they are willing to pay more in hypothetical situations (when no real money is at stake) than they actually would be in reality. Hypothetical bias can have a substantial effect (List and Gallet 2001; Little and Berrens 2004; Murphy et al. 2005), and could have operated in this case to reduce the effect of the upfront cost on people's decisions. A hypothetical study in this case was unavoidable, given the barriers to a post-hoc study discussed in Section 5.2.8, and the impracticality of asking respondents to make a real-world choice.

Nonetheless, the statistically significant change in preferences shows that financing arrangements and costs and revenue are, unsurprisingly, likely to be important determinants of people's opinions of deployment model options. The 'direction' of the effect was unexpected, although it points to a degree of economic rationality in people's decision-making about investments in microgeneration, given that the preferred scenario generates more revenue once the initial investment has been paid back. Clear and accurate cost and revenue information should therefore be presented to prospective buyers of homes incorporating microgeneration.

5.4.3 **Attitudes towards different deployment models**

Most of the attitudinal statements in the questionnaire were scored quite highly (means between 2.37 and 3.34, out of a maximum of 5). While the differences in scores between the statements are instructive, the scores themselves should not necessarily be treated as reliable indicators of the absolute importance ascribed to them, due to the possibility of acquiescence bias.

5.4.3.1 Ownership, control, and sharing microgeneration

On average, respondents ranked the desire to own their own microgeneration technology, and the desire to control it, highest of all the possible reasons given in the questionnaire. As may be expected, scores for both reasons were also correlated with a tendency to choose the plug and play option (medium effect size), both with and without cost information. Of the additional reasons given by respondents for their choice, wanting to have ownership and control was the most frequently mentioned. This is surprising given that in the absence of cost information, 54%of respondents preferred the ESCO option. However, the spread of the scores shown in Figure 29 shows that while the majority of respondents ranked these reasons at 3/5 or lower, a relatively high number of 4/5 and 5/5 rankings raised the average. In other words, while a minority of respondents felt that this issue was important, those that did felt quite strongly about it.

The statements made in the ‘additional reasons’ text box provide some valuable insights into the different reasons people may have for wanting to retain ownership and control over the technologies. The majority related to issues around dealing with a company: some respondents were concerned that an ESCO’s response to technical faults or blackouts would be inadequate, and some stated a general distrust or dislike of energy companies. Regarding the former, it is interesting to consider that under a conventional energy supply arrangement, responsibility for repairs and restoring power is also under the control of a company. Respondents' unwillingness to transfer that responsibility to an ESCO could simply indicate that given the choice, they would prefer not to deal with a company at all. Alternatively, it could signal scepticism or distrust of unfamiliar systems and technologies, giving rise to fears that blackouts or faults could become more common. Regarding the former, it reflects the generally poor perception of energy companies among UK consumers. It should be noted that the dissemination of the questionnaire (November 2013) coincided with announcements of price rises from several UK energy companies, which received a large amount of media coverage. The issue may therefore have been more prevalent in respondents' minds than it would be usually. However, even before this event energy companies were generally unpopular with UK consumers. In a survey by YouGov published in February 2013, 56% of respondents agreed with the statement, "energy companies treat people with contempt", and 45% stated that their trust in energy companies had declined in the last two years, while only 10% stated that their trust had increased (YouGov 2013). Given these issues, it may be that smaller, local or co-operatively owned ESCOs would not be subject to the same objections from householders.

In a different vein, some respondents indicated a general desire for self-sufficiency in their answers, while others indicated unwillingness to be tied into a contract (discussed above in Section 5.4.2). In some cases concerns over being 'locked in' related not to the contract but to what would happen if they wanted to upgrade or remove the technology, or sell the house. Some people pointed out concerns over 'freeloading' – people using communal resources irresponsibly. The latter could be one facet of an unwillingness to share a boiler with other people, which (in the absence of cost information) correlated more strongly than any of the other Reason variables with preference for the plug and play model. However, many respondents indicated in the optional textbox that they had a favourable opinion of sharing energy. Some believed that a neighbourhood scale scheme would be more efficient, and some expressed an ideological preference for sharing (*"Sharing is good"*). One respondent was specific: *"Not wanting to work with a private company… I would much prefer the more community based approach".*

The survey results show empirically that, as previously predicted in qualitative studies, owning and controlling one's own energy generators is appealing to many UK consumers. Including messages about self-sufficiency and 'taking control' in marketing for developments using the plug and play model could therefore make it more desirable for many people. Conversely, if an ESCO arrangement is being used, concerns over sharing resources and giving control to the ESCO will need to be overcome. Some of the statements from respondents suggest that some people may prefer a co-operatively owned ESCO as opposed to control by a private company. Forming a community project is problematic for new developments, as discussed in Chapter 33. One possible solution would be to start with an ESCO, then offer residents the option of 'buying-in' once they have moved in: either by becoming shareholders, or by taking over entirely as a co-operative. This does however require the potentially risky assumption that sufficient numbers of residents would be interested in becoming stakeholders in a neighbourhood scheme.

5.4.3.2 Using and maintaining microgeneration

As expected, scores for the statements *"I would prefer not to have the effort involved in maintaining my own energy generation technologies"*, and *"I'd be worried about using newer energy technologies myself: I'd rather have an expert do it"* both correlated with a tendency to prefer the ESCO model (medium and small effect size respectively). Developers using an ESCO arrangement could therefore emphasise its convenience aspects and provide assurances about service levels in order to make it appealing to prospective buyers.

5.4.3.3 Scepticism about microgeneration

Scepticism about microgeneration was the lowest scoring of the Reason variables. It did not correlate with deployment model preference in the absence of cost information, but when costs were provided it correlated (small effect size) with a preference for the ESCO option. This suggests, unsurprisingly, that those who are sceptical about the benefits of microgeneration are happier to let a private company bear the upfront costs and financial risks. This must be viewed in the context of the overall choice split however: despite sceptics having a greater tendency towards the ESCO option, only 29% of the sample favoured that option when costs were presented, whereas 66% preferred the plug and play option.

5.4.3.4 Space

The statement about having more space without a boiler in the home was ranked second least important, but was correlated with a tendency to prefer the ESCO option, as expected (small effect size). While this may not be a particularly important factor in most people's decisions about an ESCO scheme, it would perhaps be worth pointing out as an advantage when marketing an ESCO arrangement.

5.4.4 **Effect of householder attributes on choice and attitudes**

5.4.4.1 Demographics

Three demographic attributes correlated with choice of deployment model: age, education and urbanisation. All were statistically significant for both the choice without cost information and the choice with cost information. However when logistic regression analysis was carried out, only age was a significant predictor, and only when cost information was not presented (NC Choice).

The absence of a predictor effect for some of the variables in the logistic model, despite their correlation with choice, could be due to sample size or collinearity. If effect size is small (as indeed the Pearson correlation indicates), a minimum sample size of 400 is usually required to detect it using regression analysis (Field 2009b; Miles and Shevlin 2001), whereas the sample sizes here were ≤315. Additionally, while tolerance and VIF values were within acceptable limits for all the regression models, inspection of the variance proportions on the smallest eigenvalue for Models 1 and 3 suggested collinearity between age, education and urbanisation. Age was the only significant predictor of NC Choice, showing that urbanisation and education do not covary significantly with choice when age is held constant. This suggests that the covariance of education and urbanisation with NC Choice shown by the Pearson correlation is in fact due to their covariance with age.

Therefore only age can be said with confidence to have a bearing on choice of deployment model, when cost and contracting information is not presented. While considerations of payback and contracting evidence take precedence, the older someone is, the more likely they are to prefer the plug and play model. This could indicate either that people's preferences change as they get older (individual change), or that social trends and attitudes are changing over time (individual preferences don't change, but aggregate societal attitudes do). If the former, it could be that as people become older they are more likely to own large or complicated systems such as houses and cars, and therefore become more used to the idea of owning them and taking responsibility for their maintenance. If the latter, it may be that as an increasing number of technical or time-consuming processes have been facilitated or automated by technology, and ownership of household appliances has increased, people have become more used to having less personal control over them.

Contrary to the expectation that income would positively correlate with preference for the plug and play option, income was not significantly correlated with the choice in either case. The reasons suggested for the unexpected direction of the effect of price and contract information on choice (hypothetical bias and the dominance effect) would also apply here. In particular, regarding hypothetical bias, respondents with low income asked to imagine purchasing a house may imagine a situation in which they have sufficient capital to do so, and could therefore afford the additional upfront cost of the plug and play option. Indeed, one of the respondents to the "additional reasons" question stated: "*The upfront costs are prohibitive but if* ***I had the money*** *I would spend it on sourcing my own renewable energy (Option 1)*" (emphasis added). This respondent indicated a preference for the plug and play option (Option 1) after price information had been presented, suggesting that she was answering as if she could afford it, rather than basing the decision on her actual current income.

5.4.4.2 DSI

DSI in both the green products and consumer electronics domains was not correlated with a deployment model preference at a statistically significant level. This indicates that DSI is not likely to be a useful predictor of someone's preference for a particular deployment model. It should be noted that a lack of correlation between DSI and preference does not mean that innovative behaviour is definitely not related to preference. However, given the strong correlations between DSI and innovative behaviour found in other studies, it does provide some potentially contradictory evidence to this theory.

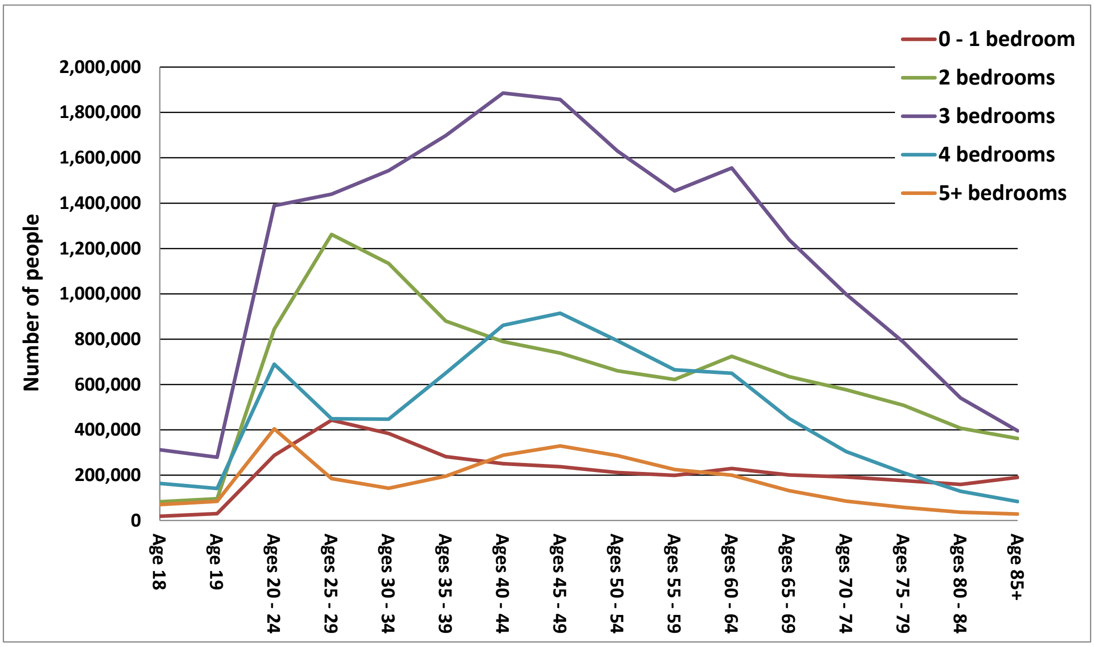
DSI did correlate with some attitudinal variables however, with higher scores on the GreenDSI scale associated with lower scepticism about renewable energy technologies, and higher scores on the TechDSI scale associated with lower scepticism about renewable energy technologies and lower concern about using microgeneration. It is interesting to note that neither DSI scale correlated significantly with the attitudinal variables relating to ownership and control of the technology. Sauter and Watson (2007) and Fischer (2004, 2006) theorised that innovators' financial assets, their tendency to desire autonomy, and their high levels of knowledge about and interest in technology, would cause a desire to own and control microgeneration technologies. However, the results of this survey do not provide supporting evidence for these theories. Unsurprisingly, those with higher DSI scores are less sceptical of newer energy technologies, but this does not translate into a preference for the plug and play model. It may be therefore that householders' circumstances, ideologies and perceptions of the different characteristics of the deployment models are more important than personality attributes related to innovativeness.

Indeed, the demographic variables found to correlate with a preference for the ESCO model (younger age, higher level of education and more urban location) are those which have correlated with higher levels of innovativeness in previous studies. Additionally, scepticism about renewables was not highly scored as a factor in the decision for most respondents, and comments from participants on the ESCO model were frequently phrased as questions (*"Who takes* *responsibility?"*) or referred to the arrangement as an 'idea'. Taken together, this evidence suggests that rather than an ESCO arrangement representing the 'status quo' and plug and play the innovative arrangement (as suggested by the studies discussed in Section 4.4), many participants felt the opposite. It is argued therefore that the 'innovation' in question here is not microgeneration technologies, but the new business models which have grown around it; and that the focus of research into consumer adoption of microgeneration technologies may need to shift away from technological attributes and towards the attributes of different ownership and maintenance arrangements. This is likely to be due in part to consumers' increased familiarity with microgeneration (in particular PV) due to its rapid uptake since the introduction of the FIT. As shown in Figure 1 (Chapter 1), when Watson and colleagues made their predictions regarding innovativeness and householders' choices there were very few microgeneration installations in the UK. By the time this study was conducted (2013 – 2014), there were thousands.

5.4.5 **Alignment of preference with dwelling characteristics and tenure**

Since age has been shown to the only reliable predictor of preference for different deployment models, predicting the alignment of preference with dwelling type is not straightforward. Dwelling type is a function of several factors including personal preferences and priorities, income/assets, family composition, job location and region. However, the 2011 UK Census provides data on dwelling types and age of residents in England and Wales, which can be used to illustrate general trends as shown in Figure 40 and Figure 41. Children have been excluded from the figures as it is assumed that they do not make decisions over dwellings.

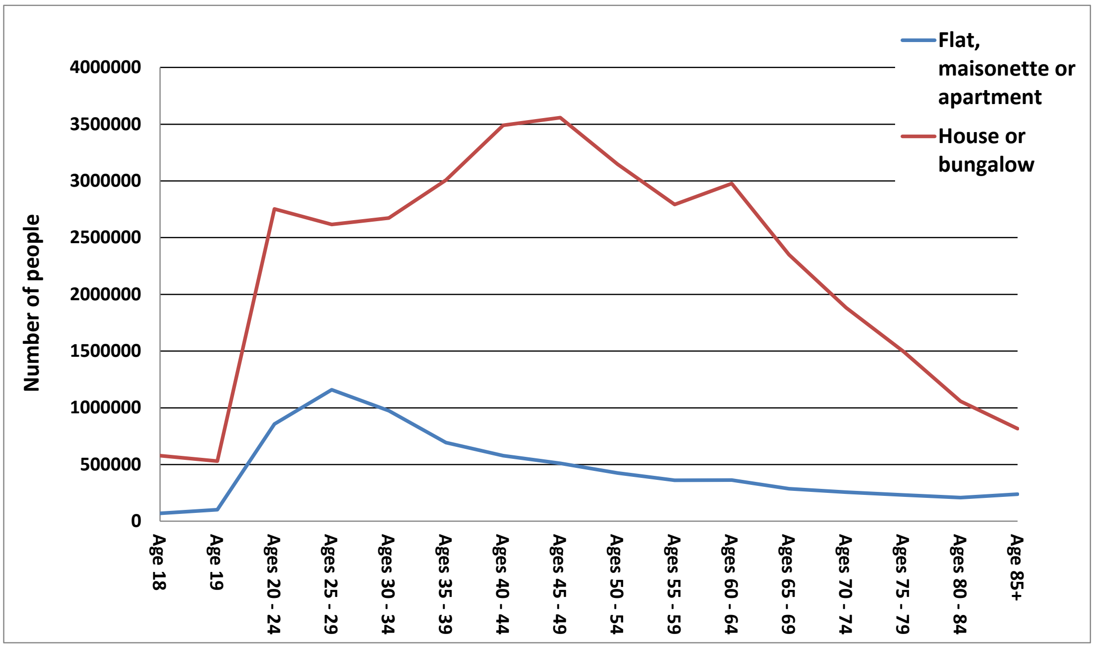
Figure 40. Residents of England and Wales: age of resident and number of bedrooms in dwelling in 2011



Data source: (Office for National Statistics)

Figure 40 shows that occupancy of three and four bedroom dwellings is dominated by people in their forties and fifties, while occupancy of one and two bedroom dwellings is dominated by people in their twenties and thirties. This likely reflects family and career development throughout these periods, with average salary and family size rising with age, and home size increasing accordingly. Occupancy of four and five bedroom dwellings shows two peaks: one in the 20 – 24 age bracket, which is likely due to student and young professionals renting shared houses, and one in the 45 – 49 age bracket, which is likely to reflect occupancy by affluent family groups. Figure 41 shows that in general, younger people are more likely to live in flats or maisonettes, while older people are more likely to live in houses or bungalows.

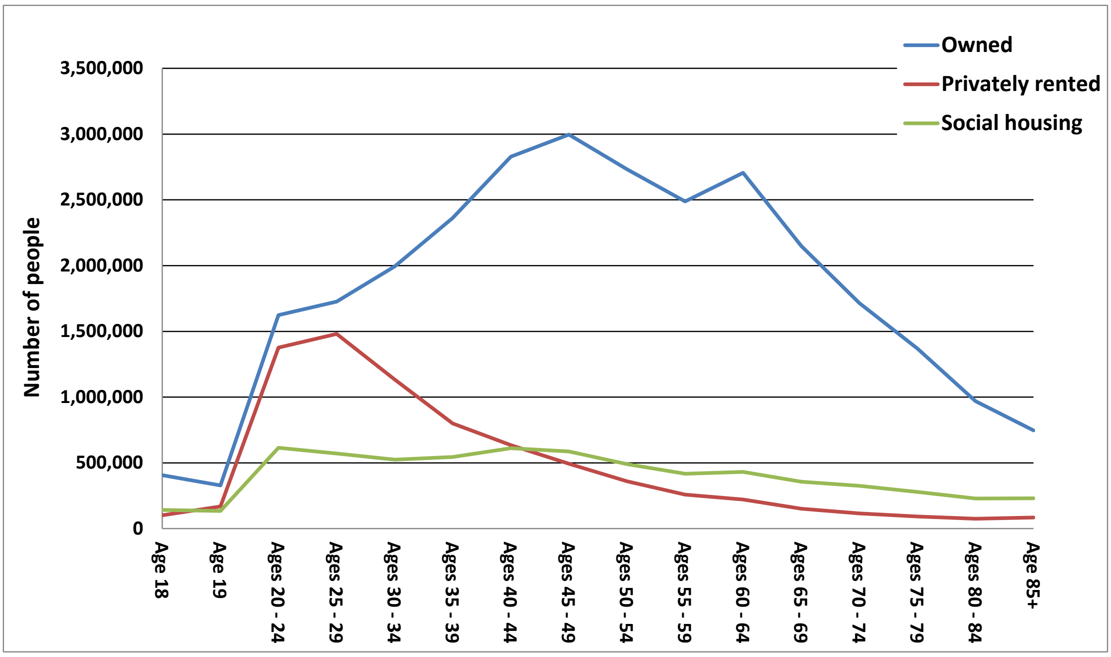
Figure 41. Residents of England and Wales: age of resident and type of dwelling in 2011



Data source: (Office for National Statistics)

Broadly then, there is a general trend towards larger dwellings and houses (rather than flats) as resident age increases, with the exception of people in their early twenties, who may be living in large rented shared houses. As shown in Figure 42, younger people are also more likely to be private renters than older people, although residence in an owner-occupied house is still slightly more common even at younger ages. The number of people in social housing is roughly constant across age groups.

Figure 42. Residents of England and Wales: age of resident and type of tenure in 2011



Data source: (Office for National Statistics)

In general, younger people are more likely to rent, live in a flat, and live in smaller dwellings. Older people are more likely to be in larger houses which they own. As discussed in Chapter 3, flats are particularly suitable for ESCO arrangements as they are dense developments, the fees could be bundled with other service fees, and the arrangement could help to overcome the landlord-tenant incentive divide. Larger dwellings with higher heat demand may be more suitable for plug and play arrangements, especially if they are on developments with lower dwelling density. Since, *ceteris paribus*, younger people are more likely to prefer Option 2 , while older people are more likely to prefer Option 1, householder preference may well be in alignment with dwelling suitability for the different deployment models in the majority of cases.

Another factor with particular relevance here is that younger buyers tend to be more attracted to new build homes (Leishman et al. 2004). This is partly because new builds tend to be more affordable, and partly due to the government's help to buy schemes, the first of which launched in April 2013 and allowed first-time buyers to take out a 20% equity loan from the government for a new build home. As discussed in Section 5.4.5, current trends in new builds mean that increasing numbers are likely to be suited to ESCO arrangements. Here again, consumer preference is slightly more likely to align with a dwelling's suitability for a particular deployment model.

The results of this survey have not identified a reliable way to use demographic information to predict which deployment model people are likely to prefer. However, they have provided evidence showing that for many new developments which could benefit from the services of an ESCO, prospective buyers are likely to be open to the arrangement. However, developers wishing to deploy microgeneration using an ESCO on developments where prospective buyers are likely to be older may have to put more effort into marketing the arrangement to make it attractive to consumers.

5.5 Conclusions and future work

The aim of this chapter was to collect and analyse quantitative data to consider the empirical evidence supporting or contradicting some of the hypotheses formed in Chapter 34. While the correlations (or lack of correlations) identified cannot be assumed to indicate a direct relationship between variables, they do add to the evidence base relating to the hypotheses.

We now return to the hypotheses to reassess the evidence for or against them in light of the results of this chapter, and to briefly discuss the opportunities for methodological improvements and further investigation identified.

5.5.1 **Attitudes toward deployment model attributes**

Which attributes of the different deployment models have the greatest effect on householders' attitudes, and which deployment model (if either) is likely to be more popular with people in the UK?

This survey found that, if an ESCO arrangement and a plug and play arrangement are equal financially, there is an almost even split in preference, with neither significantly more popular than the other. When the plug and play model has a high upfront cost but yields higher income compared with the ESCO model, the plug and play model is more popular. The attributes judged most important to the decision were ownership and control (or otherwise) of microgeneration technologies.

Original hypothesis: The following factors will cause householders to prefer the plug and play model:

A desire for autonomy and control

The correlation between desire to own and control microgeneration provides quantitative evidence for this hypothesis. Additional qualitative evidence for the importance of autonomy and self-sufficiency was present in statements from respondents.

Interest in technology

Mixed evidenced for this hypothesis was found. TechDSI did not correlate with preference for either option, but level of agreement with the statement “I'd be worried about using newer energy technologies myself: I'd rather have an expert do it” was correlated with a preference for the ESCO Option.

Original hypothesis: The following factors will cause householders to prefer the ESCO model:

The high upfront cost associated with the plug and play model

Evidence here was mixed: respondents indicated that they gave some importance to the fact that the ESCO model allowed them to spread payments, but presenting them with cost information for the models in fact caused more respondents to choose the plug and play option.

The ‘hassle factor’ of using and maintaining unfamiliar technology

There was quantitative evidence for this hypothesis, as respondents’ level of agreement with statements about preferring not have the effort of maintaining or using microgeneration correlating with a tendency to prefer the ESCO model (medium and small effect size respectively). Further qualitative evidence was seen in additional statements by respondents.

Scepticism about renewable energy

There was mixed evidence for this hypothesis. Scepticism was rated the least important consideration by respondents, and in the absence of cost information did not correlate with choice. However when respondents were informed of cost and contracting information there was a weak correlation with preference for the ESCO option.

Increased availability of living space in the absence of a boiler

There was quantitative evidence that this factor has a weak effect on preference.

A potential methodological improvement identified here would be to ask respondents to rate the importance of the different considerations twice: once after the scenario with no cost information, and once after the costs had been presented. This would provide more insight into the relative weight accorded to them compared with pricing information. Additionally, having identified which of the hypothesised contract features and attitudes are most important to respondents, and additional reasons (such as a dislike of energy companies and ideological preference for communal facilities) which were not initially considered; the impact of each deployment model feature on willingness-to-pay for microgeneration could now be analysed. This could be achieved using a conjoint analysis experiment in which participants make choices between pairs of options covering different combinations of features.

While the survey design was beneficial in allowing sufficient numbers of responses to be collected for statistical analysis, further detail on people's attitudes could be obtained through interviews or focus groups. Given that a desire for control and ownership of generating technologies has been identified as particularly important, it would be interesting to investigate further the specific reasons for this preference: is it predominantly due to logistical concerns, fear of the unknown, or is a more abstract cultural preference? Insights into this phenomenon could help developers and marketers to overcome consumer reluctance to sign up for ESCO or microgrid arrangements. Furthermore, if domestic ESCOs become more prevalent, there would be significant scope for interviewing and surveying ESCO customers to find out if such concerns persist after uptake, or indeed if a new set of benefits and concerns come to light.

5.5.2 **Effect of householder characteristics on deployment model preference**

Do people's demographic characteristics or personal attributes affect their preferred choice of deployment model, and if so – how?

Original hypothesis: DSI will positively correlate with a preference for the plug and play model over the ESCO model.
No quantitative evidence for this relationship was found, as DSI did not correlate with choice in either the consumer electronics or the green products domain.

Original hypothesis: Income will positively correlate with a preference for the plug and play model over the ESCO model.
No quantitative evidence for this relationship was found, as income did not correlate with choice.

Original hypothesis: Age will negatively correlate with a preference for the plug and play model over the ESCO model.
Contrary to what was expected given the theoretical evidence examined in Chapter 3, age was found to positively correlate with a preference for the plug and play model.

Original hypothesis: Level of education will positively correlate with a preference for the plug and play model over the ESCO model.
Mixed evidence for this hypothesis was found: there was a weak positive correlation, but logistic regression analysis suggested that this was due to collinearity with other variables.

With the exception of the link between age and deployment model preference, the results of this chapter suggest that future explorations of attitudes to microgeneration deployment models should focus on political and social beliefs, and people's perceptions of the characteristics of different options, rather than demographic differences between householders. Rather than a concentration on tailoring solutions to preferences which are hard to predict, the latter would allow the most important 'sticking points' for consumers to be identified and addressed through service adaptation and the provision of relevant information. Additionally it was argued that consumers' perceptions of unfamiliarity, newness and 'innovativeness' in microgeneration are in many shifting towards the business models used for ownership and maintenance, rather than the technologies themselves.

However, if further investigations into the relationships between householder characteristics and their preferred deployment model were to be conducted, there are some potential avenues of exploration. For reasons of parsimony this survey did not collect detailed information on respondents' lifestage, family composition, socioeconomic status, or political attitudes. For example, people's assets or debt levels could give a more accurate measure of socioeconomic status than income. Regarding attitudes, it may be that regional political trends have a bearing on attitudes: for example, do people on the left of the political spectrum favour ESCO involvement more due to the traditional liberal ideals of government intervention, as opposed to conservative emphasis on hands-off governance? Voting patterns are very predictable in many areas of the UK, so identifying relationships here if they exist would be useful.

5.5.3 **Alignment of preference with dwellings**

Do consumer groups' preferences for a specific deployment model align with the physical suitability of the types of dwelling they are likely to buy?

This chapter has provided some quantitative evidence that ESCOs are likely to be an 'easier sell' to younger people, who are more likely to buy dwellings suitable for ESCO arrangements: on smaller, denser, new build developments. This is a generalisation however, and the pattern of new build purchase is complex, and will depend on a number of other factors apart from age. Therefore another useful methodological development would be to link survey respondents or interviewees to a classification system such as Experian MOSAIC. Such consumer classification systems are valuable as they not only provide information on typical demographic and attitudinal characteristics, but also describe the geographical spread of different consumer categories across the United Kingdom. This would allow patterns of preference (if existing) to be compared with the locations of new residential developments.

6 Conclusions and recommendations

The overarching conclusions of this thesis are that many of the drivers and barriers for microgeneration in new UK homes differ significantly from those for retrofitting: in particular the lack of economic incentives for developers and apathy or reluctance on the part of prospective home buyers. New business models, in particular ESCO arrangements, are likely to have a significant role in overcoming these barriers, by providing an ongoing revenue stream from microgeneration for developers, and by overcoming several of the antecedents to householders' reluctance to adopt microgeneration. However, an ESCO option will not be financially feasible for all developments therefore the plug and play arrangement is likely to continue to play a role in the diffusion of the technology. This is particularly the case since a small majority of householders would still prefer the plug and play option over the ESCO option if given the choice. However, there is evidence to indicate that trends in new residential developments, the UK's regulatory environment, and the attitudes of those most likely to purchase new homes, will collectively cause the ESCO arrangement to become more common in new build homes in the UK over the coming decades.

This chapter brings together the detailed conclusions from three interlinked research chapters in this thesis, revisiting the research questions set out in the introduction, and summarising the novel contributions to knowledge that this thesis has made. A review of the research is presented, reflecting on the methods used and limitations of the thesis in order to inform future studies in this area. Finally, recommendations are made regarding how the research in this thesis could be extended and built upon in future studies.

6.1 Conclusions

This thesis sought to characterise the drivers and barriers to the inclusion of microgeneration in new homes, and to identify ways in which barriers could be overcome. A review of the literature revealed that existing studies on microgeneration largely focused on retrofit, particularly those concerned with consumer adoption of the technologies; and that studies of 'eco-homes' often did not differentiate between microgeneration and other low carbon technologies. This provided the motivation for the focus on new homes. The review also identified that ESCO arrangements, despite being rare among domestic developments at present, may have a role to play in encouraging the use of microgeneration in new homes. This provided the motivation for a focus on different deployment models and consumer attitudes towards them. Five overarching research questions were addressed in the thesis:

What are the drivers and barriers for microgeneration in new homes in the UK? In particular, do they differ significantly from those relating to retrofitting microgeneration?

What interventions could be used to overcome barriers to microgeneration in new homes in the UK?

Chapter 3 comprised a coevolutionary analysis of the drivers and barriers for microgeneration in new homes, using evidence from research interviews and existing literature. Significant differences between retrofitting microgeneration and incorporating it in new homes were identified, with respect to the factors affecting uptake and the actors involved. While for retrofit homeowners are the primary decision-makers and subsidies are the main drivers for uptake, for microgeneration in new build homes developers are the primary decision-makers and regulations such as the Zero Carbon Homes target and the Building Regulations are the main drivers. In both cases capital cost is a significant barrier, but for new build this issue is also linked to property valuation, developers' perceptions of consumer desires and priorities and cultural issues within the building industry. The most significant barrier was found to be a lack of financial incentives for developers to include microgeneration in their developments. As a result, a suggested intervention was to introduce a financial incentive for developers to include microgeneration in developments, potentially by extending existing subsidies such as the FIT.

New build also presents opportunities for an additional intervention: the expansion of developer activities to make use of energy service contracting arrangements which may provide the financial incentive which has been lacking. Although relatively uncommon at present, evidence from the interviews suggested that these arrangements may become more important in future.

How can different deployment models for microgeneration be used to overcome barriers to the technology in new homes in the UK?

Building on this latter finding, Chapter 4 synthesised literature from several disciplines (diffusion of innovations, economic analysis of district heating, social science and psychology) to consider in more detail what role different deployment models for microgeneration could play in encouraging its use and uptake in new build housing. The effects of heat demand, house type, development size and householder characteristics on the optimal choice of deployment model were considered. A technoeconomic analysis was also conducted to measure the effects of electricity demand on householders' energy bill savings/technology payback period under different deployment models. It was found that current trends in new residential developments, institutional factors and consumer attitudes could be predicted to favour the development of ESCO arrangements in the UK, but that this was not certain as some factors still favoured private ownership of microgeneration by householders. While householder electricity use was found to affect payback periods and savings from solar PV, it had little impact on the comparative profitability of the two deployment models. The theories that the ESCO model could overcome consumer reluctance to adopt microgeneration, and that more innovative householders would prefer private ownership while less innovative householders would prefer an ESCO arrangement were discussed. Finally the definition of 'innovativeness' was clarified, in order to develop a quantitative method for investigating the theories.

What are consumers' attitudes to different microgeneration deployment options, and how do they differ for different demographic groups?

What effect will differences in attitude (if any) have on consumers' choice of microgeneration deployment model in new builds in the UK?

Having identified the need for a quantitative investigation of householder attitudes towards different microgeneration deployment models and the role of innovativeness in householder preferences, Chapter 5 presented a method for quantitative analysis and its results. A questionnaire was used to measure UK adults' preferences for the ESCO or the plug and play model of microgeneration ownership, and the relationships between respondents' attributes and their choices and attitudes. Preferences were found to be mixed: if money were no object, respondents' preferences were split very evenly between an ESCO or a plug and play arrangement, with slightly more people preferring the ESCO arrangement. Respondents were largely not apathetic to the choice, with only 9% saying they did not care which arrangement was in place. Financial and contracting factors, ownership and control were most significant in respondents' choice between the models; and younger age, higher level of education and living in an urban area were found to weakly correlate with a preference for the ESCO model. No correlation between respondents' innovativeness and their preference for a particular model was measured. It was argued that new business models for the ownership and maintenance of microgeneration are now likely to be perceived as more innovative than the technologies themselves, and that marketing and research efforts should focus more on the attributes of these business models in order to increase the uptake of microgeneration technologies. Evidence of trends in new residential developments, UK regulations and policies, and the attitudes of those most likely to purchase new homes, suggests that the ESCO arrangement may become more common in new build homes in the UK over the coming decades.

6.2 Contributions

The importance of the conclusions stated above has been discussed in the relevant chapters. This section brings these discussions together and briefly summarises the contributions of this thesis, to highlight its novel contributions to microgeneration research: in terms of knowledge of the subject, and the techniques used to research it.

6.2.1 Insight into unique drivers and barriers for microgeneration in new build homes

The coevolutionary analysis of drivers and barriers provided evidence that many of the social, economic, technical and institutional issues involved with incorporating microgeneration in new homes are substantially different from those involved with retrofitting the technologies. As such, it demonstrates the importance of considering new build domestic microgeneration as an issue in its own right, rather than subsuming it into analyses of retrofitting. The coevolutionary analysis also provides an updated appraisal of the drivers and barriers for microgeneration in the UK, being the first to explicitly focus on microgeneration (as opposed to 'eco-homes') since the introduction of the FIT. Identifying the barriers to the uptake of microgeneration in new homes may also inform decisions by policy-makers and developers who wish to encourage the diffusion of these technologies.

6.2.2 Demonstration of the application of Foxon's coevolutionary framework

An additional contribution of Chapter 3 is as a demonstration of the use of Foxon's coevolutionary framework to investigate the diffusion of a specific group of technologies in a certain sector. Since its development in 2010, the framework has been used to analyse the development of ESCO business models (Hannon et al. 2013), and to the development of energy efficiency strategies in the UK more broadly (Foxon and Steinberger 2013). This study has demonstrated the flexibility of the framework by applying it to a technology and sector specific research question, and by incorporating the concepts of 'virtuous' and 'vicious' cycles of evolution from the work of Hekkert et al.

6.2.3 New insights into the role of microgeneration deployment models

Chapter 4 brought together previously disparate strands of research to draw new insights: namely that the ESCO deployment model is likely to have a significant role to play in facilitating the uptake of microgeneration in new homes, but that the plug and play arrangement will still be more suitable in some cases. This both informs decision-making in this area and demonstrates the value of considering results and techniques from disciplines outside those directly connected to the area of study.

6.2.4 Quantitative evidence on householder attitudes to deployment models

In Chapter 5, the first quantitative study of householder attitudes towards different microgeneration deployment models was conducted. In addition to providing previously unavailable quantitative data on householders' attitudes and choices, this chapter also serves as a first demonstration of techniques for describing and measuring attitudes to the deployment models, and the challenges involved (discussed further in the following section). Additional to its contribution to the research questions in this thesis, the use of Goldsmith and Hofacker's DSI scale with British participants was validated in the two domains of 'green' products and household technologies. The scale was shown to be internally consistent in both cases. This strengthens the case for its use in other studies of innovativeness in the UK.

6.3 Research review

Having considered the novel contributions of the research, it is useful to reflect on the challenges involved in conducting it, and the strengths and limitations of the methods used. This review serves as a statement of the context in which the conclusions set out above must be considered, a demonstration of the development of research skills by the author since the start of the study, and also to inform future studies which may use similar methods.

6.3.1 Developments since 2010

Given the timescales involved in producing a PhD, it was inevitable that political, social and technical changes would occur between its inception and completion. Since 2010, when this project started, many such changes have occurred which have impacted on the study's context and subjects.

The most significant occurrence, discussed in several of the relevant sections of this thesis, has been the large and rapid increase in the number of microgeneration installations in the UK, in particular installations of PV. Since the start of this thesis, microgeneration has grown from a little-known niche technology to a familiar feature for many people. As uptake increased in response to the introduction of the FIT, new manufacturers and installers entered the market, and prices for many technologies (particularly PV) fell. As discussed in Section 5.5.2, this is likely to have had an effect on many of the issues discussed in this study, particularly those relating to householder attitudes to microgeneration. However, it is still far from a mainstream technology, and the majority of opinions expressed and results presented herein were collected after this change had come about. Despite increasing use of microgeneration, there is a long way to go before its potential – outlined in Section 1.2 – is fully realised.

In addition, the policy landscape for low carbon new homes and microgeneration in new homes has changed – particularly during the final stages of this research in 2013 and 2014, during which the Government commissioned a housing standards policy review. In March 2014, plans were announced to ‘wind down’ the Code for Sustainable Homes and incorporate more standards into the Building Regulations. This will inevitably have a bearing on the institutional issues discussed in Chapter 3.

It is also important to note that for much of the duration of this research, the UK, and indeed most of Europe, was undergoing a recession. Unemployment, static or shrinking GDP and a rising cost of living tend to reduce spending by consumers and investors, and are likely to have had led to more cautious financial decision-making. While the impact of these circumstances on the interviews and questionnaires conducted in this study cannot be quantified from the available data, the results and conclusions must be considered in this context. In a more buoyant economy, respondents may have been more willing to take on (hypothetical) capital costs and financial risks.

6.3.2 Interdisciplinary research

This thesis took an interdisciplinary approach to investigating the research questions posed. Drawing together previously disparate strands of research provided fresh insights into the role of different deployment models in encouraging the uptake of microgeneration in new homes, and applying techniques and theories from psychology, innovations research and social science provided quantitative data on householder attitudes. Using a previously validated psychological construct scale in Chapter 5 increased the reliability and accuracy of the data collected and the conclusions drawn. The use of this interdisciplinary approach in Chapter 4 could have been improved by conducting a more systematic search of the literatures of different disciplines: differentiating by discipline rather than searching by the topic of interest. While a topic-based approach was applied in order to maintain focus on the central research question, with the benefit of hindsight it is apparent that a more systematic approach would have allowed the following discussion to be structured in a way which signalled the value and contribution of the approach itself more clearly.

Interdisciplinary research also carries the risk of investigations becoming too “broad and shallow”: touching on various important points without fully investigating any. This research has sought to avoid this by setting clear and detailed research questions throughout, and selectively narrowing the lines of enquiry throughout the thesis: from UK-wide drivers and barriers, to the subject of microgeneration deployment models, to householders’ attitudes to two specific deployment models. While this means that some of the questions raised by this research have not yet been answered (for example, a more detailed consideration of how the UK regulatory environment affects choice of deployment model) , it has avoided the pitfalls associated with attempting to address too many research questions in too short a time. The opportunities for future research studies to take on some of these unanswered questions are discussed in the relevant results chapters, and in Section 6.4 of this chapter.

6.3.3 Interviews

The interviews conducted for Chapter 3 provided insights from stakeholders in the construction industry, government and researchers in microgeneration. However, of the three developers interviewed, only one was from a ‘mainstream’ housebuilding firm as opposed to specialists in eco developments. The under-representation of mainstream housebuilders was due to difficulties encountered in contacting the firms, and a lack of responses to enquiries. It is not possible with the available data to determine whether this reluctance to engage was representative of mainstream homebuilders’ attitudes to microgeneration, or due to other factors such as workload and time constraints. A key learning point for future research interviews is to prioritise recruitment in the project timeline – beginning the approaches to potential participants alongside or prior to detailed preparation of the interview method. An additional strategy would have been to allocate more time after interviewing participants who did respond, so that any recommendations or contacts gained during the interviewing process could be followed up.

An additional limitation of the interviews was that participants were not specifically asked to quantify the relative importance of different drivers and barriers, and certain key points were not followed up in detail. While the intention was to avoid bias by not pre-judging the opinions of interviewees; having heard their initial opinions, follow-up questions could have drawn out opinions on the importance of different factors. While the semi-structured approach was valuable in ensuring that researcher bias did not preclude the discussion of important topics, a slightly more structured approach, with more standardised questions, would have facilitated more detailed information-gathering in some cases.

6.3.4 Surveys and statistical analysis

Following the researcher’s experiences with recruitment for the research interviews in Chapter 3, more time was allocated for recruiting participants for the questionnaire in Chapter 5. The sample size obtained (which although larger, was still limited by the time and resources available for research) was large enough for the purposes of most statistical tests, and with the exception of age distribution the sample was adequately representative of the UK population. However, an even larger sample size (>1000) would open up additional possibilities:

- The sample size for this study was not sufficient to ensure that the logit model used captured small effect sizes. In this case, time and resource constraints precluded a longer recruitment period or the use of other methods such as telephone or widespread postal surveys. However, if future studies in this area (see Section 6.4) have sufficient resources available, these methods would likely obtain a larger and potentially more representative sample, sufficient to detect smaller effect sizes for correlation between variables.
- A larger sample size, coupled with additional computing power, would allow for testing of collinear variables (such as age, education and urbanisation) using more sophisticated computer models.
- The Experian MOSAIC tool used in this study can assign people to one of 15 groups and 66 sub-groups based on their postcode. These groups represent segments of UK society, and are richly detailed in terms of attitudes, lifestyle and demographic attributes. The sample size in this study meant that the resulting groups were too small to produce accurate or reliable conclusions from statistical analysis. Larger sample sizes would allow the use of this or other geodemographic tools.

Obtaining a larger sample size could be achieved by allocating more time to recruitment, or by disseminating questionnaires through a third party with expertise in the area, such as a commercial call centre or a local authority.

The questionnaire used in this study was piloted prior to being disseminated more widely. However, some flaws were discovered upon analysing the resulting data, which should be rectified in any future iterations or validations of this study:

- As discussed in Section 5.2.3, the questionnaire included a question on other household members, in order to apply a measure of equivalised income. However, after the dissemination of the questionnaire it became apparent that the question on income did not capture total household income in cases where occupants did not share finances. The equivalised measure was therefore invalid, and respondent income was therefore used in the final analysis instead. Future questionnaires wishing to capture a measure of respondents' financial status should either request total household income to apply an equivalised measure, or request details of respondents' disposable income and assets.
- After the first choice between an ESCO or plug and play arrangement, respondents were presented with cost information, then asked to make the choice again. The cost information included details on the contract entered into for the ESCO arrangement. It is unclear therefore how much of the difference between the two choices was down to the financial information, and how much was due to respondents' attitudes to contracting arrangements. A solution to this issue would be to avoid mentioning any contract arrangements when presenting financial information, instead including the contract as one of the attributes/reasons to be scored in the next section of the questionnaire.
- Due to the varying and uncertain nature of maintenance costs, no cost information was given regarding technology maintenance for the different scenarios. One respondent pointed out in the comments section that this made it difficult to make an informed choice between the two options. In future, this could be dealt with by including a statement saying that there would be no marginal maintenance costs for microgeneration technologies compared with 'conventional' technologies such as gas boilers, or by attempting to calculate an average for maintenance costs using quotes from different UK manufacturers/maintenance firms.

A general learning point here is that with additional time available, a more comprehensive pilot study should be conducted before disseminating the questionnaire, in which pilot results are analysed using the methods planned for the final results.

6.4 Recommendations for future research

One of the aims of this thesis (Chapters 4 and 5 in particular) was to identify possible avenues for future research into how different deployment models for microgeneration could facilitate its uptake. While time and resource constraints have prevented the use of certain techniques and the investigation of certain research questions, the process of conducting this research has highlighted areas which could be pursued in future studies. This final section suggests ways in which the research presented in this thesis could be extended and built upon in light of the conclusions and research review above.

6.4.1 **Case studies of different deployment models**

The literature synthesis and technoeconomic analysis in Chapter 4 provided insights into the effects of varying development and householder characteristics on the economics of different deployment models. In order to more accurately predict outcomes such as internal rate of return, payback periods (for developers or householders) and carbon savings, a more detailed model including parameters such as development size, fabric efficiency standards and capital and operating costs for district heating could be constructed. Much of this data could be drawn from real-world case studies of ESCO contracts, district heating schemes and new developments incorporating microgeneration, which are likely to become more common (and hence available for study) in coming years. The ultimate goal of this research could be to produce a multi-criteria decision-making tool for planned developments, which would indicate whether an ESCO/district heat arrangement or a plug and play arrangement would be better suited.

6.4.2 **Post-hoc study of householder attitudes to different deployment models**

Section 5.2.6 set out the rationale for conducting a hypothetical choice study rather than a post-hoc study to measure attitudes to different deployment models. However, with more time to dedicate to participant recruitment (particularly if residential ESCOs become more common in future), opinions and attitudes of householders under an ESCO contracting or district heating arrangement could be measured. This would have the advantage of removing the 'hypothetical' aspect of enquiries, and ensuring that participants had a full understanding of the ESCO arrangement. It would also highlight any advantages, disadvantages or problems perceived by the service users, which may not have been thought of by the researcher or the participants in the present study. While direct comparison of individuals' attitudes would not be possible, comparisons could be made with similar studies of householders using a plug and play arrangement.

6.4.3 **Willingness-to-pay studies**

In Chapter 5, the relative importance of different attributes of the two deployment models was measured by asking questionnaire respondents to score them. Additional attributes perceived as important by respondents were also identified in the 'additional comments' section of the questionnaire. A valuable addition here would be the use of a willingness-to-pay (WTP) study such as those carried out by Claudy et al. (Claudy et al. 2011; Claudy et al. 2010b) for technological attributes of microgeneration, to determine the utility or disutility ascribed to each attribute of the deployment models by householders. In addition to providing a less subjective measurement scale, this would also indicate to developers how much home buyers would be willing to pay either up front for microgeneration technologies, or for the provision of district heating or energy services: facilitating decisions about which scheme to implement.

Further studies in this area using WTP techniques could also include deployment model attributes which were mentioned by participants in the 'additional comments' section of the questionnaire for this study but not included in the scoring section, such as distrust of energy companies and concern over other people's use of shared resources.

6.4.4 The effect of marketing messages for microgeneration on different segments of the population

The underlying motivation for investigating householders' deployment model preferences and their correlates was to produce evidence which would assist in effective communication about microgeneration to encourage its uptake. A logical next step therefore would be to test the effects of different communication methods and messages on different segments of the population. This could be achieved using a similar questionnaire to the one used in Chapter 5, varying the descriptions of the scenarios depending on the communication method to be tested, and bearing in mind the attributes rated as important by respondents in this study: ownership, control, spreading the cost and the effort involved in using or maintaining microgeneration. Householders' opinions on their preferred information sources could also be sought, using focus groups or questionnaires.

6.5 Concluding statements

This research was motivated primarily by the need to increase the proportion of renewable energy used and reduce GHG emissions, in order to avoid the worst effects of anthropogenic climate change. The focus on microgeneration was due to its potentially large contribution to the decarbonisation of the UK's energy supply, and the potential for paradigm shifts in the ways in which energy consumers view and use energy. However, this thesis does not seek to claim that microgeneration is the only, or the best, solution for decarbonising our energy supply and reducing our emissions. Achieving a step change in the way we generate and use energy will require the use of a variety of technologies and techniques, and the commitment of a diverse range of actors, from international agencies to individual householders.

This thesis has provided new insights into a group of technologies which have significant potential to reduce GHG emissions, diversify energy sources and increase energy security, which are nonetheless only part of a multi-faceted approach to combatting climate change. Applying these insights in isolation may achieve only incremental changes, but alongside inputs from the many researchers now tackling climate change from multiple disciplinary angles, it is hoped that they may contribute to a turning of the tide.

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Appendix A: Sample interview transcript

HJ = Hannah James (interviewer)

Identifying remarks have been redacted to preserve interviewee anonymity.

Content	**Speaker**
So if you could just quickly say who you are and what you do at *[redacted]*?	HJ
My name's *[redacted]*, I'm an associate in *[redacted]* and I work within the sustainability team. So that has two factions: basically two that are more sustainability assessment kind of work, and also sort of technology focused and design on more marginal newer technologies, which have been prevalent over the last couple of years. We also do computer simulations on new buildings and technological systems as well.	Consultant 2

Ok. Are most of the projects in *[redacted]*- are they mainly commercial buildings rather than housing?	HJ
Yeah... I mean, I'd say commercial buildings, I mean we do mostly non-domestic, but when we work on large and mixed-use developments there's certainly an element of domestic property within that that we work on too. I think the real limitation from our point of view as a consultancy getting involved in domestic property is that a lot of it is fairly commoditised and most developers conjointly work with contractors, so a consultant's role - you know, there's not such a need for us to be involved at that kind of stage. So, for example Barratt Homes, they would probably work with an architect in the early stages, and they may even have in-house architects, and then the system design within each of those might be led then by a contractor working with them. So that's probably the reason why we don't really get too involved in a lot of domestic property work. But certainly aware of some of the lower-energy buildings that I've worked on - some of those have been more bespoke domestic property that maybe required a consultant to actually be taken on, because of the non-standardised approaches to designing a building.	Consultant 2

So when you say 'commoditised', do you mean it's all being - it's all very standardised just to get a quick turnover, or...	HJ
Yeah, obviously a contractor, whether it be Bovis or Barratt, or whatever, they basically, they roll out similar building designs throughout the country, and when it comes round to system integration you may install some of the more leading technologies such as solar thermal, and potentially PV, or air source heat pumps, but they're very much commoditised in themselves anyway. I mean 10 or 15 years ago there was still very little awareness within the industry, but now a lot of them are pretty quick to install those technologies on an economic basis for a lot of their properties. Certainly driven by local planning, which is not always bad from a cost point of view.	Consultant 2
So how much does microgeneration feature in the types of projects that *[redacted]*gets involved with?	HJ

I must say, probably up to about 2005, certainly I would say it was very much led by the client in terms of their aspirations. And the costs were quite prohibitive really to look at things on a purely economic point of view, i.e. in terms of simple payback for a technology. What we found with building regulations and local policy, such as the Merton Rule in London, that started to drove the absolute need to integrate low- or renewable energy technologies within buildings, so that was coming from... we focused on driving down demand through more passive measures, then you're adopting some of the more mainstream lower cost technologies within buildings. Interestingly, the really big restriction now that we've found is a bit of an unfortunate outcome, was that you may have a 10% renewables requirement, so a lot of technologies started being sized to meet 10%of the renewables as opposed to being the optimum kind of engineering solution. And I think that caused a few... well, certainly from our perspective we were very keen to drive... you know, with PV you can size the number of panels to meet 10% and it doesn't really affect their performance, but maybe with a heat generation technology, you start to size technologies to meet 10% and you think well actually, it's better that we size this from a controls perspective to 30 or	Consultant 2

40%, or even peak load, and you start to... become a bit of an issue I think.	
It's actually less efficient isn't it, to have something that's not working at peak load?	HJ
It can be, I mean there's certain ways you can connect heat pumps and biomass boilers to buffer tanks and thermal stores, so you can run them at effectively full load, even though the secondary side kind of building demand is well below that.	Consultant 2
So, is it a case of just for cost reasons: meeting the minimum standards then not going any further because there's no point and there's no regulation to say that you have to?	HJ
Yeah that's exactly right, you've got Part L compliance, building regulations and then you've got maybe a requirement through BREAAM or Code for Sustainable Homes, and then maybe on top of that you've got some local policy legislative drivers that mean from a planning perspective you have to meet a certain percentage, but inevitably, I mean, if you strip away feed in tariff and	Consultant 2

renewable heat incentive, then the driver's cost really, to size for compliance, as opposed to sizing from an engineering optimum point of view or indeed literally, you know, size to the maximum possible on a site, where they would be especially constrained...	
That's really interesting. So, you've mentioned cost - I mean, what - this is a bit of a broad question really - but what kind of cost impact does including microgeneration have on a building development, and how do developers try to recoup that cost, is it mainly through the feed in tariff or is it elsewhere?	HJ
On a domestic point of view, you have to really take a step back and think well, the developer-stroke-contractor will build a house, and then sell that in its entirety to a home-owner. So, anything like the feed in tariff or renewable heat incentive will then only benefit the home-owner. Unless they come up with a decentralised energy strategy for the site, which may be like a central energy centre with a biomass boiler district heating and then maybe they retain ownership, essentially, of anything that's installed on individual houses. And then they essentially sort of sell	Consultant 2

energy, whether it be heat or electricity, to the homeowner, so there are obviously precedents of that, but if it's simply a developer building a hundred houses on a site and then selling each of those individual plots to a home-owner, there's no real benefit to him to install renewables is there? Other than, you know, probably a subjective kind of aspect to selling the house, which - you may think there's added value in terms of being PV on a roof and solar thermal, and there's obviously lots of discussions about that, but it's not really discrete or clear-cut how much value spending £10,000 to install PV on a house actually brings to the market value. And that's obviously been something that's been questioned quite a lot over the last couple of years, and I think a number of different estate agents have tried to approach it.	
So it's difficult to say how much it adds onto the value of the house?	HJ
Definitely, yup.	Consultant 2
Do you get any sense, maybe subjectively, of whether it - how much kind of consumer appetite	HJ

there is for these houses which have got technologies - microgeneration technologies - on them?	
I think it was - certainly 10 years ago it would've been a quite marginal subset of the population who were kind of, obviously very passionate about green technologies and sustainable living, and the few examples you saw originally were co-operative kind of small-scale housing developments were literally collectives of people, who - you know - had read a lot in their own free time and perhaps even worked in the industry and knew - like, as an architect or maybe building services engineer. Those kind of people were driving the earlier market I would have said. But more recently, people are more aware about energy costs, and obviously rising gas and electricity bills, and you can obviously start to sell these technologies on that basis. You know, because gas prices are going up exponentially, and electricity, and if you extrapolate historical trends in electricity and gas prices forward 20 or 30 years, it's quite a compelling story for people. And people tend not to move around a lot from house to house, so they can look at a long term investment in a bit more of a positive way.	Consultant 2

So emphasising the economic benefits is probably going to be the selling point?	HJ
Yeah... trying to sell carbon to people, it gives people like a fluffy feeling: nice happy feeling. But do people really know what a tonne of carbon looks like? You know, and what that means - I mean, it really is seriously a drop in the ocean compared to carbon reduction requirements in the country. But to give people that feeling that they're actually supporting that - now I'm sure some people would be driven maybe to spend a bit more money on their house because of that, but really I suppose what they'd be thinking about is reduced energy costs versus a conventional house, and that probably will always be the biggest driver I think.	Consultant 2
Just quickly going back to what you were saying about who retains ownership of the technologies: whether it's the developer or whether it gets sold onto the homeowner, have you noticed any trends in which of those options is the most prevalent at the moment, and how that's sort of developing?	HJ

Yeah, depending on the procurement process, you may find that developers are starting to retain ownership, or at least partner with an energy supply company, whether that be an ESCO... and we've noticed that on one particular project which we worked on in *[redacted]*, it was a large-scale residential scheme, and that was very much focused right from the outset on a consultancy role for us guys, as taking it up to a point where the developer was happy with the technology and the integration strategy - district heating and heat exchangers in each of the houses, and things like air dispersal, carbon targets, policy-led... local policy-led targets, such as Code for Sustainable Homes, you know - we got to a position where it's like stage C, stage D from a RIBA stages at work kind of process, and then we act to help facilitate the ESCO coming on board and sort of taking that on. I don't think a lot of - traditionally developers are really... it's not their business necessarily to maintain a presence within a development once all the plots are sold on, you know - they'll be looking to hand it over to an energy supply company: if you do go down that decentralised route, where you are looking at a new energy centre, maybe with a CHP engine in there or a biomass boiler or whatever, but if it's PV on roofs then I wouldn't really see the model for that, because they're fairly low-maintenance, and the same with solar thermal as well, you'd	Consultant 2

probably question whether those technologies would be retained in terms of ownership by anybody other than the house owner. Because it'd raise some questions, I mean certainly if you're selling a house, you've got the integrity of the roofing and everything else, and that'd be quite a difficult thing to split up I suppose, the liability in terms of who's... yeah, I don't know...	
You said stage C, stage D, I'm afraid I don't really know what you mean by that - is that different phases in the construction?	HJ
Yeah, well if you look at a traditional procurement process for a building, which might not necessarily be a domestic building, RIBA (which is the Royal Institute of British Architects), they basically come up with the procurement stages which reflect where the respective design team and construction team should be at, so you basically define from stage A to RIBA stage M, but you know detailed design *[inaudible]* and where you hand over the tender package can either be at stage C, stage D, which is seen as more of a design and build route. Or indeed if you take a more traditional route, you obviously take it up to detailed design which is kind of stage F and then	Consultant 2

you're obviously retained and have detailed design liability during construction phases, whereas design and build route, you basically take up stage C and stage D, potentially, and at that point you've got basic schematics about how everything works, but you basically hand that over to a contractor, and you have performance criteria which enables them to take on board, so depending on which route you go can actually influence - because, as a consultant we're obviously independent designers, and we've got clients' desires and aspirations - that's our primary duty to obviously match those, whereas a contractor - wouldn't necessarily think they're out just to make money, but they'll be obviously looking to reduce costs wherever they can, to maximise their profit. So, while we put down requirement for solar PV panels and so much biomass and everything else, that might get questioned by the contractor, you know, for various different reasons, and they might like to try and reduce, so that can sometimes be a bit of a conflict, when you're looking at renewable energy technologies.	
So, given that it's a relatively new basket of technologies, does including microgeneration - does that kind of slow things down a bit and cause difficulties during the phasing?	HJ

Yeah, it does really, from our perspective the fees haven't changed from where they were 10 or 15 years ago [laughs], so there's a lot of added complication with integration with these technologies, but you know - as engineers we're all quite passionate about working with new technologies, and also making sure that they work sufficiently well that they don't cause more complication to the end user. Now, I'd certainly suggest that there's definitely - well yeah, maybe a bit of a conflict on some projects, with the client sort of saying well, "I don't want to pay x fees to actually design something that's more complicated when I don't really want it anyway." So, you know - you get to a point where you go through basic building services design, and work with the architect to reduce demand, but ultimately that can be a bit of a constraining factor, when you actually consider it, new technologies if you like.	Consultant 2
So would it be the architect and the consultants that really choose which technologies are going to go in and how they are going to operate? I mean obviously in consultation with the developer but...	HJ

Yeah, and the client more to the point. I mean with domestic property you don't know who the client is really do you, necessarily. The developer knows - thinks they know - who the client is, and they're obviously designing something that they think the client's going to think's desirable and want to buy. Now, with a lot of the projects we work on, the end client has basically driven the procurement process right from the start, so it may be a local authority wanting social housing for example, they may actually sort of say "well we want certain buildings in this area to be code for sustainable homes, we want them to look like this, roughly, and these are the people that are probably going to be housed within these buildings. And, they may stay very visible during the early stages of design to help drive where we go and certain technologies and certainly the planning generally goes in - can go in - at stage C, stage D, where you get to that point and you get a working design - outline design - and then everything has to be packaged up and you get planning approval for it. And it's at that point where the planning officers might start driving the design a little bit more. Ultimately, it's up to us as engineers and architects to actually take on the responsibility, and we do have a primary role I suppose in advising a client, whether that be a	Consultant 2

developer or indeed local authority, whoever might be...	
This may be a bit after you've finished with the project, but is it difficult to find accredited installers for these technologies? Is there a shortage or is it relatively easy?	HJ
I think a few years ago it was quite difficult and there was a lot of people coming forwards saying they can install anything [laughs], and they have lots of experience, but I think, you know - there's been lots of start-up companies over the last 10 years, and it's been an age-old problem with new technologies in building, whether it be renewable energy technologies or anything else. There may be lots of precedents abroad, maybe in Scandinavia or mainland Europe but ultimately you know, having somebody who can install it correctly, commission it correctly and be there to maintain it is always a bit of a problem. But the MCS scheme has provided a condensed list of supposedly - contactors who have got experience and can install things to a sufficient standard, but I don't think we've really found more recently that there's a huge problem finding installers, certainly for mainstream technologies. I mean, some of the more marginal technologies such as	Consultant 2

biomass CHP for example, or micro-scale CHP, you know - in domestic use, there probably aren't so many contractors who can actually install those.	
I know that different technologies are suited to different types of building and different demands, but are there any - speaking generally, are there any kind of clear winners emerging amongst the technologies or conversely any that don't seem to be quite fit for purpose?	HJ
Yeah, that's a leading question... well, in many ways if you're designing to meet a target then you'll probably look at certain technologies that can fulfil that. Now, you know - maybe if you're working to 10% renewables on a certain building you may put forward a strategy which includes kind of conventional technologies and then you may install solar thermal panels to meet 50% of the domestic hot water demand for examples. And that - if the passive design has been optimised - then you might find that 50% is equivalent to 10% of the total energy use for the building. So that's quite a nice discreet way of meeting legislative requirements. If you need something a bit more substantial in terms of percentage, then you need to start looking at space heating and small	Consultant 2

power and electrical consumption, you can make small inroads into electrical consumption using photovoltaics, and certainly with the feed in tariffs they're a very competitive technology now. They're fit and forget as well, similar to solar thermal, they can basically be installed and there's no onerous operation for the building owner or residents. Now, in terms of heat generation: biomass - pellet, or indeed woodchip, generally isn't suited to single dwellings because I don't think developers are keen on the idea of trying to sell something which may require more maintenance in terms of servicing. But certainly from a decentralised point of view for a development as a whole, biomass is being seen as quite a strong technology because it's essentially carbon neutral, there's a small carbon coefficient which is used to calculate - nominally calculate - some of the transport and processing energy that's gone into bringing the chip to site, or the pellet to site. So yeah, air source heat pumps, ground source heat pumps are becoming a lot more popular now as people are realising there's very little maintenance required for those technologies. Ground source heat pumps are a lot more expensive generally to install, and air source heat pumps are not seen by some people as actually a low carbon technology anyway, so you actually need a - if you're comparing the space heating of a building from	

convention which may be a gas boiler, to an air source heat pump, which obviously uses grid electricity, then you need a minimum COP or efficiency of that air source heat pump to actually provide a saving versus what is convention. Now, that minimum COP - I think, it is 0.198 the latest Part L coefficient for gas, and the electricity's about 0.51 isn't it, or something like that I forget the new figure, but if you take efficiency of gas boiler, then for every unit of heat that you actually generate it's probably about 0.22 or something, or 0.21 the actual kilograms of CO_2, now if you take an air source heat pump or a heat pump working at a COP of 3 or 2.5, you actually divide through that 0.51, you can quite quickly see you need quite a big COP, a relatively large COP and need to maintain that throughout the whole year to actually have the same versus a gas boiler. So, I think that's something we obviously like to try and put forward and make quite transparent, because some local authorities see air source heat pumps as a renewable energy technology. Now, whilst you're using grid electricity, they're not necessarily that at all, and it's quite difficult to convey that to a local authority or indeed a developer. [Pause] But the grid is supposedly going to be decarbonised in the next 20 to 30 years [laughs] so	

you could sort of say - if you take the David McKay 'Without the hot air' approach, now he's professing how great heat pumps are because of decarbonisation, then there's a real big question marks over whether can actually - because electricity consumption in this country is relatively constant throughout the whole year - you get diurnal swings, but if you look at it on a bin basis month by month - it's quite similar throughout the whole year. Now if you're suddenly going to flip over to electrical heating, you're going to end up with a seasonal bias for electrical consumption, and also supply, so the grid infrastructure and the current capacity for electricity generation in the country's not really geared up for that, and we're going to have huge problems trying to meet that. So that was a bit of a - something that perhaps David McKay had overlooked a little bit, and I think quite a few commentators have brought that up as well. Sorry, that's a bit tangential.	
No, that's very useful actually, yeah, that's good. So you've been talking about how regulation is kind of driving these installations, and you've mentioned 10%, 50%, how likely is it that the 2016 Zero Carbon Homes target is going to be met? Because that's talking about almost 100%...	HJ

Yeah, there is a big question about whether we should be forcing developers to generate that energy on site. Legislation can drive things, but I suppose ultimately there's quite a lot of lobbying in industry at the moment to try and relax some of those targets. I think - as has been quite topical over the last few days - there's obviously, the housing market's kind of stalled - both in terms of selling and buying. But also from a developer point of view, obviously not looking to want to build houses while the value of those houses to be sold then on is kind of reduced at the moment. So I kind of, my feeling is that legislation - if the government stay strong, whether it be a coalition *[inaudible]* the next government stay strong - will ultimately force developers to do that. Is it feasible to actually make a house zero carbon? Well it's been proven in various different examples in the UK, but it's going to take an awful lot of effort from a passive design point of view, now if you were to adopt more of a passivhaus kind of approach, you maximise insulation and everything else to an absolute limit that you can from a practical point of view, then ultimately your electricity and heat demand is radically reduced versus current Part L requirements. Then it's a lot easier to actually think about low and zero carbon technologies that you can actually	Consultant 2

adopt and you know, the sizing of those technologies is relatively smaller than they would need to be if you were just designing to current building regulations. I think it is possible. Is there a market appetite? Probably not. But it's not necessarily up to the developer what they... *[laughs]*. If it was left to market forces then no, I don't think it would happen. Not at all.	
So given that it's going to take so much effort and there has been this lobbying, do you think there's likely to be a lot of non-compliance when 2016 comes around?	HJ
Um, I don't know, I mean... I don't think I could take a guess at that. I mean, if you think about requirements for EPCs and DECs now, and actually monitoring things from a compliance point of view post-construction, is there going to be the space for developers to actually get away with it? I mean, how are they going to get away with it? Each developer has to do a SAP calculation for each of the dwellings that he's going to build, now building control really, a lot of the emphasis is going to be on those guys. Or indeed if a consultant is retained by maybe the local authority or some kind of third party to actually oversee the quality of the workmanship and everything else	Consultant 2

and then provide some independent monitoring post-construction to actually prove that the house is essentially zero carbon, then how can a contractor or developer or whoever actually get away with it? Maybe the challenge really is to put in a kind of checking procedure to actually make sure that they do actually meet their targets.	
I think finally, speaking about regulation and policies, do you have any predictions about how policies - I suppose on the national scale and on the local scale - how policies relating to microgeneration might develop over the next few years? I mean, would we see a microgeneration-specific target in the same way that we've got a renewables target, or is it mainly going to be through the building regulations?	HJ
I think you have to think about what you're trying to achieve. If you're trying to achieve a low/zero carbon house, now it doesn't matter if that energy or the ability to get to that point is from microgeneration or through passive measures. Does it really matter? I mean, of course it doesn't. So building regs will probably drive passive design to a certain point because they'll put	Consultant 2

in minimum standards for U values, walls, floors, ceilings, roofs etc but ultimately there's always going to be a trade-off where you get to the point where you're thickening the wall to a certain point where the marginal benefit of increasing that by an extra 25mm versus the cost of installing a physical technology, there's going to be that crossover point. And a lot of people use MAC curves and marginal abatement cost curves to evaluate that on a very high level. So, what policy measures need to be brought into place? Should it drive microgeneration technologies? I don't think it should. I think really you should be setting an absolute target and then allow all developers, all the design teams, to actually come up with their own methodology or their own approach to different contexts and different applications. Because what we found with the Merton Rule and these 10 and 20% targets being set up by local authorities is that, as I said at the start of the discussion, that kind of drives sizing of technologies, which really shouldn't be the point. What you should be trying to do is - obviously you want to instigate the use of these technologies, but really you don't want to affect the sizing of them. You want to retain - the design teams need to be able to have a flexible approach, they don't want to be driven by an artificial target which can be seen as a bit arbitrary, versus - you've got the whole house which may use	

1,000 or 2,000 kWh of heat or require 2,000 kWh of heat; now should you be setting a target on what percentage of that is by renewables, or should you just leave the design team to say, "well actually, we're going to spend a lot more money increasing the wall thicknesses and using a certain type of insulation, get that down to 1,200 and then we're going to start approaching maybe other technologies as well" ? That seems the better approach. And some local policy does actually inadvertently take you down that point, because they'll sort of say "10% of total energy of a new build should be from renewable energy", so ultimately if you improve the passive design to a point then 10% is obviously a lot smaller than if it was...	
So it's better almost to just set the desired outcome in terms of carbon reduction, and let the developers do it in their own way.	HJ
Yup. And that's what the zero carbon target's about - it's not about percentage targets, it's about how much energy the building uses and consumes.	Consultant 2

That's about it in terms of questions, is there anything else you want to add - any general observations or comments?	HJ
No, no that's very interesting and it's obviously a difficult thing to discuss in any objectivity *[laughs]*.	Consultant 2

Appendix B: Techno-economic calculations

Variable name	**Description**	**Value**	**Units**	**Data source**
TFA	Assumed total floor area of dwelling	Attached: 118 Detached: 76	m^2	Zero Carbon Hub[a]
PV_{size}	Assumed capacity of PV installation	*TFA * 0.3 * 0.18* 0.3 = Assumption of 30% TFA available for PV 0.11 = Conversion factor to convert m^2 to kW capacity	kW	30% TFA assumption: Zero Carbon Hub[a] Conversion factor: Ownergy[b] and SunRun Home[c]

PV_{use}	Proportion of PV generated used by household	Variable (between 0.1 and 1), user defined	Decimal	n/a
PV_{gen}	Assumed annual electricity generation from solar PV	Attached: 2091 Detached: 3252	kWh	Energy Saving Trust Solar Calculator[d] Inputs: System size = PV_{size} Orientation = south Postcode = SW1 2AA
FIT_{gen}	Annual FIT payment to household for generation	ESCO: 0 Plug and Play: $0.1 * PV_{gen} * \mathit{Generation\ tariff}$ 0.1 = convert pence to £ Generation tariff = 14.9p/kWh	£	Ofgem[e]
FIT_{exp}	Annual FIT payment to household for export	ESCO: 0 Plug and Play: $0.1 * [(1 – PV_{use})* PV_{gen}] * \mathit{Export\ tariff}$	£	Ofgem[e]

		0.1 = convert pence to £ Export tariff = 3.2p/kWh		
Elec_{dem}	Assumed annual electricity demand per household	3300	kWh	Zero Carbon Hub[a]
$\text{Elec}_{\text{cost}}$	UK average electricity unit cost (direct debit customers)	0.139	£/kWh	Confusedaboutenergy.co.uk[f]
$\text{Elec}_{\text{disc}}$	Assumed discount on electricity purchase from ESCO	0.1	Decimal	Heuristic, user defined (see discussion in Section 5.2.4.3)
Capex	Capital cost of PV technology	ESCO: 0 Plug and Play: Attached: 6060 Detached: 6960	£	Energy Saving Trust Solar Calculator[d], inputs as above.

[a] Zero Carbon Hub, 2009. *Defining a Fabric Energy Efficiency Standard for Zero Carbon Homes*.

[b] Ownergy, 2013. *About Solar Photovoltaics.* Available from: http://www.ownergy.co.uk/roof_solar/about/, Access date: July 2012.

[c] SunRun Home, 2012. *Solar FAQ.* Available from: http://www.sunrunhome.com/solar-for-your-home/solar-faq/#3, Access date: July 2012.

[d] Energy Saving Trust, 2013. *Solar Energy Calculator.* Available from: http://www.energysavingtrust.org.uk/Generating-energy/Getting-money-back/Solar-Energy-Calculator, Access date: July 2012.

[e] Ofgem, 2013. *Tariff tables.* Available from: https://www.ofgem.gov.uk/environmental-programmes/feed-tariff-fit-scheme/tariff-tables, Access date: August 2013.

[f] Confusedaboutenergy.co.uk, 2013. *Fuel Prices.* Available from: http://www.confusedaboutenergy.co.uk/index.php/domestic-fuels/fuel-prices, Access date: August 2013.

Model calculations:

$$\pounds Net\ cashflow\ year\ 1 = \left\{ PV_{gen} * PV_{use} * Elec_{cost} \right\} + \left\{ \left[Elec_{dem-} \left(PV_{gen} * PV_{use} \right) * Elec_{cost} \right] * Elec_{disc} \right\} + FIT_{gen} + FIT_{exp} - Capex$$

$$\pounds Net\ cashflow\ year\ n\ (n > 1) = \left\{ PV_{gen} * PV_{use} * Elec_{cost} \right\} + \left\{ \left[Elec_{dem-} \left(PV_{gen} * PV_{use} \right) * Elec_{cost} \right] * Elec_{disc} \right\} + FIT_{gen} + FIT_{exp}$$

$$\pounds 20\ year\ cashflow = \pounds Net\ cashflow\ year\ 1 + \sum_{i=2}^{20} \pounds Netcashflow\ year\ n\ (n > 1)$$

Appendix C: Full questionnaire script

Home Energy Preferences

Welcome to this survey about home energy preferences. We really appreciate you taking the time to help us with our research. It is being carried out by Hannah James and two supervisors at the University of Leeds as part of a PhD project about home energy generation.

We'll be asking for your opinions about different scenarios to do with generating energy at home, and about your shopping habits. We're interested in your personal preferences, so there are no right or wrong answers. The questionnaire takes around 10 minutes to complete.

Once you have completed the questionnaire, you will have the opportunity to enter a prize draw to win £30 worth of Marks and Spencer vouchers.

All the information you give in this questionnaire will be kept completely anonymous, and will never be used to identify you. The data we collect will be analysed in aggregate: we will not analyse your responses individually. The data will be entered into a statistical analysis program and kept on a secure server which can only be accessed by password (known only to Hannah). The hard copy of your response will then be destroyed by shredding.

Your data will never be passed onto anyone else. We will not use any of the information you give to contact you, apart from notifying you if you have won the prize draw. Once the study has finished your data will be kept securely for three years, and then destroyed.

If you have any questions about this survey - before, during or after filling it in, please contact Hannah:

Email: pmhcj@leeds.ac.uk
Telephone: *[redacted]*

ERI/SPEME
University of Leeds
Leeds
LS2 9JT

Question 1

I am over 18 and a resident of the UK. I am happy for you to use my answers to this questionnaire as described above.

☐ Yes

☐ No

Question 2

Please enter your postcode (e.g. LS2 9JT). If you are a student, please enter the postcode of your TERM TIME address.

Your address will never be shared or used to contact you, and will not be used for anything except this research. However, if you would prefer not to enter the full postcode, please enter the first half (e.g. 'LS6' or 'S2')

☐

Question 3

Please enter your age in years

Question 4

What is your gender?

☐ Female

☐ Male

☐ Other/prefer not to say

Question 5

What is your net monthly income from all sources, after tax? For this question, include anyone who shares your income or who shares their income with you, such as a spouse or partner. Do not include any housemates whose finances are separate from yours. If you are not sure of your exact monthly income, or it varies, please enter your best guess or an average. Enter your answer as a number without a £ sign, e.g. 1000, not £1,000.

Question 6

What is the highest level of education you have achieved? If you have international qualifications, please choose the closest UK equivalent.

☐ School to age 16 or younger

☐ GCSEs/Scottish Standard Grade or equivalent

☐ A levels/International Baccalaureate/Scottish Higher Grade/Scottish Advanced Grade/HND/Foundation Degree or equivalent

☐ Bachelors degree (e.g. BSc, BA, BEng etc) or equivalent

☐ Masters degree (e.g. Msc, MA, MRes etc) or equivalent

☐ Doctoral degree (e.g. PhD, EngD, PsyD etc) or equivalent

Question 7

How many of the following people do you live with? Please enter your answer as a number (e.g. 2, not 'two'). Enter 0 for those you don't have living with you.

Spouse/partner	
Adult who is not a spouse/partner	
Child under 14	
Child aged 14 or over	

Question 8

In this question you are going to be presented with a scenario, followed by two options to choose from. We will then ask you a few questions about how you made your decision.

<u>The scenario:</u>

You are buying a new home, which is powered by renewable energy. 'Renewable energy' refers to energy from natural resources that do not run out, such as sunlight, wind and the Earth's heat.

Your home is heated using a combined heat and power (CHP) unit, which operates in a similar way to a conventional gas or oil boiler to provide hot water and space heating. It is more energy efficient than a conventional boiler, and also generates some electricity alongside the heat. Your electricity is provided by solar panels which harvest the energy from the sun.

The renewable technologies on your home meet all of your heat and electricity needs.

This could be arranged in one of two ways: see next page.

	Option 1	Option 2
Description	In this scenario, you buy the CHP unit and the solar panels along with your new home. You are given instructions on how to use them.	In this scenario, an energy service company owns the CHP unit and solar panels. Your heating unit and solar panels are connected to a neighbourhood grid which allows heat and electricity to be shared between the homes.
Where is the CHP unit located?	In a suitable location in your home such as the kitchen or landing.	A large CHP unit is located in your neighbourhood and supplies heat to all the homes. There is no unit in your house, just a thermostat.
Where are the solar panels located?	On your roof	On your roof

Who operates the CHP unit?	You and anyone else living in your home, in a similar way to a conventional boiler with a thermostat.	The energy service company controls it remotely, in order to keep your home at the temperature you set with the thermostat.
Who operates the solar panels?	They are automated and don't require any additional action to work.	They are automated and don't require any additional action to work.
Do I need to do any maintenance?	Yes: the CHP unit needs to be serviced occasionally. It costs the same as conventional boiler servicing. The solar panels require little maintenance, but they need to be cleaned occasionally.	No, the energy service company deals with maintenance.

Assume now that money is no object. Both options cost exactly the same and do not cost more than a home without renewable energy.

In this scenario, there is no option not to have renewable energy: you must have one of the two options.

Which of these options would you prefer?

Strongly prefer Option 1	Slightly prefer Option 1	No preference either way	Slightly prefer Option 2	Strongly prefer Option 2
☐	☐	☐	☐	☐

Question 9

Now we are going to add some information about costs to the two options:

	Option 1	Option 2
Recap	You own the CHP unit and solar panels. You operate and maintain the CHP unit and solar panels. The CHP unit is in your home and the solar panels are on	The energy service company owns the CHP unit and solar panels. The energy service company operates and maintains the CHP

	your roof.	unit and solar panels. The CHP unit is *not* in your home. The solar panels are on your roof.
What are the financial benefits?	The electricity generated is free for you to use and the boiler is very efficient, so you make savings on your energy bills. You receive a monthly payment (a 'feed in tariff') from the government for each unit of renewable energy you generate. These payments are guaranteed for 20 years. Due to these savings and payments, an average UK household would receive an extra **£1043** per year under this arrangement.	The energy service company sells you electricity and heat at a price that is guaranteed to be less than or equal to the prices charged by conventional energy companies. (You cannot switch providers while under this contract). Due to these savings, an average UK household would receive an extra **£145** per year under this arrangement.
What are the costs?	Your home will cost more to buy due to the renewable energy technology installed. The cost of an average home would increase by **£10,000**	The cost of your home is not increased. You make a monthly payment to the energy service company to cover the costs of maintenance and operation.

	under this arrangement.	An average monthly payment in the UK would be **£10.**

In this scenario, there is no option not to have renewable energy: you must have one of the two options. In light of this additional information, which of these options would you prefer?

Strongly prefer Option 1	**Slightly prefer Option 1**	**No preference either way**	**Slightly prefer Option 2**	**Strongly prefer Option 2**
☐	☐	☐	☐	☐

Question 10

When you made your decisions in the previous question, how important were the following considerations on a scale from 1 to 5?

Where 1 = Extremely Important and 5 = Extremely Unimportant.

	1	2	3	4	5
I would prefer to own my own energy generation technologies rather than have a company own them	☐	☐	☐	☐	☐
I want to have control over how my energy generation technologies operate	☐	☐	☐	☐	☐
I would prefer not to have the effort involved in maintaining my own energy generation technologies	☐	☐	☐	☐	☐
I'm sceptical about newer energy technologies: I'd prefer not to invest my own money in them	☐	☐	☐	☐	☐
I'd be worried about using newer energy technologies myself: I'd rather have an expert do it	☐	☐	☐	☐	☐
Not having a boiler in the home increases the space available for me to use (e.g. more kitchen cabinet space)	☐	☐	☐	☐	☐

I don't like the idea of sharing my boiler with other people	☐	☐	☐	☐	☐
I would prefer to spread the cost of the energy technologies over monthly payments rather than pay the full cost upfront	☐	☐	☐	☐	☐

Question 11

If you had any other reasons which weren't mentioned, please enter them here:

Question 12 (this is the second last question)

We would now like you to think about environmentally friendly products (shortened to 'green products'). By this we mean any products which are designed or produced to minimise impacts on the environment. Examples could include low energy lightbulbs, environmentally friendly cleaning products, sustainably produced food, re-usable nappies etc, but are not limited to these. Think about products that are relevant to YOU and your interests.

Please say how much you agree or disagree with each statement:

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
I will not buy a new green product if I haven't been able to try it first	☐	☐	☐	☐	☐
In general, I am the first in my circle of friends to know the brands of the latest green product	☐	☐	☐	☐	☐
In general, I am among the first in my circle of friends to buy a new green product when it appears	☐	☐	☐	☐	☐
I do not like to buy green products before other people do	☐	☐	☐	☐	☐

Compared to my friends I own a lot of green products	☐	☐	☐	☐	☐
If I heard that a new green product was available in the store, I would not be interested enough to buy it	☐	☐	☐	☐	☐

Question 13 (this is the last question)

This time we would like you to think about household technologies. By this we mean technological products that you would buy to use at home. Examples could include sound systems, smart phones, games consoles, e-readers etc, but are not limited to these. Think about products that are relevant to YOU and your interests.

Please say how much you agree or disagree with each statement:

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
I will not buy a new household technology if I haven't been able to try it first	☐	☐	☐	☐	☐
In general, I am the first in my circle of friends to know the brands of the latest household technology	☐	☐	☐	☐	☐
In general, I am among the first in my circle of friends to buy a new household technology when it appears	☐	☐	☐	☐	☐
I do not like to buy household technologies before other people do	☐	☐	☐	☐	☐
Compared to my friends I own a lot of household technologies	☐	☐	☐	☐	☐
If I heard that a new household technology was available in the store, I would not be interested enough to buy it	☐	☐	☐	☐	☐

Thank you and prize draw

Thank you very much for completing this questionnaire. We really appreciate you taking the time to help us with our research.

If you would like to be entered into the prize draw to win £30 Marks and Spencer vouchers, please enter your email address or phone number below and click 'Done' below. Your email address/phone number will not be associated with your answers, and it will never be used to contact you unless you have won the prize draw.

If you do not wish to enter the draw, leave the box blank.

If you have any questions or comments about this questionnaire please contact Hannah James:
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Appendix D: Disclaimer from Experian

The use of the Experian Mosaic tool in Chapter 5 was subject to the following disclaimer from Experian:

“The information contained within this report is not intended to be used as the sole basis for any business decision, and is based upon data which is provided by third parties, the accuracy and/or completeness of which it would not be possible and/or economically viable for Experian to guarantee. Experian's services also involve models and techniques based on statistical analysis, probability and predictive behaviour. Accordingly, Experian is not able to accept any liability for any inaccuracy, incompleteness or other error in this report."