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It's not personal: modelling a downstream household cap and trade scheme for residential energy in the UK

by

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ABSTRACT

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IT'S NOT PERSONAL: MODELLING A DOWNSTREAM HOUSEHOLD CAP AND TRADE SCHEME FOR RESIDENTIAL ENERGY IN THE UK

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Examination of climate policies such as downstream cap-and-trade brings into sharp focus the tension between environmental and broader social policy aims. This is particularly true in the residential energy sector. Here, policies to reduce general levels of greenhouse gas emissions must be reconciled with ensuring the affordability of energy for vulnerable consumers.

This thesis examines the practical application of justice concerns at the nexus of environmental and social policy, specifically in the domain of household energy demand. To tackle issues of justice in this context an understanding of sufficiency is required: the moral distinction between under- and over-consumption. This thesis presents the application of two theories to understand this notion: first, a 'needs' interpretation of household energy as a requirement to support wellbeing; and second, a 'capabilities' approach for understanding the opportunities and constraints of households in responding to policy incentives. Further, microsimulation modelling provides a comparative analysis of the potential impact on households using different interpretations of justice.

The contribution made is the application and integration of a theoretically grounded understanding of justice to the empirical context of household energy demand reduction. A framework is described within which the moral dimension of policy decisions are made more explicit. Thus, policy-makers are provided with a decision-support tool with which to approach energy related justice concerns. More specifically, the findings will be relevant for the public acceptability and political feasibility of downstream carbon trading schemes.

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Declaration of authorship

I, Thomas William Rushby declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

Thesis Title: *It's not personal: modelling a downstream household cap and trade scheme for residential energy in the UK*

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. None of this work has been published before submission

Signed: ....

Date: ....

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Finally I would like to thank my family: my parents, for instilling in me a concern for the environment and the importance of social justice; my father, for his endless support and confidence in me; my wife Anna, who has shared all of the highs and lows of this long journey; and my son Edison, the light of my life and my inspiration.

Definitions and Abbreviations

BRE	Building Research Establishment
BREDEM	Building Research Establishment Domestic Energy Model
CCC	Committee on Climate Change
COGS	Consumption of other goods and services
CO_{2e}	Carbon dioxide equivalent
CSE	Centre for Sustainable Energy
C&D	Cap and dividend
C&S	Cap and share
DCAT	Downstream cap and trade
DECC	Department for Energy and Climate Change
DCLG	Department for Communities and Local Government
DEFRA	Department for Environment, Food and Rural Affairs
dHCA	Differentiated Household Carbon Allocation
DTQ	Domestic Tradable Quotas
EAC	Environmental Audit Committee
EHS	English housing survey
EPCA	Equal per capita allowance
EPCA+ch	Equal per capita allowance, plus allowance for children
EPHH	Equal per household
GHG	Greenhouse gas
GIA	Gross internal area
GLA	Greater London Authority
HCA	Household carbon allocation
HHCT	Household carbon trading
INDIE	Indirect infrastructure to deliver individuals' energy
kg	Kilogramme
kWh	Kilowatt hour
LCF	Living costs and food survey
MIS	Minimum income standard
ONS	Office for National Statistics
PCT	Personal carbon trading
PCA	Personal carbon allocation
SAP	Standard assessment procedure

TCQ	Tradable Consumption Quotas
TEQs	Tradable Energy Quotas
TWh	Terawatt hour
USC	Universal satisfier characteristics

1. Introduction

1.1 Background and rationale

1.1.1 Why might PCT be needed as a policy tool?

In the United Kingdom (UK), an 80 per-cent reduction in greenhouse gas emissions by the year 2050 has been legislated for in the Climate Change Act, setting the long-term goal for climate change mitigation (HM Government, 2008). Such targets have been criticised for not taking into account the latest climate science and importance of cumulative emissions budgets (Anderson *et al.*, 2008). Further, the urgency of rapid reductions in emissions requires a shift in policy focus from energy supply to reducing demand:

> …only by tackling energy demand in the short term, and energy demand and supply in the longer term, will the UK be able to sustain the emission reductions necessary to remain within budget (Anderson *et al.*, 2008, p.3721)

The energy used in homes in the UK: accounts for 30 per cent of final energy demand (Palmer and Cooper, 2013) and a quarter of UK greenhouse gas emissions (Department of Energy and Climate Change, 2013). Reducing emissions from the residential energy sector is therefore essential if the UK is to meet its mitigation commitment. While energy use per household is declining, the growth in household numbers has resulted in an aggregate increase in energy demand (Palmer and Cooper, 2013). In the period 1970 to 2000, the number of households increased 44 per cent while emissions per home decreased by over 50 per cent during the same period (Palmer and Cooper, 2013). The increase in the levels of energy services demanded has, therefore, been outweighed by the reduction in emissions from improved thermal performance of housing, heating efficiency improvements, changes in the electricity supply fuel mix and other emissions factors (Shorrock, 2003). This decoupling of the demand for energy services and emissions is likely to be difficult to maintain into the future. A large proportion of the short term, cost effective energy conservation measures such as cavity wall insulation and loft insulation have already been exploited, resulting in lower energy savings than predicted and indicating that emissions targets will be technically more difficult and more costly to meet (Lowe and Oreszczyn, 2008). Recent policy changes have also contributed to a slowdown in the rates of energy efficiency improvements:

> In recent years, emissions from homes have reduced due to improved energy performance from higher levels of insulation, as well as more efficient appliances and lighting. **However, recent policy changes have resulted in a slow-down in the rate of installation of insulation measures in homes** (Committee on Climate Change, 2015, emphasis added)

While the UK is meeting the required emissions reduction trajectory, "... the delivery of key measures has slowed down since 2012, putting further emissions reductions at risk" (Committee on Climate Change, 2015, p.73). Since that report, there is further evidence of a lowering of ambition in the regulatory environment in the UK[1].

Gupta et al.(2015) suggest that upgrading existing dwellings to meet emissions targets in line with the Climate Change Act "...will unquestionably require a paradigm shift from existing approaches that tend to support the most cost-effective measures in worst performing dwellings" (p.436).

Evidence of a slowing down of the regulation of emissions from dwellings, together with the limited scope of existing regulation and the required acceleration of emissions reductions, points to the need for additional policy instruments in order to meet climate change mitigation goals. Alternatives to increased regulation are: voluntary mechanisms, government expenditure and financial incentives (Jacobs, 1991). From these alternatives, financial incentives including a carbon tax or tradable emissions rights are seen to provide a market solution to the environmental externalities; the root of the 'market failure' of climate change (Stern, 2007). Such market solutions are seen to play a major role in stimulating innovation and directing investment

[1] In July 2015, both the Zero Carbon Homes and Green Deal financing mechanism for energy efficiency improvements were withdrawn (HM Treasury, 2015). The scrapping of these two flagship policies without alternative mechanisms in place indicates policy falling behind the strategic pathway considered cost effective by the Committee on Climate Change: emissions reductions required from the residential sector will not be achieved without additional incentives to increase the uptake of efficiency measures (Committee on Climate Change, 2015).

towards efficiency, energy conservation, and renewable sources of energy (Giddens, 2011).

In principle, only quantity-based instruments are able to deliver guaranteed emissions reductions to ensure climate change commitments are met due to their implementation of an absolute cap on emissions (Chamberlin *et al.*, 2014). Furthermore, 'downstream' cap-and-trade (DCAT) schemes are viewed as being potentially more effective in stimulating behaviour change than other market-based instruments, due to explicit framing in terms of a budget or quota, giving increased salience to resource constraints (Parag *et al.*, 2011). DCAT policies provide a framework for mitigating the emissions of greenhouse gases in response to climate change. One common formulation of DCAT is a scheme design involving the mandatory participation of all individuals. Varying scheme proposals exist and are generally referred to under the umbrella term 'Personal Carbon Trading' (PCT) (Fawcett and Parag, 2010).

A number of different scheme proposals have been advanced (Fleming, 1996; Ayres, 1997; Fleming, 1997; Hillman and Fawcett, 2004; feasta, 2008) and the idea has been viewed as complementary to existing regulatory instruments in controlling residential energy demand (Boardman, 2007, 2012). PCT is considered to be unpopular, both with the public (although less so that carbon taxes) and policy-makers, but if progress on energy efficiency, or decarbonising household fuels, continues to fall behind, such instruments may become more politically acceptable (Bird and Lockwood, 2009). The potential opportunities and risks, strengths and weaknesses of these policies should be investigated, in anticipation that they may be required in future. Such a strategy has been suggested by the parliamentary Environmental Audit Committee (2008), and academics (Fawcett, 2010).

In responding to climate change, financial mechanisms in the form of taxes and other instruments are likely to be implemented to provide increased incentives to find emissions abatement opportunities. However, in the domain of residential energy, these market-based instruments risk disproportionate impacts upon lower income households due to the pre-existing inequalities in energy demand (Roberts, 2008). In order to understand the potential impact of climate mitigation policies, a more comprehensive understanding of the role of household needs and resources is required and how it affects energy consumption (Schaffrin, 2013).

1.1.2 Climate change mitigation and fuel poverty

The limitations of energy efficiency improvements have been identified in the literature: for example, Sorrell (2015) describes the links between efficiency improvements and demand reduction as complex and subject to 'frequently large' rebound effects, where common efficiency measures yield lower savings than building energy models estimate. More recently, a distinction has emerged between the rebound effect and a more specific term referred to as 'prebound', describing the effect of poor households under-consuming energy services prior to energy efficiency renovations (see Sunikka-Blank and Galvin (2012) and Teli et al. (2015)). The extent to which households use improved efficiency to realise increased levels of heating as opposed to energy and cost savings, depends to a great extent on whether households are able to achieve the desired levels of heating before efficiency measures are installed (Milne and Boardman, 2000).

> The rebound effect is known to occur when a proportion of the energy savings after a retrofit is consumed by additional energy use [...] By contrast, the 'prebound' effect refers to the situation before a retrofit, and indicates how much less energy is consumed than expected. As retrofits cannot save energy that is not actually being consumed, this has implications for the economic viability of thermal retrofits.(Sunikka-Blank and Galvin, 2012, p.265)

Sunikka-Blank and Galvin (2012) state that the prebound phenomena has two policy implications: first, energy and emissions savings through energy efficiency retrofits are often overstated; and second, the potential to achieve energy and emissions savings through occupant behaviour are potentially much larger than assumed by policy makers.

The concept of prebound is also significant as it is closely linked to another major concern in energy policy, fuel poverty (Roberts, 2008). Households in fuel poverty often cannot afford the energy services required to meet their needs and policies such as DCAT have the potential to exacerbate these problems (Thumim and White, 2008). For this reason, analysis of DCAT in the context of residential energy demand must integrate an understanding of both under- and over-consumption (Walker and Day, 2012).

1.1.3 What is it that we don't know?

The practical feasibility of DCAT schemes is affected by aspects such as: cost-effectiveness, redistributive impact, public opinion and political acceptability (Defra, 2008b). These factors are strongly influenced by scheme design. As the method with which emissions rights are allocated among participants is central to the design and operation of DCAT schemes, it is therefore also central to their feasibility in practice.

To date, the dominant method used by PCT schemes to allocate emissions rights among participants has been the equal-per-capita allocation (EPCA). This method has been critically examined within the academic literature and shown to have drawbacks in terms of perceived fairness and redistributive impact. While alternative distributive principles are well represented in the climate change mitigation literature, these allocation methods have not been applied in the context of DCAT[2]. The effect of adopting an alternative allocation method upon the feasibility of this policy idea therefore remains unknown.

PCT has received interest from senior political figures in the UK and has been the subject of a pre-feasibility study by the Government. Despite brief political and media interest and a subsequent surge in academic research, the view from the Department for Environment, Food & Rural Affairs (Defra) that the policy was 'ahead of its time' has tempered political interest in the policy (Defra, 2008b). The Environmental Audit Committee (EAC) criticised the Government, following the Defra pre-feasibility study, for not taking a more central role in coordinating research and policy development (Environmental Audit Committee, 2008). They suggested that a sensitive and moderate scheme might overcome the policy barriers to PCT.

Using an alternative scheme design will affect the cost, redistribution impact and public acceptability; it is therefore worthwhile examining an alternative allocation method and the implications for the design of DCAT policies and their feasibility. This research draws upon multiple disciplines to propose an alternative to the equal-per-capita method: a differentiated Household Carbon Allocation (dHCA). Further, it examines the distributional implications of

[2] With the exception of an equal-per-household allocation (see Niemeier et al., 2008)

adopting this alternative allocation method compared to other proposed allocation methods such as equal-per-capita and equal-per-household.

1.1.4 Why is it interesting/important/worthwhile that we find out?

The work described in this thesis has implications for the political feasibility of PCT schemes and also engages broader debates on climate change and energy justice, and policies aimed at the regulation of emissions from individuals and dwellings.

1.2 Research aims and objectives

1.2.1 Aim

The aim of this research is to develop and test an alternative method for allocating emissions quotas under a downstream cap-and-trade scheme: a differentiated household carbon allowance (dHCA).

1.2.2 Research objectives

In order to achieve the stated aim, the research will: challenge the dominant individualist conception of PCT; review appropriate theory and empirical work from a range of disciplines; and integrate into a new framework for distributing emissions quotas among participants. The specific objectives are set out in the boxes below:

Objective 1.	Determine what stage PCT has reached within the policy process and what opportunities and barriers exist for further development.
This objective will be met by reviewing the literature with a focus on the development of PCT policy and political interest in the UK. Key critiques of the policy will be identified. The equal-per-capita allocation method will be identified as an aspect of the policy that cuts across these critiques.	

<table>
<tr><td>Objective 2.</td><td>Review the theoretical underpinnings of allocating emissions rights using EPCA and demonstrate ethical and methodological challenges to PCT as currently conceived.</td></tr>
<tr><td colspan="2">This objective will be met by:
1. Reviewing the theoretical underpinnings of allocating emissions rights using EPCA and outlining the ethical challenges
2. Critiquing the individualist account of household energy demand and proposing a household approach as methodologically more accurate, and
3. Demonstrating that EPCA leads to unjust outcomes by examining empirical data from previous studies</td></tr>
</table>

<table>
<tr><td>Objective 3.</td><td>Review alternative principles for allocating emissions that are compatible with the ethical challenges and determinants of household emissions. Operationalise these principles into a model for allocating household quotas.</td></tr>
<tr><td colspan="2">This objective will be met by examining alternative frameworks for understanding distributive justice and alternatives to the EPCA principle. Principles will be evaluated against an understanding of the determinants of household emissions and aims of DCAT policy. The accepted principle will then be operationalised into a new method for allocating differentiated emissions quotas to households as opposed to individuals – the differentiated Household Carbon Allowance (dHCA) model.</td></tr>
</table>

<table>
<tr><td>Objective 4.</td><td>Provide analysis of the redistributive impact of dHCA and compare with existing methods for allocating emissions-rights such as equal-per-capita (EPCA) and equal-per-household (EPHH).</td></tr>
<tr><td colspan="2">This objective will be met by modelling household emissions quotas allocated by each method and the emissions related to each household’s energy demand. The residual quota levels – the household quota minus household emissions - will be compared across allocation methods according to a selection of social variables.</td></tr>
</table>

<table>
<tr><td>Objective 5.</td><td>Examine the implications of adopting dHCA in practice. Provide an analysis of the impact of dHCA for the feasibility of DCAT schemes in the UK.</td></tr>
</table>

This objective will be met by placing the findings into context by returning to the themes revealed in review of PCT (objective 1). Questions of how dHCA would affect scheme design, administration, enforcement, and costs will be considered.

1.3 Scope

While the review of DCAT literature and scheme proposals is not limited, the review of political interest in PCT is restricted to the UK. The comparative distribution analysis of allocation methods is restricted to England due to the coverage of the main housing survey dataset used for the empirical work: the English Housing Survey (EHS).

1.4 Approach

By thinking of environmental policies in isolation, for example reducing greenhouse gas emissions using individual quotas, a proposed per-capita solution appears at first appropriate and equitable. However, when applied to the real world with, for example pre-existing inequalities, other problems emerge. In this thesis, for example, an evaluation of PCT reveals a disproportionate redistributive impact on households according to size. In applying the solution to the real world, complexities are revealed that had not been considered in the design; in this case, household size being a key determinant relating to inequalities in greenhouse gas emissions. In order to adequately understand and respond to complex, real-world policy problems therefore, theory and evidence from multiple academic disciplines must be brought together. Using such an approach in this thesis, the aim is to take a broad, interdisciplinary approach to a critical evaluation of PCT policy in the UK. The contribution will therefore be one of integration: integrating theory from social, human and physical science to provide a normative framework for understanding residential energy requirements, then applying this framework to downstream cap-and-trade policy and evaluating the impact against existing proposals.

The motivation of this study is to demonstrate proof-of-principle of an alternative approach to DCAT. This research was intended to be broad in its aims, from identification of the policy problem, through proposing and testing a solution in principle, to evaluation. As an agenda-setting piece of work it will therefore identify the many limitations of such a broad exercise and identify where further work will be required; for example, where policy variations require further analysis (or more data to evaluate), and where the implications of dHCA on scheme design need to be examined.

1.5 Thesis outline

This thesis consists of eight chapters. Figure 1.1 below provides a graphical representation of the structure of this thesis and the relationship of each element. The numbers within yellow hexagons indicate chapter numbers.

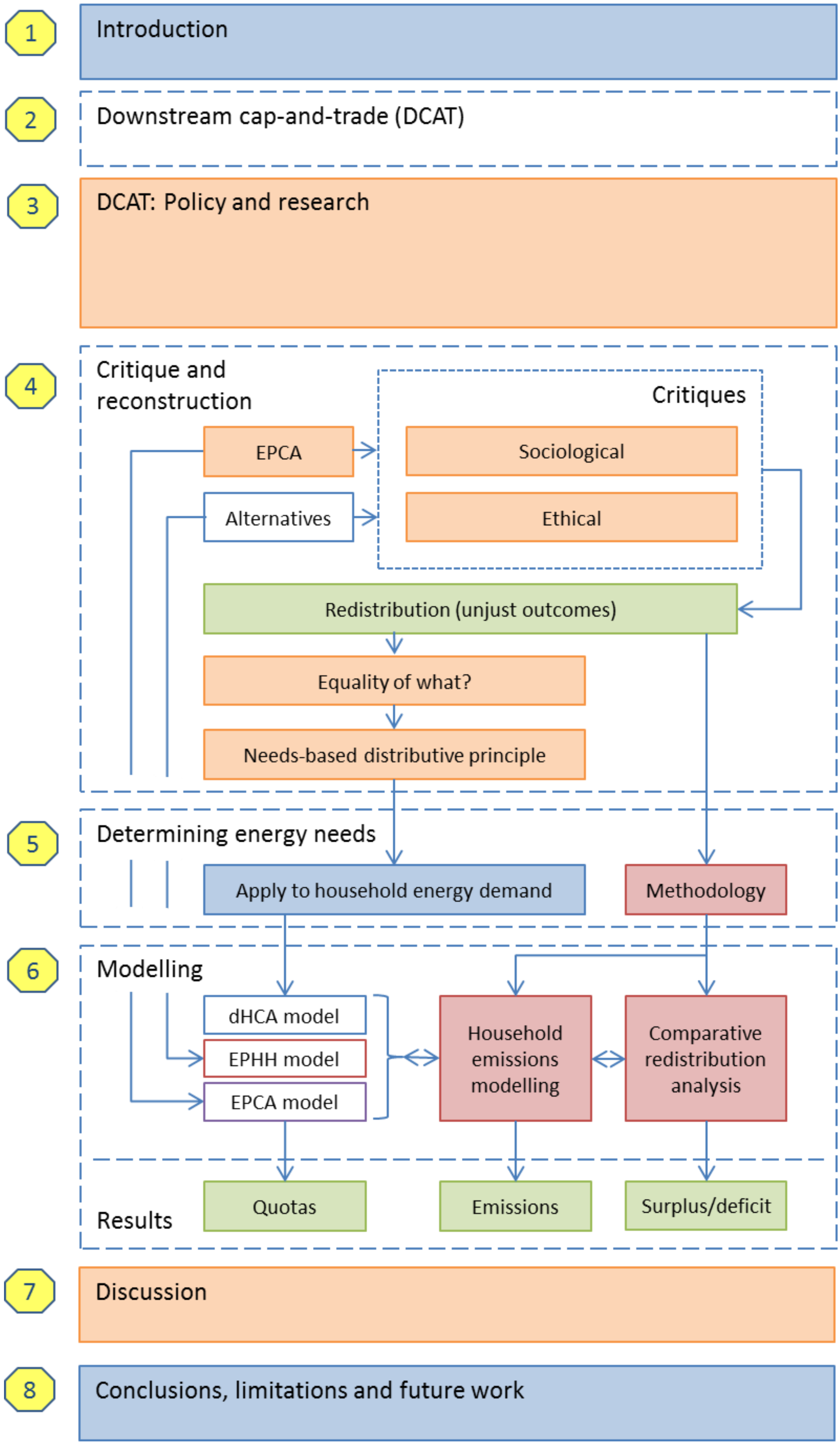

Figure 1.1 Diagram of thesis structure showing chapter numbers

2. Downstream cap and trade

2.1 Overview

This chapter provides an introduction to downstream cap and trade policies (DCAT). In this thesis the term ‘downstream’ follows the description by Chamberlin et al. (2014) and refers to the control of greenhouse gas (GHG) emissions at the source of demand, i.e. at the level of end-users (individuals and households), as opposed to ‘upstream’ control of emissions at the source of supply of fossil fuels and electricity. In the UK context, DCAT policy instruments are often referred to under the umbrella term Personal Carbon Trading (PCT) which became commonly used during the period of government interest in these policies (see Fawcett and Parag, 2010). Starkey describes PCT as:

> … (sub-)national emission trading schemes for reducing emissions from fuel combustion, under which at least some emissions rights are allocated to and surrendered by eligible individuals. (Starkey, 2012b)

There are a number of different proposals for these schemes which will be introduced in this chapter. The chapter will outline similarities and differences in the proposals, as well as providing background as to how such policies operate. In this thesis, both PCT and DCAT are used to refer to this collection of scheme proposals and distinctions between scheme proposals are provided where necessary. To aid the reading of this introductory chapter, a list of acronyms is provided in Table 2.1 below for different schemes. Other common terms can be found on the list of abbreviations. The reader is also directed to the summary table provided at the end of the chapter (page 27).

Scheme name	**Acronym**	**Author/reference**
Tradable Energy Quotas	TEQs	Fleming (2007)
Personal Carbon Allocation	PCA	Hillman and Fawcett (2004)
Tradable Consumption Quotas	TCQ	Ayres (1997)
Household Carbon Trading	HHCT	Niemeier et al.(2008)
Cap and Share	C&S	feasta (2008)
Cap and Dividend	C&D	Barnes (2001)

Table 2.1 List of Personal Carbon Trading scheme abbreviations

Downstream cap and trade

The term Personal Carbon Trading (PCT) is used to describe a number of specific cap-and-trade scheme proposals that are aimed at providing a framework for delivering greenhouse gas emissions (GHG) reductions over the medium to long term. While a number of different policy designs exist, all schemes are based on the following principles:

- Designed as national, or sub-national
- GHG emissions covered by the scheme are capped and reduce over time
- Permits (rights) are required to cover GHG emissions by individuals
- Participation in the scheme is mandatory with no opt-out
- Tradable emissions permits or revenue generated by the scheme are distributed periodically among participants

This chapter will discuss the general principles of PCT and the common features of individual schemes. The chapter will also detail significant differences between schemes and the effect of these differences should such policies be implemented.

2.2 Policy aims

This section will describe the policy aims of PCT schemes. It will set out which aims are unique to PCT and what sets them apart from other policy instruments.

2.2.1 A framework for emissions reduction

PCT schemes aim to provide a mechanism to cap the amount of carbon dioxide or greenhouse gas emissions produced by the economy and provide a market-based system allowing the trade of emissions permits. Embedded within PCT is the principle of pricing the emissions content of goods and services.

2.2.2 Individual engagement and increased incentives

While other policy instruments, for example the EU Emissions Trading Scheme, provide a similar 'cap and trade' mechanism for controlling GHG emissions (Calel, 2013), PCT schemes are distinct in that they claim explicitly to provide engagement and participation of individual citizens as explained by Fawcett and Parag (2010):

> PCT involves a radical change in the use of market-based climate instruments: one that seeks direct involvement of the entire population and involves widespread distribution of environmental property rights. (2010, pp.334)

It is the participation of individuals and the existence of a limited personal carbon allowance, or budget, which is often cited as a reason that PCT has the potential to provide additional abatement opportunities or more effective emissions mitigation than tax-based instruments. Under other economic policy instruments, such as taxation, financial incentives are seen as the primary driver of behaviour change. Under PCT however, Fleming and Chamberlin (2011) claim that financial incentives would be a secondary motivation:

> If the energy descent were seen by consumers as, in essence, a money problem, it would be just one more charge on the household budget. Although the most successful energy-savers will be able to sell excess units, financial incentives are peripheral to the scheme, and [Tradable Energy Quotas] TEQs avoid the demotivating effect of a system based on extrinsic rewards. (2011, pp.16)

Of course, individual motivations to reduce emissions will vary and Hyams (2009) provides a more nuanced view in describing them, suggesting that PCT provides a supplementary motivation:

> …the point is that agents' motivation to reduce their emissions is less likely under a system of [Personal Carbon Allocations] PCAs to be entirely economic. The economic motivation would be supplemented by the additional moral motivation accompanying the belief that one is contributing ones fair share to the burden of discharging a collective responsibility (2009, pp.238)

2.3 The issue and surrender cycle

The processes by which emissions permits are controlled under PCT schemes are outlined below (and shown in Figure 2.1):

1. Emission Cap: Greenhouse gas emissions are capped and permits are issued to participants in line with the total amount of emissions

allowed in a specified period. Emissions permitted in subsequent periods reduce over time in line with national commitments such as the Climate Change Act (2008). Although it is not currently within its role, an independent agency such as the Committee on Climate Change is assumed to be responsible for setting the level of permits issued in any period (Fleming and Chamberlin, 2011).

2. Permit Issue: Participants are issued emissions permits by the issuing authority - the Registrar (Fleming and Chamberlin, 2011).
3. Permit Circulation: In general permits are sought by organisations to cover the emissions content of the fuels supplied or embedded within goods and services exchanged. Permits are issued to, and circulate between, different parties under different schemes. Common to all schemes is the flow of permits through the economy to fuel suppliers (in the opposite direction to the flow of fuels supplied).
4. Permit Surrender: Permits are surrendered back to the issuing authority by fossil fuel suppliers to cover emissions from the fuels supplied (Fleming and Chamberlin, 2011).

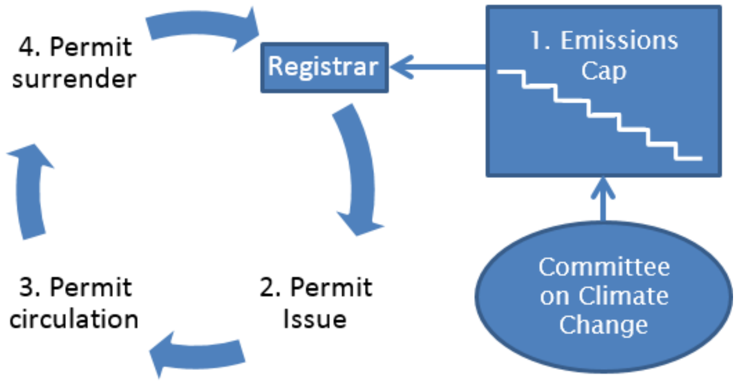

Figure 2.1 Emissions permit issue and surrender cycle apated from Fleming and Chamberlin (2011)

While proposed variants of PCT follow the principles outlined above, each scheme differs in respect of the following:

- the scope of emissions covered
- who participates in the market for permits
- how units circulate within the economy

These factors are explained in the remainder of this chapter.

2.4 Scope of emissions covered

The emissions that PCT schemes aim to control are described in this section. Using a typology adapted from Starkey (2012b), Figure 2.2 below illustrates how emissions arise from the use of fuels by different end-users. Emissions can be described as arising directly from the combustion of fuels (row 1), or indirect from the use of electricity and heat (rows 2 to 4).

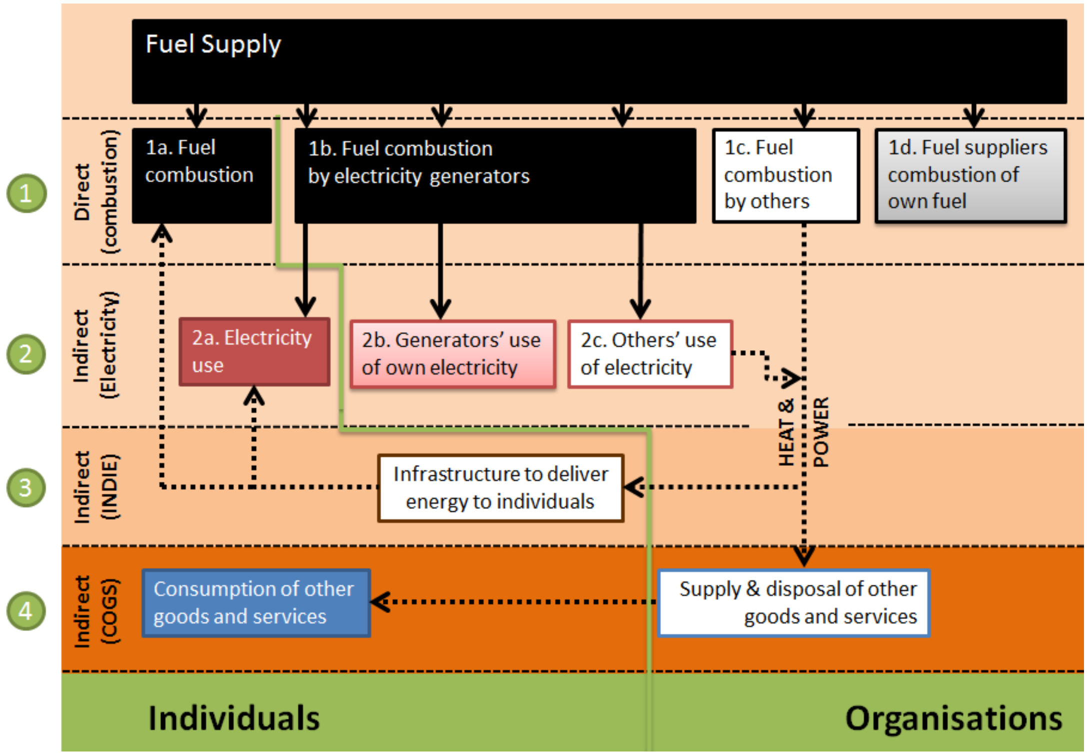

Figure 2.2 Typology of emissions from fuel combustion adapted from Starkey (2012b)

Responsibility for emissions from fuel combustion falls into two groups of end-users, organisations and individuals. The boundary between these groups is shown by the green line in Figure 2.2 above. The energy used by individuals (or households) results in direct emissions from fuel combustion (1a) and indirect emissions from or electricity use (2a)[3]. Energy use by organisations results in emissions from fuel combustion (1c) and/or electricity use (2c) (Starkey, 2012b).

Emissions from organisations are also embedded within energy consumed by individuals (Starkey, 2012b). These emissions arise from the infrastructure

[3] Emissions arising from the demand for electricity are occasionally referred to as direct energy emissions. The accurate description is indirect as emissions are displaced from the end-use.

required to supply the energy to the customer and are represented by the *indirect infrastructure to deliver individuals' energy* (INDIE) category shown in row 3. A proportion of both the fuel suppliers' own combustion of fuel (1d) and the electricity generator's own use of electricity (2b) are also used during the supply and distribution of energy to individuals leading to greater embedded emissions content. The quantity of these emissions, and the responsibility for them, is dependent on where system boundaries are drawn. For the benefit of simplicity, these considerations will be put to one side.

The remaining emissions created by organisations are embedded within the goods and services consumed by individuals and are represented by row 4, *indirect consumption of goods and services* (COGS) (Starkey, 2012b).

For clarity a simplified version of Figure 2.2 removing the emissions embedded within the *Indirect INDIE* category will be used to identify differences between individual PCT schemes. The simplified diagram is shown in Figure 2.3 below.

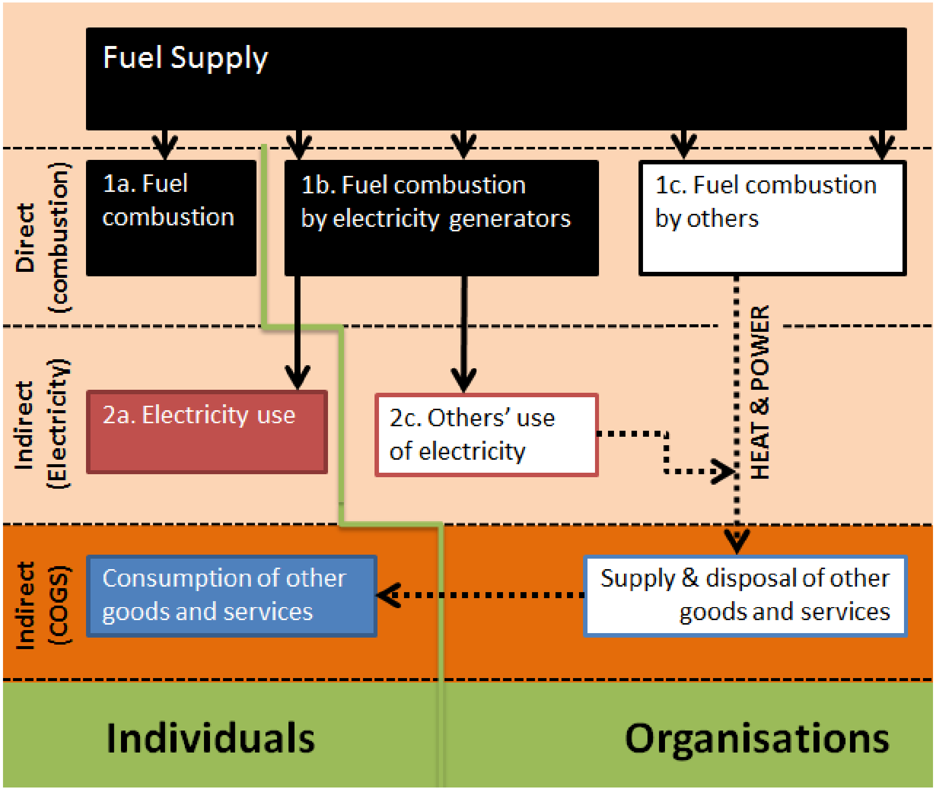

Figure 2.3 Simplified combustion emissions typology

In terms of scope, PCT schemes can be split into two groups: the first cover the whole economy and include direct, indirect electricity and indirect COGS emissions (TEQs, PCA, C&D and C&S schemes); the second covers only the emissions arising from energy use (1a) and (2a) in Figure 2.3 above (PCAe and HHCT).

2.5 How permits circulate within the economy

Each scheme differs in the way emissions permits are issued and traded, and how the permits, or revenue from the trading of permits, circulate within the economy.

Fuel suppliers must surrender permits to the issuing authority equal to the emissions arising from the use of those fuels. This control of the supply of emissions generating fuels is common to all schemes. Permits must be sought by fuel suppliers; either from other participants in the scheme or from the market in tradable permits. The mechanism by which permits circulate in the economy is therefore driven by two factors; who initially receives emissions rights and who participates in the market for permits.

A distinction between similar schemes can be drawn on these terms, distinguishing scheme designs by market structure and flow of permits. Eyre (2010) suggests that there are two different market structures that emerge from the literature. The first assumes that permits will flow from individuals to fuel suppliers via financial intermediaries (the permit market). Here the permits required by fuel suppliers (for surrender) are first allocated to individuals and then bought from individuals via ‘market makers’ (Starkey, 2012b). The Cap and Share scheme adopts this structure. Individuals receive revenue from the sale and this revenue is used to offset the additional carbon cost applied to fuels, and subsequently goods. This structure is referred to as ‘upstream’. The second structure, commonly referred to as ‘downstream’, involves permits flowing, through the economy; from individuals to fuel suppliers via retailers, wholesalers, producers *et cetera*. The permits would flow in the opposite direction to the emissions content of each transaction of goods and services resulting in both direct and indirect emissions. In this way, the fuel suppliers obtain the quantity of permits required to cover the fuels sold indirectly. Schemes such as TEQs and PCA assume this structure.

These structures determine how and when individuals are required to interact with the scheme. The interaction under an upstream scheme would take place only when individuals chose to sell their permits. In these schemes the value of the embedded emissions are replaced 'upstream'; i.e. the transaction cost of goods and services increases to reflect the quantity of embedded emissions. Under a downstream scheme for example, individuals would be expected to surrender permits to retailers whenever goods within the scope of the scheme were purchased (Hillman and Fawcett, 2004; Fleming, 2007). Under this structure, individuals would be required to surrender emissions permits with every direct purchase of energy. In this case, permits pass from the individual to the retailer, reducing the balance of permits available to the individual to 'spend'. Starkey refers to this as a *Type 1 (S1)* surrender (Starkey, 2012b). Here, the value of embedded emissions is replaced at the point of purchase by individual consumers.

In operation, it is likely that a downstream scheme would need to allow some individuals to make energy purchases without either having the sufficient balance of permits to surrender, or, being able to verify that they own the required permits (i.e. having forgotten their carbon account card) (Lane *et al.*, 2008; Starkey, 2012b). Under these circumstances energy retailers would need to obtain the required permits to cover the transaction on the individuals' behalf, in order to hold the required number to cover the transaction. The customer would be charged an additional amount to cover the cost of the permit acquisition by the fuel supplier. This method is referred to as *pay-as-you-go*, or *Type 2 (S2)*, surrender (Starkey, 2012b). Due to the existence (and potential extent) of the *pay-as-you-go* mechanism, Eyre concludes that the two structures are actually *upstream* and *midstream*, as opposed to *upstream* and *downstream* (Eyre, 2010).

2.6 Who participates in the market?

Trading occurs in PCT schemes between agents in the following configurations:

- Between individuals or households. The market enables the trading of permits between individuals who require emissions permits above their allocation and those requiring fewer permits than their allocation.
- Between organisations. Under a scheme where organisations bid for emissions permits at auction, the market provides for organisations to sell surplus permits to other organisations requiring additional permits.

- Between individuals and organisations. Where emissions abatement occurs more quickly or economically in one sector, the market allows trading between sectors.
- Between individuals and fossil fuel suppliers. Individuals sell their allocation of permits directly to fossil fuel suppliers who buy enough permits to surrender for fuel sold.
- Between the Registrar and fossil fuel suppliers with revenue passed on to individuals. Again fuel suppliers are required to obtain enough permits to cover the fuel they sell.

Not all agents participate in the market under each scheme variant. For example, only individuals require access to permit trading under PCA. In the diagrams below, the market and the circulation of permits and revenue are indicated for a selection of illustrative PCT scheme designs. The permits are shown as purple rectangles with arrows to indicate the flow from the issuing authority (Registrar) through the economy and back to the Registrar upon surrender. Where currency has replaced permits, yellow circles and orange arrows indicate the flow of revenue. Dashed arrows indicate participation in the market for permits.

2.6.1 Hybrid schemes

The TEQs scheme allows all three types of trading defined above and both mechanisms for transferring emissions rights are adopted. Individuals are allocated a proportion of the total permits free of charge and organisations bid for the remainder at auction (Fleming, 1997).

Downstream cap and trade

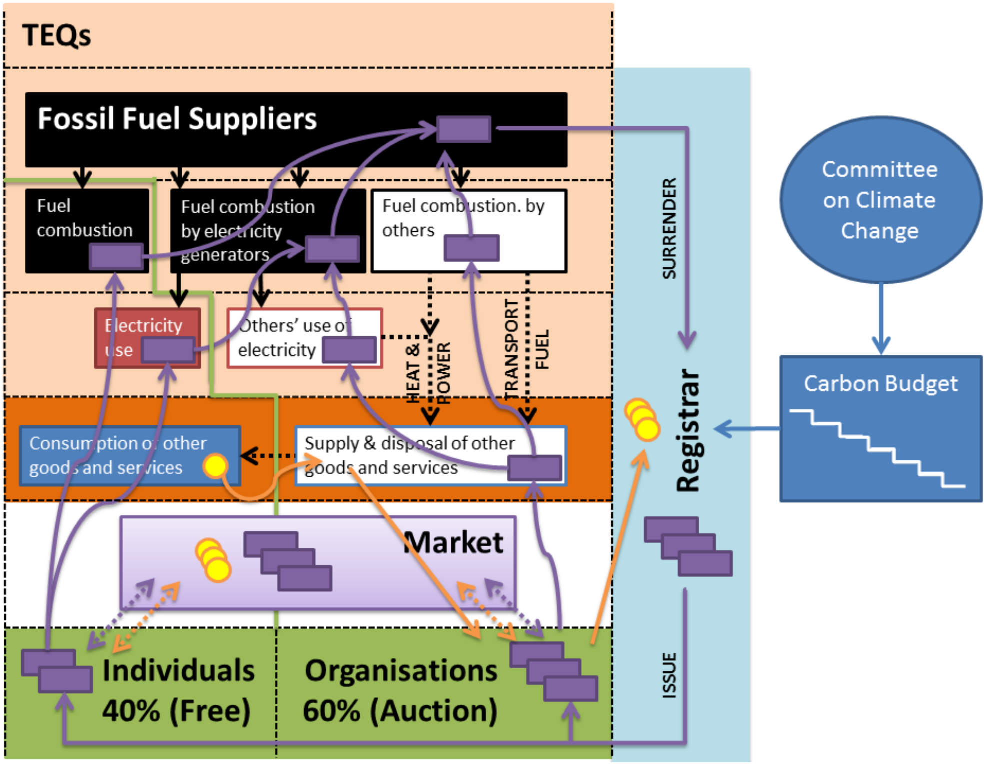

Figure 2.4 TEQs permit issue, market and circulation

Both individuals and organisations surrender emissions permits when making energy purchases. However, for the trade of goods and services between organisations and individuals, the producer has already surrendered permits covering the energy emissions embodied within the product or service prior to sale. Therefore, to avoid permits being surrendered twice for the energy emissions for goods and services, the value of the emissions permits required to cover these emissions is instead added as an additional cost. This results in increased revenue flow, representing the embodied carbon, from individuals to organisations providing goods and services and on to the registrar.

2.6.2 Whole economy

Under a PCA scheme all emissions permits are issued to individuals. The market allows for trading between individuals only. Permits are surrendered for all purchases with associated energy emissions (Hillman and Fawcett, 2004).

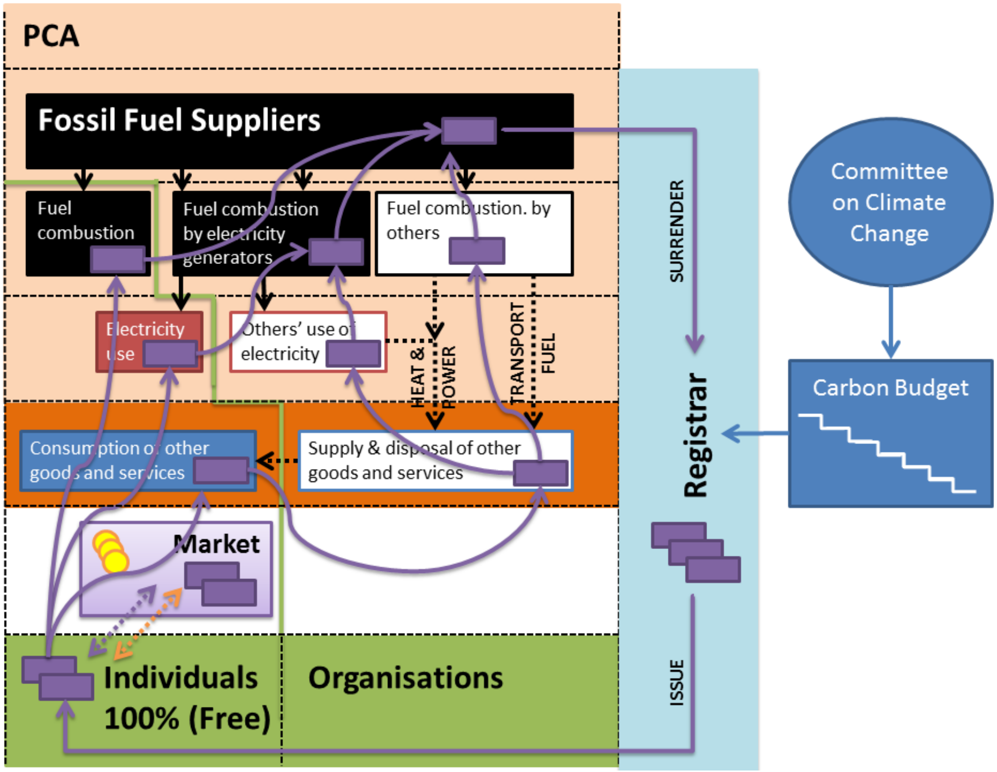

Figure 2.5 PCA permit issue, market and circulation

Under this scheme design, the permits for the energy emissions embodied within goods and services are exchanged at every purchase. Organisations must obtain the permits to cover the embedded carbon from individuals.

2.6.3 'Direct' emissions schemes

Under PCAe[4] and HHCT schemes, the market for permits is also restricted to individuals or households only but the scope of these schemes only covers the emissions relating to energy use by individuals, not the embedded emissions in products and services. Permits are therefore only surrendered when purchasing fuels for combustion or electricity. In the HHCT scheme design the fossil fuel suppliers (energy companies) create and maintain the householder permit accounts using their existing accounting systems, with control of the account being retained by the householder. The Registrar would deposit the quota for each household in this 'residential utility account'.

[4] PCA scheme design but with reduced scope covering only emissions from energy use

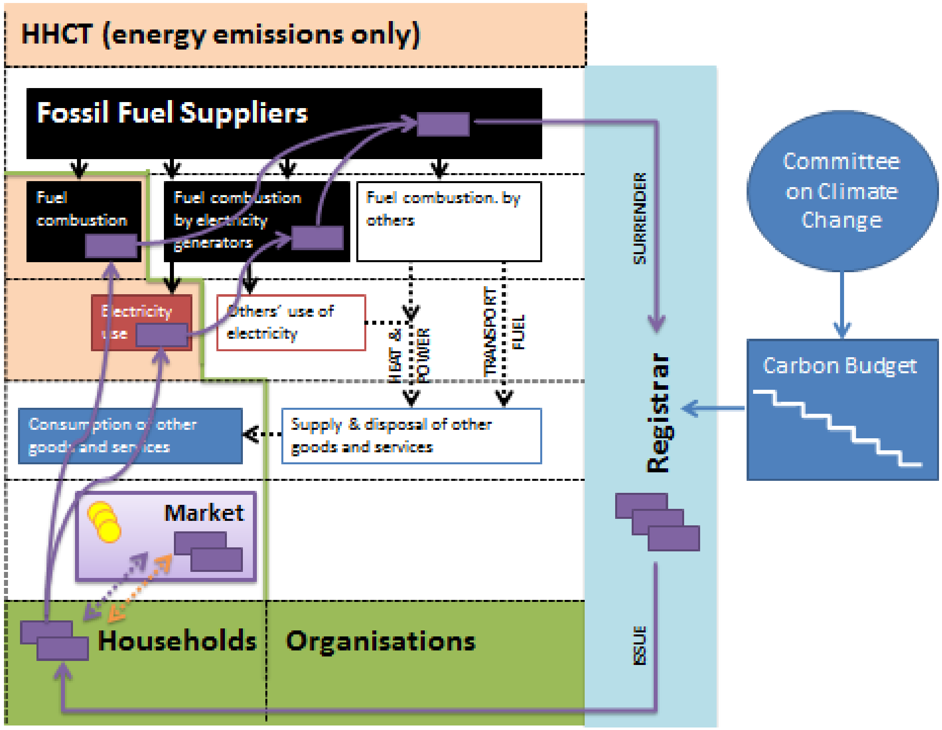

Figure 2.6 HHCT permit issue, market and circulation

2.6.4 Upstream schemes

The two schemes that follow are examples of PCT using an upstream trading approach. The market structure under both Cap and Share (C&S) and Cap and Dividend (C&D) would not result in the flow of emissions permits through the economy. Fossil fuel suppliers are still required to surrender emissions permits for the fuels that they sell, however these permits are bought directly from the market. The permits are made available on the market by the Registrar directly for C&D (with revenue distributed back to individuals), however for C&S, individuals sell permits that have previously been issued to them for free to fuel suppliers via the market. In both cases individuals receive revenue from the sale of emissions permits (Barnes, 2001; feasta, 2008). Under these schemes the cost of emissions permits are embedded 'upstream' by the fuel suppliers who pass these costs onto individuals, electricity generators and organisations who purchase fuels. The cost of the embedded emissions is passed on and leads to the circulation of currency within the economy to the value of the emissions. This is in contrast to the circulation of emissions permits under a 'downstream' scheme.

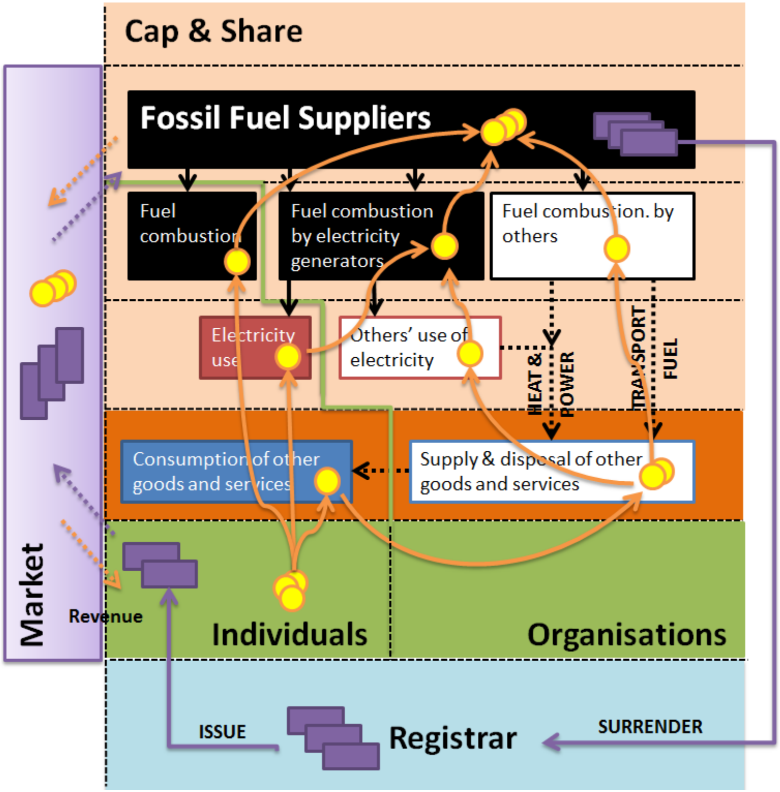

Figure 2.7 C&S permit issue, market and circulation

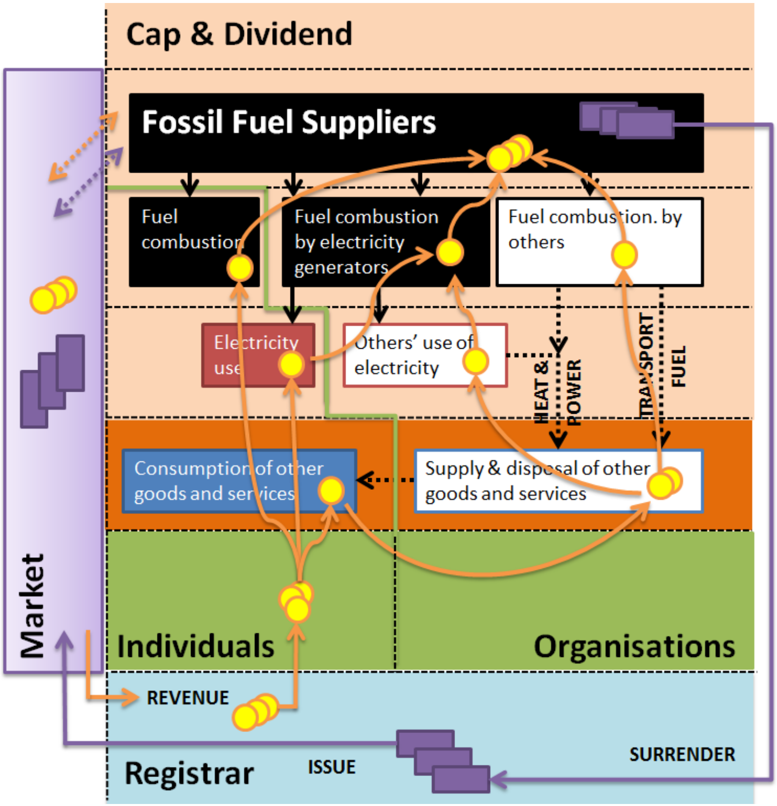

Figure 2.8 C&D permit issue, market and circulation

With the final two examples, C&S and C&D, the distinction between PCT and other cap-and-trade policies becomes less clear. As the embedded emissions content of goods and services has been replaced with a monetary value, one of the unique characteristics of PCT, the 'carbon accounting' element (Parag *et al.*, 2011), has been removed. The remaining common feature shared by these schemes becomes the allocating of emissions right or revenue (dividend) to individuals. The next sections consider the allocation of emissions rights to individuals and the flow of revenue from the trading and auctioning mechanisms.

2.7 Allocation of emissions rights

The methods with which emissions rights or the revenue from auctioning are allocated varies little between proposed schemes. The equal-per-capita allocation (EPCA) method features among all schemes except the alternative equal-per-household allocation proposed by Niemeier et al. (2008). Three distinct allocation regimes are described within the proposed schemes:

1. EPCA. Only adults receive an equal allocation (TEQs).
   The simplest allocation method and the cheapest to implement. All adult participants receive an equal allocation.
2. EPCA +Children. Equal-per-capita-allocation with children receiving an allocation (PCA, C&D). In recognition of the fact that households with children consume more energy and resources, children are included in the allocation. Children typically receive a smaller allocation than adults (Starkey, 2012b).
3. Equal-per-household allocation (EPHA). Under this allocation method, permits are distributed equally between households for a household trading scheme (HHCT).

Differences between schemes arise from the treatment of children, the proportion of rights allocated to individuals, and how revenue is redistributed. The next section will describe the revenue generated in each scheme.

2.8 Revenue

Where schemes generate revenue from the sale of emissions permits, the methods with which this is redistributed to the participants (or hypothecated) has an impact on both the equity and effectiveness of PCT (Starkey, 2012b). A distinction has to be made here between the types of revenue generated under PCT, which can take one of three forms:

i. Revenue from the sale of emissions permits between individuals, organisations or fuel suppliers.
ii. Revenue representing embedded emissions (for example where individuals purchase goods or services with embedded emissions cost from organisations under TEQs).
iii. Revenue from the auction of permits to organisations or fuel suppliers (under C&D).

Type (i) revenue is generated from the sale of emissions permits between parties for example between individuals (TEQs, PCA, TCQ), between households (HHCT, HCA) or between individuals to fuel suppliers (C&S). For individuals and households, it represents the flow of revenue from above average energy users to below average energy users. For C&S the revenue generated flows from fuel suppliers to individuals. This revenue flow creates a distributional effect of the policy on individuals and households.

Type (ii) revenue is generated when embedded emissions are represented as an additional cost to products and services in the economy and flows from consumers to organisations and on to fuel suppliers. This revenue reflects the market price for emissions and impact of pricing them in the economy.

Type (iii) revenue is generated from the sale of permits:

- by the issuing authority to organisations via auction (TEQs and PCA)
- by the issuing authority to fuel suppliers via auction (C&D)

Under TEQs and PCA, revenue from the auction of permits to organisations flows to the issuing authority. Fleming (2007) proposes that this revenue be used in projects aimed at mitigating emissions. In C&D the revenue generated flows from fuel suppliers to individuals and is recycled through the issuing authority who is responsible for its distribution. The recycling method used for this revenue has implications on the equity and distributional impact of the scheme.

2.9 Summary

All of the schemes commonly compared in the literature have been outlined here. Cap and Share, Cap and Dividend and Tax and Dividend have been included despite not being considered by some to be PCT: this is because individuals are not involved in the trading process (Fawcett and Parag, 2010). Tax and Dividend is also often compared to other policies considered here but the scheme does not operate under a hard cap on emissions, nor are individuals involved in the trading of permits. It is valid to compare these schemes to PCT schemes as under both the revenue is recycled using the same distribution to participants. While the distribution impact would be the same in terms of income/revenue generated from the scheme (also assuming equal scheme costs & carbon price) the overall effectiveness may well be different due to the differing level of carbon visibility and participant involvement between schemes. (Roberts and Thumim, 2006).

Table 2.2 PCT scheme comparison

Name	Scope of emissions covered	Enforcement	Units circulating	Emissions rights issued to:	Allocation method	Emissions permit surrender	Market[**]	Revenue recycled:
TEQs	All	Downstream	Carbon	Individuals 40% Organisations 60%	EPCA Auction	Fuel suppliers	Ind Org	- Hypothecated
PCA	All[††]	Downstream	Carbon	Individuals 58% Organisations 42%	EPCA+Children Auction	Fuel suppliers	Ind Org	- Not stated
PCA_e	HH Energy + private trans.	Downstream	Carbon	Individuals 100%	EPCA+Children	Fuel suppliers	Ind	
TCQ	All	Downstream	Carbon	Individuals 100%	EPCA		Ind,Org,FS	-
HHCT	HH Energy	Midstream	Carbon	Households 100%	Equal per household	Utilities	HH	-
C&S	All	Upstream	Currency	Individuals 100%	EPCA	Fuel suppliers	Ind-FS	-
C&D	All	Upstream	Currency	Fuel suppliers 100%	Auction	Fuel suppliers	FS	EPCA+Children

[**] Ind – Individuals, HH – Households, FS – Fuel suppliers, Org - Organisations

[††] Variants of PCA have been proposed to cover range of emissions. The scope of the emissions covered affects permit issue, allocation method and who participates in the market. Two schemes are considered here, PCA covering all emissions from fuel combustion, and PCA covering only emissions from energy use, denoted as PCA_e.

3. Policy and research

3.1 Overview

The PCT literature shows steady development from an initial stage, where specific scheme proposals were outlined and ideas developed, to the present where a more mature academic debate is focussed on specific aspects of PCT policies. The literature is defined by four periods:

1. Initial development – describes a period where the focus of literature was the setting out of individual PCT scheme designs.
2. Building interest in PCT – describes a period of increasing academic and political engagement with PCT policies.
3. Defra research 'spike' – describes the substantial increase in research activity spurred by interest from Government. In this period, there is more detailed consideration of aspects related to policy development and implementation.
4. Post Defra – the period following the completion of the Government's pre-feasibility study. This period is marked by more peer-reviewed academic research with papers focussed on individual aspects of PCT.

In a journal article, Fawcett (2012) provides analysis of media coverage and academic papers published between 2004 and 2011. Fawcett shows that while the media interest in PCT peaked in 2007 during the Defra research period, academic publications peaked with fifteen articles published in 2010[7] (and twelve in 2011) compared to a maximum of three articles published in any one year in the period 2004 to 2009.

3.2 Initial development

A system of rationing domestic energy was first proposed by David Fleming, first covering only transport fuel (1996) and then the whole economy (1997). The proposed system was named Domestic Tradable Quotas (DTQs) by Fleming and claimed to meet "the two sides of the energy problem: climate change and the depletion of fossil fuels" (Fleming and Chamberlin, 2011, pp.6). By 2005

[7] Although two-thirds of the academic articles published in 2010 were in a single special issue of Climate Policy.

Fleming had renamed the system as Tradable Energy Quotas or TEQs (Fleming, 2007). Other schemes have also been proposed, such as Personal Carbon Allowances (PCA) which are described in depth in the book *How we can save the planet* (Hillman and Fawcett, 2004), and Tradable Consumption Quotas (TCQ) (Ayres, 1997). Alternative schemes have been developed more recently, based on an 'upstream' scheme design; Cap and Share (feasta, 2008) and Sky Trust (Barnes, 2001). Household-based schemes have also been proposed: as household carbon trading (HHCT) by Niemeier et al. (2008) and differentiated per household allocation (HCA) by Rushby (2011).

3.3 Building interest in PCT

3.3.1 Academic

The concept of DTQs was subject of a full academic analysis by Starkey and Anderson between June 2003 and June 2004. The research project was carried out under a larger body of work on the theme of 'Decarbonising the UK' undertaken by the Tyndall Centre for Climate Change. The report was published in December 2005 and set out to "evaluate the feasibility of DTQs and their appropriateness as an instrument of public policy." *(*Starkey and Anderson, 2005, p.2)

January 2004 marked the beginning of a two year period of dissemination of the Tyndall research project. Starkey and Anderson detail many of the events in their report, including presentations, workshops, appearances on broadcast media (BBC TV and radio) and in published media: broadsheet newspapers (Telegraph, Independent) and other academic, NGO and industry literature. These dissemination activities undertaken as part of the project introduced PCT to a number of parties previously unaware of the concept Starkey and Anderson comment on the effect of this activity:

> At the beginning of the project, DTQs were not widely known within the policy community. However, the project has stimulated a very considerable interest in DTQs and at the end of the project, DTQs are much more widely known and is being taken increasingly seriously as a potential instrument of public policy. (Starkey and Anderson, 2005, p.5)

In August 2005, during the dissemination of Starkey and Anderson's work, the Royal Society for the encouragement of Arts, Manufacturers and Commerce (RSA) announced a project looking into PCT. The project had a budget of £0.5 million and ran from January 2006 to November 2008 (Starkey and Anderson, 2005), culminating in the release of a report entitled *A Persuasive Climate* (Prescott, 2008). In order to maintain a sense of chronological order within this text, the RSA report will be discussed in section 3.4.3. It is worth noting that this project was active during the final stages of the Tyndall dissemination and also the research effort to be discussed in the next section.

3.3.2 Political

Colin Challen MP became a champion of DTQs in the early stages of the Starkey and Anderson's project dissemination. At this time he was chair of the All Party Group on Climate Change and member of the Environmental Audit Select Committee. He contacted Kevin Anderson after hearing his interview on BBC Radio 4 in January 2004 and invited Anderson to present DTQs at a meeting in the House of Commons. Challen went on to introduce the concept in a private members bill in the House of Commons in July 2004: (Domestic Tradable Quotas (Carbon Emissions) Bill (HM Government, 2004). Another significant outcome of the raised awareness created by the Tyndall research was an approach by Defra to the authors, to submit a paper on DTQs to their Climate Change Programme Review. (Starkey and Anderson, 2005)

The events described above led to awareness of PCT within Defra and the commitment, in the 2006 Energy Review, to look further into personal carbon trading (Bradshaw *et al.*, 2008). On 19th July 2006, David Miliband gave a speech outlining the Government's energy review and mentioned PCT. The review reveals that the Government were looking to new policy ideas and set out their plan to take the PCT policy idea forward:

> Over the next 12 months, DCLG, Defra, DTI and HM Treasury will undertake a joint study which will look at the role of 'community level' approaches to mobilising individuals, and the role of local authorities in particular in making them work effectively. It will draw on experience of what initiatives have worked and which haven't in both the environmental area and other policy areas, such as public health. In

> the light of this information, **the study will also examine what new policy options, such as tradable personal carbon allowances (PCA), could be deployed to stimulate local action** and consider their relative pros and cons. We expect it to report to Ministers in the first half of 2007." (DTI, 2006, p.53, emphasis added)

The following year, the Energy White Paper set out the Government's position concerning the energy taxation situation at that time:

> "The Government believes that the current system of taxation strikes the right balance between protecting the environment, protecting the most vulnerable in society and maintaining sound public finances." (DTI, 2007, p.61)

The White Paper also set out the questions to be answered by the PCT research programme:

> "There remain many high-level questions about whether a personal carbon allowance scheme could be proportionate, effective, socially equitable and financially viable, particularly when compared or combined with existing policies and other options for controlling carbon emissions; whether it could be a practical and feasible option; how such a scheme might work in practice; and whether it would avoid placing undue burdens on individuals. The Government is therefore undertaking a programme of work intending to look into these issues in more detail." (DTI, 2007, pp.61-62)

3.4 The Defra feasibility research 'spike'

The result of the commitment set out in the Energy White Paper was a surge of research activity. This began with the commissioning by Defra of an initial scoping study by the Centre for Sustainable Energy (CSE) carried out in 2006 (Roberts and Thumim, 2006).

3.4.1 Scoping report to Defra November 2006

Published in November 2006, the short scoping study titled *A Rough Guide to Individual Carbon Trading* sought to provide Defra with an initial analysis of the issues concerning PCT.

> "The primary purpose of the study was to assess the range of questions which arise when such a concept emerges from the rarefied atmosphere of academic debate and 'think-tanking' to be considered seriously as a potentially practical policy option." (Roberts and Thumim, 2006)

The authors were critical of the existing state of research into PCT stating that debates focussed on the "operational minutiae of specific schemes" and "minor theological differences". These were seen as less important than untested assumptions about public acceptability and political feasibility. They also highlighted the risk that the "…debate on the relative merits of individual carbon trading will descend quickly into confrontational debate in which practical understanding and analysis take second place to the preservation of increasingly entrenched positions" (Roberts and Thumim, 2006, p.3). While not explicitly stating what these positions were, it is assumed that this refers to the debates over carbon taxation and trading policy instruments (see quote from the Energy White Paper above) with advocates focussed on selling their particular approach rather than moving the debate forward. The report by Roberts and Thumim set out the main issues requiring further research and developed a road map providing a framework to assess the development of PCT policy.

3.4.2 Personal Carbon Trading –Defra Synthesis 2008

Following the 2006 report by Roberts and Thumim, Defra commissioned four reports to investigate various elements of PCT. This was summarised and collated in the synthesis report published in April 2008. The substantial research effort included the following contributing reports:

i. Technical feasibility and potential cost (Lane *et al.*, 2008)
ii. Effectiveness and strategic fit (Defra, 2008a)
iii. Public Acceptability (Owen *et al.*, 2008)
iv. Distributional Impacts (Thumim and White, 2008)

It is important to note that this work did not constitute a full feasibility study. The scope of the research was limited to the high level questions related to the concept rather than an options analysis of the best individual scheme design. While Defra found that PCT was under-developed and that significant challenges existed to the potential use of PCT as a policy tool, the Government remained interested in the concept. The report set out recommendations for further research and development of PCT:

- Options analysis to determine the best technical option in terms of cost and public acceptability.
- A pilot or trial to test the findings of the technical feasibility and public acceptability. Although there is also a recognition of the inherent limitations of such research i.e. not able to test the mandatory element of PCT.
- Assessment of the 'key cost drivers' and how these could be reduced.
- Evaluation of the effectiveness of PCT on effecting behaviour change and comparison to other policies.

The report stated how Defra saw the involvement of the Government in PCT research going forward:

> These conclusions point towards Government maintaining engagement in the debate by keeping a watching brief as further research is taken forward by academics and research institutions, but not moving forward to a full feasibility study at this stage. (Defra, 2008b, p.22)

3.4.2.1 Environmental Audit Committee report

The Environmental Audit Committee (EAC) was critical that, following the Defra synthesis report, the Government was winding down its involvement in the continuing research into PCT (Environmental Audit Committee, 2008). It urged the Government to take a more central role in "…leading and shaping debate and coordinating research." (p.4) They suggested that without Government involvement, PCT was unlikely to become viable policy. If Government were to participate in the design and implementation of a sensitive and moderate scheme, the barriers to PCT could be overcome. The report suggested that a shift in the debate around PCT was needed, away from the details of how the policy would operate and towards the issues of public and political acceptability. (Environmental Audit Committee, 2008)

3.4.3 CarbonLimited project

A Persuasive Climate (Prescott, 2008) is part synthesis report and part outlook paper. The report summarises the 'Carbon*Limited'* research project undertaken by the Royal Society for the encouragement of Arts, Manufacturers and Commerce (RSA) into PCT. The project ran from January 2006 to November 2008, the same period as the Defra study. The project consisted of four pieces of research including the following elements:

- Loyalty Card trial of 100 volunteers using loyalty cards to record motor fuel purchases. Aiming to understand individual participation and the technology required
- Behaviour Change – computer assisted behavioural tests to assess how different policies (carbon tax, PCT) affect decision making (Bristow *et al.*, 2010)
- Public attitudes and carbon market – research by consultancy E3 evaluated the policy landscape and economic efficiency
- CarbonDAQ (now carbonlimited) – online experiment into 'incentive only' voluntary individual and group emissions reductions

The Carbon*Limited* research was directed at understanding and evaluating public engagement and participation aspects of PCT scheme proposals.

3.5 Post Defra

This period of literature is distinctive as the research is no longer driven by Defra (although research started in this period and published later tackles themes identified in this period e.g. Bristow). Academics and other researchers engage in developing PCT further. Some synthesis papers review the development/state-of-the-debate to date (Bird and Lockwood, 2009; Prescott, 2008; Keay-Bright et al., 2008) but more focussed papers begin to emerge, tackling specific aspects of PCT. A special edition of *Climate Policy* in 2010 added a significant amount of articles to the literature. With such a large amount of analysis produced for the Defra reports, Fawcett (2010) seems to be justified in complaining in her introduction that there had been comparatively little published in academic journals on the subject previously. The articles published in this volume therefore represent a significant contribution to the peer-reviewed literature on PCT.

3.5.1 Plan B? The prospects for personal carbon trading

While not published in a peer-reviewed journal *'Plan B?'* (Bird and Lockwood, 2009) formed a significant piece of work. The Institute for Public Policy Research (IPPR), a progressive think-tank, completed a comprehensive review of prior research and reported on new studies that they had commissioned. These pieces of research investigated the subjects of public acceptability and mitigating the distributional impacts of PCT. The contributing reports were as follows:

1. Capstick and Lewis (2008) – Personal Carbon Trading: Perspectives from Psychology and Behavioural Economics
2. Bird et al. (2009) – Political Acceptability of Personal Carbon Trading: Findings from primary research
3. Lockwood (2009) – A Review of Assumptions in Defra's Pre-feasibility Study of the Potential Effectiveness of Personal Carbon Trading
4. Thumim and White (2009) Moderating the Distributional Impacts of Personal Carbon Trading

The report can be seen as a response to some of the questions arising from Defra's pre-feasibility study.

3.6 Themes emerging in the review of literature on PCT

3.6.1 Overview

Three criteria are seen as key to evaluating environmental policy instruments and have been adopted when evaluating PCT; effectiveness, efficiency and equity (Lockwood, 2010; Starkey, 2012a, 2012b). The themes emerging from the existing literature can be broadly separated into these three categories which will provide the headings for this section. While some of the literature reviewed here looks at aspects of PCT that apply to just one of these criteria, much of it spans two or all three.

In his paper titled *The economics of personal carbon trading,* Lockwood (2010) reviews PCT in terms of all three criteria and provides an overview of the considerations involved in evaluating the policy on these terms – particularly effectiveness and efficiency. He describes how PCT (TEQs, PCA), upstream cap-and-trade (C&D, C&S), and carbon taxation all aim to create a price for carbon. He suggests that in order to make a judgement on which policy will be more efficient, the additional emissions abatement potential of PCT over and above cap-and-trade must be estimated, along with the shadow price of carbon. This must then be set against the additional costs of setting-up and running a PCT scheme. Simply put: scheme efficiency equals the administrative cost of the scheme divided by the benefits of mitigated emissions (additional emissions abated multiplied by the carbon price).

3.6.2 Administrative costs

The only detailed costing study of PCT is the contributing report for Defra by Lane et al. (2008), although this was reviewed and revised by Bird and Lockwood for IPPR for their *Plan B* report (2009). These studies have been reviewed subsequently by Lockwood (2010) and Starkey (2012a). Lockwood suggests that "most economists would rule out a downstream trading scheme such as PCT *a priori* on the grounds that transaction costs would be far too large" (Lockwood, 2010, p.453). Upstream cap-and-trade schemes would involve the participation of a few hundred energy wholesalers, whereas a downstream PCT scheme would involve fifty million individuals (Lockwood, 2010).

Lockwood highlights the problems inherent in comparing different studies due to the different estimates of carbon price and additional abatement opportunity offered by PCT. There is debate about the appropriate way to define the shadow price; social price (£0 to £1000 /tC) versus marginal abatement cost, or MAC (traded = £14-31/tCo_{2e}, non-traded = £30-90/tCo_{2e}). Defra use £30/tCO_2 (range: £29 in 2013 rising to £33 in 2020 based on Stern review) and IPPR use £50-60/tCO_2 (based on marginal abatement cost).

3.6.3 Enforcement, engagement and effectiveness

There is some debate in the literature over the potential for additional emissions abatement under PCT. Lockwood comments that Defra (2008a) appear to base their assumptions of additional abatement solely on behaviour changes due to increased energy visibility. Citing previous work (Bird and Lockwood, 2009), he argues that a wider range of emissions reductions would potentially occur under PCT. Starkey claims that both the Defra and IPPR (Bird and Lockwood) studies use an evaluation of the TEQs scheme that is “implausibly efficient” (Starkey, 2012a, p.24). Starkey supports this claim by theorising on the enhanced engagement of an individual in emissions reductions activities, what Starkey calls “engagement, consciousness, responsibility and empowerment (ENCORE)” (Starkey, 2012a, p.22).

The extent to which individuals interact with PCT is determined by the scheme design: allocation mechanism, trading and enforcement regimes (Eyre, 2010; Starkey, 2012a). Eyre investigates enforcement options at various locations where energy transaction take place within the economy. He concludes that the options are actually upstream vs. midstream, as opposed to upstream vs. downstream - the options dominant in the preceding literature.

Eyre argues that, under a TEQs scheme, it is actually the energy retailer not the individual who would have to be regulated to ensure that the energy transaction is covered by sufficient carbon permits. Energy retailers would need to hold permits equal to the carbon content of the fuels sold in the allocation period and would therefore be obligated to acquire permits for each sale. Under all surrender regimes, the system would need to allow some individuals to make energy purchases without having the sufficient permits to surrender (i.e. having forgotten their carbon account card). As energy suppliers would still need to obtain the required permits, they would purchase permits to cover the transaction from the market on behalf of the individual, adding an additional amount to the purchased goods to cover this cost.

Eyre’s description of the permit surrender regime is not new (see Lane et al. 2008), but the conclusions he draws in terms of the implications on scheme design are more explicit. He suggests that energy suppliers would have an incentive to keep transaction costs low and therefore would be likely to prefer to purchase permits in fewer large transactions than many smaller ones. This would result in reducing individual interaction with the budgeting element of PCT and perhaps reduce the effectiveness (additional abatement potential) of the scheme. Eyre suggests that this would need to be countered and “separate regulation on energy retailer systems and marketing would be required in order to increase the chances of the scheme being effective” (pp.441).

Starkey argues that the supposed increased 'ENCORE' under PCT is due to the increased interaction; individuals must surrender emissions rights at each purchase (S1 surrender). But as Starkey and Eyre show, it is not clear that individuals would be incentivised (or that energy retailers would be encouraged) to use this method rather than embedding the emissions cost at each purchase (S2 surrender). Starkey claims that PCT using S2 surrender is no different from an upstream scheme such as C&S (see also Section 2.6). Fleming recognised this critique and warned that critical analysis often compares different variants of PCT and that important differences in outcomes result from minor changes in scheme design (The Lean Economy Connection, 2008). Indeed, others also argue that outcomes are significantly affected by the specific attributes of scheme design (Prescott, 2008; Bristow *et al.*, 2010) and the need for further assessment of the additional abatement potential from increased energy and carbon 'visibility' was highlighted in the synthesis report for Defra (Defra, 2008b).

Capstick and Lewis (2008) also investigate the likely ways that PCT might affect additional emissions abatement by looking to psychology and behavioural economics. At the time they suggested that there was "almost no empirical evidence" to support the claim in the PCT literature that such a scheme would result in increased engagement (Starkey's 'ENCORE'). However, after examining indirect research from psychology and other areas of social science, the authors outline some predictions of how PCT might be received and interpreted by participants. They suggest that people could be expected to react differently to PCT than other incentives such as taxation or upstream trading. This is because the way people think about resources affects their choices over and above the financial value placed on them (i.e. people are not purely rational-economic). Much environmentally significant behaviour is habitual (and difficult to affect) but PCT may provide a combination of incentives and contextual change that is effective in changing habits. By separating out carbon as a distinct resource, "a new type of carbon budgeting and carbon conservation might be expected" (Capstick and Lewis, 2008, P.35). The authors identify potential for a carbon currency to promote and encourage environmental self-awareness and accountability but psychological reaction to PCT is "… likely to be mediated by a range of framing and presentation effects" (p.36).

Policy and research

Following on from this early exploration of the behavioural psychology approach, Fawcett suggests that "the most challenging and, arguably, most urgent need in PCT research is to identify and, if possible, quantify the benefits it could deliver beyond its economic effect" (Fawcett, 2010). Capstick and Lewis (2010) attempt to provide empirical evidence to support the claim of increased behavioural response to PCT over pure price mechanisms. They used computer simulation to examine participants' decisions about their personal carbon allowance within a PCT scheme scenario (n=65). The authors found that using two trials (the first restricting available permits to 20 per-cent below participant's footprint, the second restricting available permits to 40 per-cent below participant's footprint), participants made more carbon restrictive decisions in the second trial where permits were more restricted. A more restrictive allocation resulted in lower carbon choices. Participants relinquished emissions rights equal to an average 19 per-cent reduction in the first trial, and a 22 per-cent reduction the second trial.

Another empirical study into the additional abatement potential of PCT over other policies was produced by Parag et al. (2011). The study examined willingness of a representative sample of individuals (n=1096) to change energy consumption behaviour under three different policy framings: energy tax (Etax), carbon tax (Ctax) and personal carbon allowance (PCA). The authors found that those given the PCA framing were more likely to state a willingness to change behaviour than those given the Etax or Ctax framings. The study found no significant difference between the responses from those given Etax and Ctax framings. While the study found greater stated willingness to change behaviour under PCA, the extent of this influence was less evident. PCA was only influential on the extent of behaviour change in two out of four of the behaviours examined with Ctax returning a similar result (for different behaviours).

In summary, there are arguments for upstream schemes, that by involving fewer agents and transactions, such schemes are less complex and less costly to maintain and enforce. There is, however, a counter argument to the adoption of upstream scheme designs: that these advantages are offset, or outweighed, because they are less effective due to lower individual engagement.

3.6.4 Efficiency

In their synthesis report, Defra (2008b) conclude that current PCT scheme costs (TEQs) outweighed the potential benefits. There was recognition that significant reduction of scheme costs could be achieved with alternative scheme designs (Defra, 2008b). Costs might also be reduced by utilising existing loyalty scheme infrastructure (Prescott, 2008). An increase in the value of benefits may see PCT become cost effective (Defra, 2008b).

To compare the efficiency of differing schemes the overall cost can be plotted on a chart as in Figure 3.1 represented as curved lines. The value of a quantity of additional abatement resulting from PCT for a given carbon price can be plotted on the same chart giving a point relative to the scheme cost curve. Points lying below the curve indicate that the value of emissions abatement is lower than the cost of administering the scheme. Points lying above the curve indicate that the value of abatement is higher than the cost of the scheme. The chart below illustrates the PCT scheme cost estimates produced by Defra (a) & IPPR (b). Defra estimate the potential additional abatement of PCT in the range 0-5% of emissions in 2013 (232.5MtCO_2) at a carbon price of £30/tCO_2. IPPR estimate potential additional abatement between 3.5-8.5% and a carbon price of £50-60/tCO_2. It is clear that Defra's estimates fall well below their estimates of scheme costs, but IPPR's estimates rise partially above their lower estimates of scheme cost (Lockwood, 2010) (Starkey, 2012a).

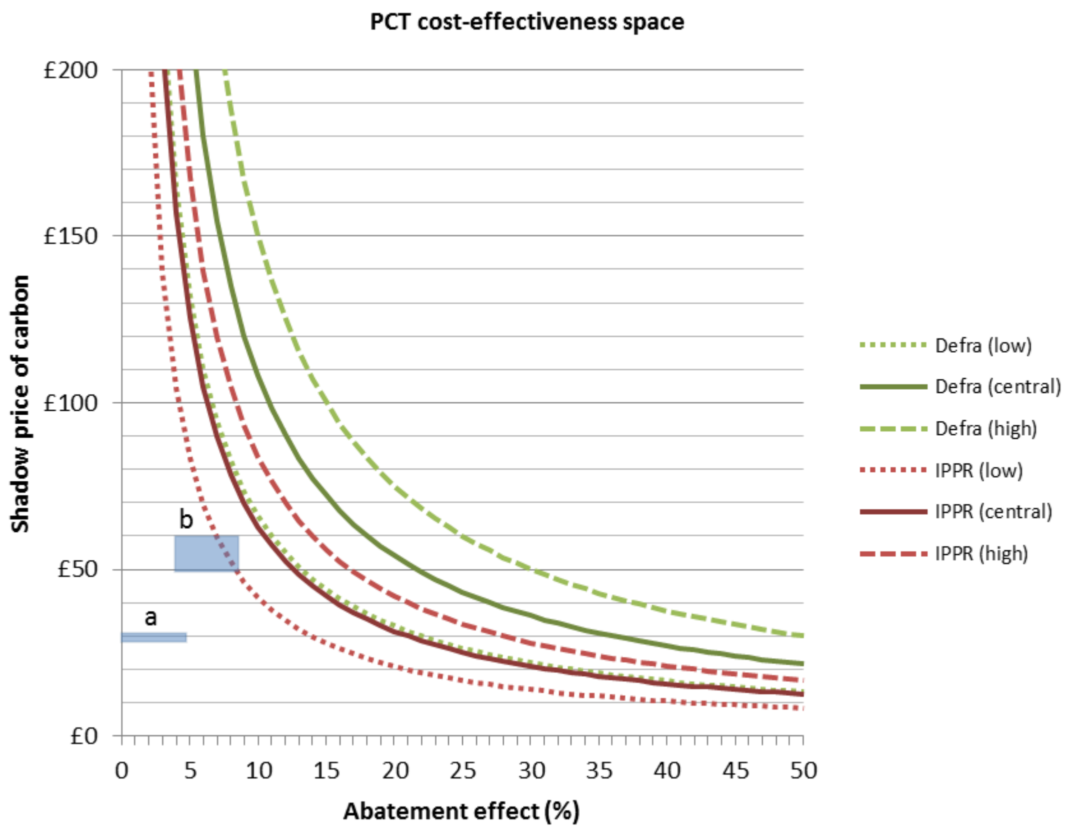

Figure 3.1 PCT cost-effectiveness space using Defra (Lane *et al.*, 2008) and IPPR (Bird and Lockwood, 2009) estimates

In his analysis of efficiency and effectiveness of PCT, Starkey (2012a) also compares the two studies produced by Defra and IPPR. He pays detailed attention to the assumptions made by each and also includes upstream schemes, C&D and C&S in his comparison. Starkey concludes that under the assumptions made by Defra, the additional abatement provided by PCT must be greater than 23 per-cent in order for the scheme to be cost-effective (cheaper than shadow carbon price). Similarly, under the IPPR assumptions, additional abatement must be greater than 6.8 per-cent. While Lane et al. (2008) use a traditional view of cost effectiveness for their report to Defra, there are other considerations that might be included in evaluations of PCT, for example, the value of equity and public acceptability (Roberts and Thumim, 2006). Starkey (2012a) explicitly excludes consideration of Fleming's 'common purpose' argument in his analysis, however he suggests that the value of this concept, along with increased equity/decreased compensatory measures, should be included in a comprehensive cost/benefit analysis.

3.6.5 Public Attitudes

In their report to Defra, Owen et al. (2008) aimed to provide an initial insight into public understanding of individual contributions to carbon emissions; attitudes to the general principle of personal responsibility for these emissions; and to the idea of Personal Carbon Trading (PCT) as a policy to limit these emissions. Their focus was on 'living with PCT' (or the more technical aspects related to scheme operation and administration) as opposed to deeper investigation of reaction to the scheme in principle. However, their report revealed a perception of PCT as 'Government-imposed' limits to individuals' emissions, highlighting "…that the way that personal carbon trading is presented and described and the context in which it is set can have a considerable impact on its acceptability" (Owen *et al.*, 2008, p.v).

Public acceptability is seen as a challenge for PCT: concerns of the effect on vulnerable groups (e.g. those in fuel poverty), fairness, the complexity of PCT schemes, Government trustworthiness, and effectiveness in reducing emissions surround the potential for implementing PCT policy (Defra, 2008b). Recognising these issues, and following the Defra report, the Environmental Audit Committee (EAC) commented that a shift in the research agenda was needed, away from the details of how PCT could operate to the issues of public and political acceptability (Environmental Audit Committee, 2008). However, as Owen et al. (2008) note, separating these issues is difficult as opinion about PCT is closely linked to aspects of scheme design.

For the longer term, the EAC recommended that the Government keep PCT open as a policy option and that, enabling policies should be developed to prepare the public, as well as noting that public perceptions of the Government's own commitment to reducing emissions were also important (Environmental Audit Committee, 2008). Suggestions of measures to support public opinion and engagement included improving 'carbon literacy' and attempting to better understand how the public perceive fairness in climate policy (Environmental Audit Committee, 2008). Others have also raised the need for supporting policies (Bird and Lockwood, 2009; Parag and Strickland, 2009).

It appears the call for a shift in the debate was heeded. Fawcett and Parag (2010) note that 'social acceptability' was the most active area of PCT research in the years following the EAC report. This is evidenced by the large amount of journal articles and reports published on this aspect.

Jagers et al. surveyed 2000 Swedes using a questionnaire aimed at exploring "the relationship between people's attitudes to a PCA scheme and their trust in politicians, its perceived fairness, and its underlying ideology, respectively" (Jagers *et al*., 2010, p.410). Factors found to correlate with support for PCT were those who have a high level of trust in politicians, and those who agree with principles of fairness such as equity, equality and need. The authors comment on their analysis of redistribution effects under EPCA; finding that individuals exhibit a self-serving bias in attitudes towards redistribution. This is due to factors such as countryside to city, single-family houses to flats, and families with children to families without. An interesting finding is that support for one redistribution did not follow the 'self-serving' hypothesis, that of people with high income to low income.

On political affiliation and ideology, the authors found no significant differences in support for PCA between groups. They conclude that the introduction of PCT would, in Sweden at least, be politically neutral.

The implications of these results for policy makers are discussed by Wallace et al. (2010). They state that the findings suggested that for PCT schemes to be introduced, self-interested groups (for example those living in the countryside and families with children) would need to be challenged. They also recommended that the trust issues around setting the cap and level of allowances be acknowledged and tackled. What is missing here is any link of the issue of fairness (and self-interest) to an alternative allocation method more sensitive to consideration of circumstance. Bird and Lockwood's research shows that individuals are sensitive to these issues. This view is supported by Starkey (2008) and Hyams (2009).

Bird and Lockwood (2009) found that the public view PCT as fairer than carbon tax and appreciate that equal-per-capita is not necessarily inherently 'fair' (some individuals 'need' more emissions permits than others). They directly challenge the public acceptability barrier identified by DEFRA and point to a regime other than equal-per-capita as the fairest method to distribute permits or revenue. A significant finding was that 70 percent of respondents supported, or strongly supported the statement that "*PCT would be unfair* *because some people need more carbon credits than others. For example, people who need to heat bigger houses or people who live in rural areas and need to drive more.*" This finding indicates an appreciation by the public of different circumstances requiring varying levels of access to energy.

Bristow et al. (2010) investigate the acceptability of variants of PCT scheme design and alternatives such as carbon tax. They conclude that support for PCT is dependent on scheme design but is greater than for carbon taxes. Support can be very high for schemes including additional allowances for children and those with additional needs, confirming the findings of Bird and Lockwood (2009).

Capstick and Lewis (2010) investigate relationships between footprint size, environmental concern and support for PCT. A significant inverse correlation was found between footprint size and support for PCT. More significant were the positive correlations between level of concern about climate change and support for PCT, and between 'self-ascribed responsibility' and support for PCT. A correlation was also found between proportional carbon reduction and environmental concern. Wallace et al. (2010) examine public response to, and support for, PCT. The study did not compare PCT against taxation, but asked participants a variety of questions relating to actions that they would take if PCT was implemented. Support for PCT was marginally greater than opposition (42% vs. 37%) and significant correlations were found between support for PCT and support for energy efficiency and renewable energy. Inverse correlations with support for PCT were found for those less likely to choose low-carbon transport modes and those unlikely to 'try to use as few units as possible' in order to sell them. Among interviewees, the researchers found "little suggestion of carbon taxation as an alternative to PCAs" (Wallace *et al.*, 2010, p.402). In much of the literature, PCT is automatically compared to carbon taxation, however the findings of Wallace's study show that participants did not automatically make such a comparison when considering policies aimed at incentivising carbon mitigation. Indeed, Fawcett (2010) urges caution when looking at social acceptability of PCT as the context in which opinions are sought are likely to affect findings. She recommends that prior to any further research in this area a critical review of the methodologies used in previous research should be completed. Following this, findings should be reevaluated along with a review of how these findings have been interpreted and used by decisions makers.

3.6.6 Fairness

The concept of fairness, or equity, referred to in the literature on PCT can be separated into two main concerns: how to realise the principle of moral equality (i.e. who has the right to emissions), and the distributional principle (who should receive the revenue, or how the revenue from the market in tradable emissions rights should be distributed). Proponents of PCT point to the inherent fairness: that an equal right to pollute and the use of the equal-per-capita carbon allowances follows directly from the moral equality of individuals. Statements such as those that follow are common in the literature describing PCT schemes:

> People have equal rights to use the atmosphere, and so should receive equal allocations of carbon dioxide emissions. (Hillman and Fawcett, 2004, p.118)

> Clearly, giving people equal carbon rations – an equal 'right to pollute' – is equitable in theory. (Hillman and Fawcett, 2004, p.126)

In their review of PCT, Defra write that "one of the attractions of personal carbon trading is that through an equal allocation of allowances it is perceived to be fair" (Defra, 2008a).

PCT schemes commonly propose distributing emissions rights (or permits to release emissions) among the population for free[8]. In this way the additional cost added to fuels due to the market value of the emissions content is offset by the value of permits received. Fleming suggests that under his proposed TEQs scheme, the allocation of permits would have the effect that individuals would experience a more equitable access to a restricted fuel supply (Fleming, 1997, p.144). Although framing the scarcity problem as a concern with limited fuel supplies (as opposed to limited emissions-rights) the argument is the same: equity for individuals is realised through equal access to energy. Fleming claims:

[8] In the case of *Cap and Share* or *Tax and Dividend* schemes – the revenue from the auction of permits (or a carbon tax) is allocated as opposed to the permits themselves.

> The unconditional allocation of quota to every adult gives them free access to the baseline quantity of fuel, and the option of selling part of their allocation opens up the possibility of earning revenue from the system. Tradable quotas therefore confer the critical benefit of equity… (Fleming, 1997, p.144)

In this quote, Fleming points to the second concern of equity in the context of PCT, the distribution of revenue. For some proponents, the equity of PCT in this aspect is also straightforward, with equity following from an equal share of the revenue from the market in emissions rights:

> It [cap & share] is based on the belief that every human being has a right to an equal share of the fees that fossil fuel users would be prepared to pay for the right to discharge greenhouse gases into the global atmosphere. (feasta, 2008, p.1).

However, as Hyams notes, leaving distribution to the market is only acceptable provided goods are introduced in a fair manner and the initial distribution is produced by the method with which emissions permits are allocated to agents. The method used will vary according to which norms are identified as important in regulating the introduction of permits. The initial distribution is important in a tradable permit system because it directly affects the redistribution that will occur when permits are traded. (Hyams, 2009)

The equity claims of proponents of PCT highlight the general redistribution effect from high income to lower income households (for example feasta, 2008). This effect is due to the correlation of emissions to income (see 3.6.6 below). The determinants of personal emissions are however, multi-dimensional, resulting in a more complex pattern of income redistribution. This has implications for certain household groups. Fleming recognises the limitations of equal-per-capita quotas and the circumstances leading to high emissions:

> Although the per capita entitlement is equal, that does not necessarily make it adequate for the individual's needs, but it brings into each individual's own life a direct encounter with the reality of diminishing access to energy […] Where there are households and individuals whose energy needs are very high (because, for instance, their house is

> poorly insulated or because they have to drive a long way to work), the equal entitlement draws focus to the problem and provides a powerful incentive to deal with it. The TEQs entitlement engages with the inherently unjust consequences of climate change and fuel depletion, prompting urgent action where it is most intensely needed, in advance of the undiscriminating reductions in energy rations which will soon be imposed by nature. (Fleming and Chamberlin, 2011, p.15)

For Fleming however, the different needs of individuals are the realm of supporting policies, not a concern to be integrated into PCT itself.

Starkey has written in some detail on the philosophical arguments for equal-per-capita shares (Starkey and Anderson, 2005; Starkey, 2008, 2011, 2012b). He writes in an early paper that 'strong arguments' in the philosophical literature support the equal-per-capita distribution as equitable (Starkey and Anderson, 2005). However, his position becomes more nuanced by the publication of his working paper *Are equal shares fair shares?* (Starkey, 2008). In this working paper, Starkey provides an extensive discussion of the philosophical literature on the subject of fair allocation of carbon allowances. He attempts to find support for the equal-per-capita allocation (EPCA), using different approaches to distributive justice, but in concluding the discussion Starkey admits:

> ... as a result of my work on personal carbon trading and of delving into the justice literature for this paper, I have come to the view that neither EPCA between nor within nations can be regarded as straightforwardly fair." (Starkey, 2008, pp.62-63)

Starkey argues that there are circumstantial factors beyond the direct control of individuals (immediate, short-term and in the longer term) that affect their demand for fossil fuels, and that these justify an unequal allowance. He suggests that to justify using EPCA one of three conditions must be met for each factor qualifying for increased emissions (Starkey, 2008, p.48):

1. It is not possible to adjust the allowance for that factor, or
2. It would be too expensive/intrusive to adjust each individual's allowance for that factor, or

3. It is possible to adjust each individual's allowance but preferable alternatives exist

If none of these conditions is met, then the allocation method should allow for that circumstantial factor in determining the individual's allowance level.

Hyams also offers a comprehensive review considering various proposals for allocating emissions rights. Dismissing auctioning, grandfathering and equal-per-capita methods, he develops an approach that he calls 'grandmothering'. Hyams describes how this method would provide additional emissions rights to those who, "...as a result of circumstances beyond their control, would require more PCAs than other agents in order to function at some normal level" (Hyams, 2009, p.19). He describes this method of allocating emissions permits as one that is sensitive to choice (i.e. needs vs. luxury goods) and insensitive to circumstance. In conclusion Hyams suggests that in practice, any distribution of emissions quotas will be an approximation to the ideal of justice but that "practical difficulties do not impugn the moral value of the distributive principle itself, and an approximation of an ideal is still a better outcome than complete disregard for the ideal." (Hyams, 2009, p.24) The author reflects on the balance between simplicity and justice. Simplicity, he states, is only of value insofar as allows smooth running of the system, in a transparent manner that the public view as fair and will help to keep administrative costs down. Hyams does accept that justice will be compromised in meeting these demands but that it should not be assumed that only EPCA will be capable of delivering these aims.

The articles on equity and justice by Starkey and Hyams echo the evidence of public opinion presented in section 3.6.5, that a fair share is not necessarily an equal share. Starkey argues that the allocation method is more important when considering issues of equity than other elements of scheme design (Starkey, 2012b) and sets out the conditions under which EPCA may be used (Starkey, 2008). Hyams' discussion addresses the philosophical justification of an alternative set of allocation principles. He goes further than Starkey and others by introducing an alternative approach based on what he calls 'grandmothering'. His argument provides a theoretical justification for a 'choice-sensitive' and 'circumstance-insensitive' approach.

3.6.7 Distributional impact

Thumim and White (2008) provide the modelling for the Defra study, finding that PCT would be a financially progressive policy but has a negative impact on some poorer households (Defra, 2008b). Indeed, problems such as fuel poverty suggest that supporting policies would be required to avoid negatively impacting poorer households (Starkey and Anderson, 2005).

The Environmental Audit Committee argue that, in restricting carbon emissions, PCT highlights the existing inequalities of income and opportunity and these issues need to be identified, assessed and compensated (Environmental Audit Committee, 2008). Running costs and revenue also contribute to the distributional impact (Defra, 2008b; Starkey, 2012b). Defra suggest that further analysis should include these effects (2008b).

Recognising the negative impacts on a significant number of poor households, White and Thumim (2009) provide the modelling of a strategy to mitigate the impact of PCT on poorer households. Allocation levels were modified using rules designed to address 'structural' factors and avoid 'choice-based carbon-intensive behaviour' or 'lifestyle' factors. The rules were aimed only at specific clusters of households that lose out and resulted in increased allowances for the following households (White and Thumim, 2009):

- Households living in detached houses
- Households not living in cities
- Households with children
- Households living in houses heated by oil
- Pensioner households

Their selection of mitigating factors was arbitrary; compensating for some traits associated with high per capita emissions but not others. More importantly, the mitigating factors were selected specifically to reduce the impact on certain groups of low-income households and without regard to the environmental aims of PCT. Noting their success, they state that certain groups of low income households are better off under their modified allocation. Of course, households that exhibit all of the traits targeted do best, "In particular, single pensioners in detached houses, in rural areas, and low income households with oil central heating…" (White and Thumim, 2009, p.35). The authors acknowledge the social justice concerns that are being mitigated against, for example single pensioners. But while the targeted clusters are provided with additional permits, these households also "... highlight the inefficiencies (in terms of household energy consumption) of under-occupation." (White and Thumim, 2009, p.35). These high-emissions households are effectively being given a subsidy, going against the environmental aims of PCT and while modified allocation rules reduced the number of low income households losing out, there were still significant numbers worse off under PCT. Although the modified allocation system might appear fairer (in that low income households are better off), implementation would still present significant problems and incur increased set up and administration costs. White and Thumim identified that there is a clear trade-off between fairness and administrative cost in terms of permit allocation. Their study also provides an acknowledgement of the role of occupation density in household energy efficiency. The non-linear relationship between the number of occupants and per-capita energy demand is well established; households with additional occupants benefit from economies of scale in the provision of energy services (Boardman et al., 2005, Büchs and Schnepf, 2013b).

3.6.8 Political feasibility and strategic fit

The EAC review concluded that the Government could not afford to neglect the domestic and personal sector in meeting the 2050 decarbonisation target. They suggested that existing initiatives were unlikely to bring about the scale of reductions required and that PCT had the potential to drive greater emissions reductions than carbon taxation. The report suggests that PCT might provide the 'radical' policy tool to bring about the level of behaviour change required (Environmental Audit Committee, 2008). Prescott (2008) suggests that different instruments have different strengths: that carbon tax might provide a greater reach but PCT would provide greater potential reductions within its restricted scope. The Defra pre-feasibility study identified no 'insurmountable' technical barriers to the implementation of PCT and that the Government appeared to be open to the involvement of the private sector, recommending that the commercial viability of PCT should also be considered (Defra, 2008b).

Policy and research

Writing her review, *Personal carbon trading: A policy ahead of its time?*, Fawcett (2010) concluded that research on PCT had made progress in several areas and while the policy was not yet 'fully worked-out', it was a radical policy fitting of the 80% greenhouse gas reduction target adopted by the UK government. Fawcett suggested that it is important to continue debate on the issue of 'fair' allocations and explore plausible alternatives to equal distribution of emissions rights.

Parag and Eyre (2010) review the current policy landscape and suggest PCT is still only a concept rather than real policy option. They suggest that PCT must tackle issues related to the policy process and that it requires more development before it can progress as a credible policy option, identifying the challenge to frame PCT as a "positive and desirable policy that enables the long-term emissions target to be met, using linguistic tools and communication that are consistent with acceptable political norms" (pp.358). PCT is also seen as incompatible with the current policy framework and the authors identify one of the significant challenges to PCT policies: that of irreconcilable differences between the problem of continued economic growth and the perception of economic solutions:

> "Governments and politicians are interested in policies and initiatives that will promote consumption as a means of retrieving economic growth, even if they are not sustainable. PCT, on the other hand, is usually presented by both its proponents and its detractors as inconsistent with that policy framework, i.e. as part of a broader challenge to the current economic orthodoxy." (Parag and Eyre, 2010)

This quote leads to some interesting discussion. Policy instruments such as PCT aim to promote carbon reduction in the most cost effective way. However, if economic growth is the primary focus, there needs to be a driver for carbon reductions that produces the most economic growth, not least cost.

Eyre (2010) considers the political risks for PCT. Energy is critical to a modern economy and any interruption to the energy supply would have serious economic and social consequences. The enforcement of a carbon cap is therefore subject to political constraints. Political credibility of a 'hard' carbon cap is reliant on the assumption that it can be delivered without interruption to energy supply. Eyre suggests that because of the risks involved, the likelihood is that the scheme would adopt a 'soft' cap and including price caps and safety valves may be required to avoid the carbon price rising to levels or disruptions to the supply of electricity. The essence of Eyre's argument is as follows:

i. If mitigation is successful and demand for emissions permits low, the cap is easy to meet and the carbon price is low. In this scenario, interruption to the energy supply is unlikely.
ii. If mitigation is unsuccessful and demand for emissions permits is high, the cap is not easy to meet and the carbon price is high. In this scenario, interruption to the energy supply is more likely.

PCT is unlikely to be considered as a policy option until other carbon reduction policies have failed. However, if current policies deliver predicted emissions savings PCT may not be needed before 2020 (Bird and Lockwood, 2009). Under these circumstances the first statement above would be true; introducing PCT would be likely to lead to failure in credibility. This scenario suggests that PCT should be implemented sooner as early emissions reductions under the policy would be relatively easy ('low hanging fruit') and the policy would therefore be likely to deliver early success in meeting a 'hard' cap.

Defra (2008a) provide a comprehensive report on the strategic fit of PCT with other policies and stating that more than 80 policies existed in the UK at the time that directly or indirectly impacted the level of personal carbon emissions. The view put forward was that PCT would only be effective if it delivered additional abatement to the low-cost technological measures costing less than the shadow price of carbon. Further, they assume that existing strategies would deliver most of the opportunities from these measures. Given the recent policy changes and slowdown in abatement measures reported by the CCC (see introduction, Chapter 1), this appears to be an optimistic view of the existing policy landscape.

In terms of the strategic fit of PCT, Prescott (2008) claims that a PCT scheme covering the whole economy (TEQs) would not be feasible due to the lack of fit with other policies aimed at controlling the same emissions. He argues that a proposed scheme would need to look 'very different' from the traditional PCT model. In *PlanB?* Bird and Lockwood (2009) report on the how PCT is perceived by the policy community. They conducted 17 interviews with stakeholders from private companies, NGOs, consumer groups, regulators and journalists. They found that, politically, there was no support for PCT and that the policy was politically risky because of the uncertainties of its effects and the range of cost estimates.

3.6.9 Author's previous work

The subject of an alternative scheme design and allocation method has previously been investigated by Rushby (2011). This work proposed the idea of a 'needs-based' per household allocation. The method sought to extend the work of Druckman and Jackson (2010), applying high-performance energy standards for dwellings in order to calculate household emissions requirements, and to calculate household emissions quotas for a PCT scheme. The household allocation method was restricted in scope (applying only to common household types) and omitted 21 per cent of UK households. It also lacked empirical analysis of the potential distributional impact, providing a methodological perspective only. Two ideas from this earlier work have been adopted in this thesis: that emissions quotas under a PCT type scheme might be differentiated by 'needs' and that the household is an appropriate unit of allocation.

3.7 Positioning

This final section reflects on some of the key lessons that we can draw from debates over PCT. These are issues that will need to be considered as the alternative approach based on household allocation is developed in this thesis.

The literature shows evidence of progress in the development of PCT as a policy idea. The research agenda raised by initial academic interest and the subsequent Government commissioned research has been taken up by the research community. This had led to empirical evidence generated for aspects of PCT such as public acceptability, effectiveness, scheme efficiency, and estimated distributional implications. Parag and Eyre (2010) suggest PCT is still only a concept rather than real policy option. They suggest that PCT must tackle issues related to the policy process and requires more development before it can progress as a credible policy option. Parag and Eyre identify the challenge to frame PCT as a “positive and desirable policy that enables the long-term emissions target to be met…” (pp.358).

Political feasibility is represented in the literature as a combination of factors including costs versus benefits (effectiveness and efficiency) and public acceptability. Debate has moved-on from public acceptability, although the issues raised have not been tackled (i.e. implications for allocation method and scheme design). The research agenda is now focussed on evaluating the effectiveness of PCT at stimulating additional abatement and reducing the large uncertainties that remain in regard to the efficiency of the policy. While the research commissioned by Defra concluded that the costs of PCT outweighed the potential benefits, there was also recognition that there may be circumstances where PCT might be cost effective i.e. significant reduction in costs or increase in the value of the benefits. “Alternative scheme designs that reduce costs and increase public acceptance could be explored” (Defra, 2008b)

Defra also highlighted the need for a PCT ‘options analysis’, giving different scheme options. Analysis of PCT schemes in terms of enforcement and the issue/surrender of emissions rights has been provided by Lane et al. (2008), Eyre (2010) and Starkey (2012a) but none has considered other scheme designs despite the existence of alternatives such as Household Carbon Trading (HHCT) (Niemeier *et al.*, 2008). Scheme design is intrinsically related to the redistributive impact of PCT along with the uncertainties around administrative costs and potential additional emissions abatement potential. Scheme design is also linked to public opinion and support for PCT. An alternative scheme design, therefore, has the potential to cut-across many of the barriers to policy implementation.

The most relevant aspect of PCT schemes in terms of equity is the allocation method used to distribute emissions rights among the population (Starkey, 2012b). The commonly proposed method in the literature on PCA is the equal-per-capita-allocation (EPCA), with some schemes including a reduced allocation for children (Fawcett and Parag, 2010). EPCA gives each individual an equal share of the available emissions rights under a scheme and is attractive due to the simplicity of the allocation method. Some PCA schemes have also argued for an allowance for children, e.g. PCAs (Hillman and Fawcett, 2004) or for the revenue from the auction of rights to be distributed to parents or held in trust, e.g. Cap and Dividend (Barnes, 2001). Modified allocation rules have been explored in an attempt to reduce the distributional impacts of schemes such as TEQs on poor households (White and Thumim, 2009), and alternative allocation methods (e.g. HHCT) have been proposed but not adopted as an alternative to EPCA.

The problem of negative distributional impacts on vulnerable households is also a recurring theme within the PCT literature, however, there is little clarity about what is considered unjust in terms of the causes of these impacts. The issue requires closer examination and a framework with which to understand and evaluate the structural causes of inequalities in energy affordability.

The public recognise that people have unequal needs for energy services and a differentiated approach is preferred according to studies by Owen et al. (2008), Bird and Lockwood (2009) and Bristow et al. (2010). The philosophical literature also supports a differentiated emissions rights allocation sympathetic to individual needs (Starkey, 2008; Hyams, 2009).

The paragraphs above describe how the scheme design, and specifically the allocation method, runs through the existing literature on PCT cutting across research into different aspects of the policy. This literature review demonstrates a space within the research where the principles of allocating emissions rights can be redefined. The principle of a ‘choice-sensitive’ and ‘circumstance-insensitive’ allocation method proposed by Hyams is yet to be operationalised and the potential of the household as unit of allocation is also yet to be explored.

This thesis provides a contribution within this space by describing a theoretically grounded alternative allocation regime: a differentiated Household Carbon Allowance (dHCA) sensitive to household energy needs. The method is operationalised and tested empirically to examine the distributional implications of adopting dHCA over EPCA and HHCT. Further, this thesis provides a contribution to the consideration of how distributional issues arising from PCT should be dealt with, and whether concerns over vulnerable groups should be mitigated against within the allocation of quotas or using external supporting policies. This contribution is made through a combined framework for understanding household energy needs, how these needs relate to occupied dwellings, and the capabilities of households to meet those needs.

Further this thesis adds specifically to the literature on PCT policy development by examining adding to the policy options, drawing out and reflecting upon some the implications of the dHCA design on the arrangements around carbon accounts, set-up and administration processes, costs, and public acceptability.

4. A critique and reconstruction

4.1 Overview

The simplicity of proposed PCT schemes rests on their adoption of the idea that carbon allowances should be distributed equally among the population. It is acknowledged that the equal-per-capita method is necessary for pragmatic reasons, the simplicity is attractive from both administrative and salience perspectives. However, the method is also justified by proponents as inherently fair, arguing that it follows from the idea of equal individual rights to emissions allowances. The equal-per-capita approach embeds the principle that justice demands the equal distribution of resources, in this case the right to release carbon dioxide and other greenhouse gases into the atmosphere. There are, however, weaknesses in this simple account of the demands of justice, both on philosophical and sociological grounds.

Philosophically, equal distribution of resources fails to take into account the idea that distributional justice is only meaningful if the distribution of resources realises equality of well-being or human flourishing. Resources are only of value if they promote well-being. Hence, it is the conditions to achieve well-being that should be distributed equally – not simply resources.

Sociologically, as a consequence of adopting the simplicity of the equal-per-capita allocation of emissions quotas, PCT schemes employ a methodological individualism. Taken in the context of the emissions arising from energy used in homes, this methodology understands energy as being consumed by individuals, ignoring the household context within which energy services are used. By allocating emissions rights on an equal-per-capita basis, the assumption is that the number of individuals living in a dwelling is proportional to the energy used. This is to misunderstand how energy is used within our homes.

This sociological insight can be combined with the ‘equality of well-being’ perspective. Any downstream trading scheme should begin with the recognition that the well-being of any individual requires a particular quantity of emissions rights, which in turn enables the use of energy to provide essential energy services. In allocating those emissions rights, the type of household in which an individual resides is a defining feature of the distribution.

4.2 Chapter structure

This chapter will provide a more detailed discussion of the challenges to the equal-per-capita allowance (EPCA). It will also outline a response to these challenges, providing a framework within which an alternative allocation method can be developed. The first section will argue that the resource egalitarian view of justice that supports an EPCA, does not follow from the principle of moral equality of individuals. It will argue that moral equality of individuals does not demand equality of resources. The second section will introduce the sociological challenge and problematize the individualistic view of household energy demand adopted by PCT schemes. It will argue that it is the household rather than the individual that is the appropriate unit of analysis. The third section will provide empirical evidence showing that household energy demand is not proportional to the number of occupants and that adopting an equal-per-capita distribution of allowances results in unjust outcomes for arbitrary reasons. The fourth section will describe the limitations of alternative methods with which to distribute emissions rights under downstream cap-and-trade. The fifth section will return to the question of what account of equality aligns with the aims of PCT. It will briefly examine welfarist approaches to wellbeing before proposing a practical framework that is consistent with an ‘equality of wellbeing’ account of distributive justice. It will describe the concepts used as the basis of a definition of a ‘minimum standard of living’, one that distinguishes between the under and over-consumption of energy services within homes. The chapter will conclude by relating this definition to the construction of an alternative method with which to distribute emissions rights; the differentiated Household Carbon Allocation (dHCA) model.

4.2.1 EPCA as resource egalitarianism

In the context of downstream cap-and-trade schemes, the principle concern of the method of allocating emissions-rights is the fair introduction into the market of permits (Hyams, 2009) or more broadly, the method of distributing the rights or revenue generated by such schemes (Starkey, 2012b). Most current proposals for downstream cap-and-trade adopt an equal-per-capita allowances (EPCA) method with which to distribute emissions rights. The exception being the equal-per-household allowances (EPHH) proposed by Niemeier et al. (2008) for a household GHG cap and trade (HHCT) system[9]. Two motivations behind adopting EPCA are the simplicity of the method and the view that it is inherently 'fair' or 'just' (Fleming, 2007).

The principle underpinning EPCA is that a just treatment of individuals requires we treat them as morally equal. EPCA provides a simple interpretation of this principle: that we treat the atmosphere as a common resource, and that by giving individuals equal rights to use the atmosphere as a sink for greenhouse gas emissions we give effect to moral equality. This can be described as a simple resource-egalitarian approach and is only one interpretation of how the moral equality of individuals might be considered in the problem of sharing the capacity of the atmosphere to absorb emissions. There is little to be found in the literature to support this interpretation and the persistence of EPCA is due more to considerations of practicability and cost effectiveness than of equality concerns (Hyams, 2009; Starkey, 2011). Dobson (1998) argues that the idea of allocating equal rights to a finite amount environmental goods (or ecological space) in this way "…possesses considerable polemical, if not theoretical force" although, "…part of its theoretical weakness is that it fails to recognise the elementary point that fair treatment might require unequal treatment" (Dobson, 1998, p.82). The *prima facie* demands of equality however are such that any unequal distribution must first be justified on the grounds of relevant differences (Lamont and Favor, 2013).

Before presenting evidence supporting such relevant differences, the discussion will first turn to a sociological challenge to PCT.

4.2.2 Sociology of residential emissions

In order to evaluate whether an unequal allowance is justified, an understanding of the emissions from residential energy use is required. The drivers of energy use within homes are complex and involve interacting technical, economic, personal, social, and cultural factors (Lutzenhiser, 1992;

[9] HHCT is examined along with other alternatives to EPCA in Section 4.2.4.

Hitchcock, 1993; Guy and Shove, 2000; Yohanis *et al.*, 2008). A brief review of the residential energy demand literature reveals two concerns related to PCT policies. The first shows that the individualist perspective taken by proposed schemes is methodologically problematic. The second finds that starting from the individualistic perspective, an equal-per-capita allocation of permits would result in outcomes that may be problematic from a justice perspective.

Residential energy demand is usefully physically bounded and the dominant fuels used within the home, electricity and gas, are commonly delivered to individual dwellings. Measuring the quantity of fuels consumed by households, and thereby emissions, is therefore relatively easy to do; either directly by reading utility meters, or indirectly via proxy measurements such as expenditure on fuels through large scale household surveys (see methodology/analysis chapter for review of studies). For individuals living alone, determining responsibility for emissions is also easily achieved as they are solely responsible for the emissions at the household level. However, when more than one person occupies the same dwelling, attributing personal responsibility to emissions becomes difficult as the household becomes a site of sharing of energy services. For example, members of a household occupy the same heated space within their home and often share cooked meals. Not all energy use will be shared in multiple-person households, however, and there will also be many instances of individual energy use using appliances such as hairdryers and mobile phone chargers,

Due to the practical difficulties of collecting data at the individual level, the existing research into the impact of downstream cap-and-trade in the UK has exclusively used household consumption data. As a consequence analysis of these schemes uses per-capita demand derived from household-level measurement. This is calculated by dividing total household emissions by the number of occupants (for example see Gough et al. 2011, p.7). The method assumes that all members of the household use an equal share of the energy and have equal responsibility for the emissions arising i.e. acting in a unitary fashion.

Methodologically, and in the context of PCT, using household-level energy demand data makes the simplification that occupants within a household are also acting in a unitary fashion with regard to their carbon allowances. Households are assumed to be pooling allowances and therefore, from a methodological perspective, the analysis is not of an individual (personal) level scheme, but of a household allocation scheme where the amount of permits allocated to each household is based on the number of occupants.

There are two potential responses to this methodological inconsistency: the first, analysis should reflect the individualist approach of most scheme designs and recognise the attribution problem; or second, to acknowledge the limitations noted above and following Niemeier et al. (2008) reconceptualise downstream cap-and-trade as a household level scheme. The response taken is informed by an understanding of the complex nature of the sharing of resources within households, briefly outlined below.

The underlying demand for energy is for the provision of a service such as heat or light. Meeting this demand requires two separate things, an appliance to produce the service, and energy to power that appliance (Baker *et al.*, 1989). It therefore follows that two levels of sharing occur where energy services are concerned. At one level the energy using appliance is in shared use, and at another level the energy consumed by the appliance during use is also shared. Sharing of the appliance does not however guarantee equal sharing of the service provided by that appliance, and in the same way, responsibility for energy consumed within a shared dwelling does not follow from the act of sharing the accommodation itself.

In economics, consumer theory describes the preferences of the consumer as a utility function (Browning *et al.*, 1994). For households with multiple occupants there have been two main approaches describing the dynamics of the consumption of goods within a household (Lundberg *et al.*, 1997). The first treats households as acting in a 'unitary' fashion; using a common preference approach where there is consensus among family (household) members or a dominant family member (head of household). Here, utility is applied at the household level, assuming that the household acts as if it is a single agent (Browning *et al.*, 1994) and a household utility function is given. Under this approach the total energy demand would be attributed to the household as a whole and the issue of individual utility of each household member ignored.

While the household model is appropriate for some single family households, it might be problematic in circumstances where household members do not benefit from such a close relationship and where shared goods (or payment for shared services) are distributed under different rules. An example of this would be shared student accommodation, or young professionals in a house or flat sharing situation. In these circumstances individual utility models would more accurately describe how goods are distributed. These models attempt to incorporate the divergent or conflicting preferences of individual household members and describe allocation mechanisms such as bargaining and collective sharing rules (Lundberg *et al.*, 1997) (Browning *et al.*, 1994).

The individual utility model may be theoretically more attractive, however it is difficult to support empirically due to the demands of collecting energy-use data at the level of the individual. Lutzenhiser dismisses analysis at the individual level altogether and describes the need (when analysing energy and behaviour) for models to be "…more directly concerned with the social contexts of individual action," because, "…human behaviour is inherently social and collective, its fundamental organizing principles cannot be discovered through the study of individuals." (Lutzenhiser, 1993, p.262). Reid et al. (2010) suggest that households that are an important unit of analysis because: "…in terms of pro-environmental behaviour, households incubate and inform the behaviours of their occupants …" (p.323).

The arguments outlined above show that a legitimate response to the methodological inconsistency identified would be to adopt the household as unit of allocation. In using this approach the problem of attributing consumption to individuals within households is avoided and allows the retention of the household as a unit of analysis. The ease of measurement of energy demand at the household level and existing analysis can be retained and extended. In doing so, the complexities of energy sharing dynamics between individuals are accepted and considered as characteristics of households. Such characteristics might be analysed but the limited data and understanding would not limit the validity of the analysis as the methodological inconsistency has been addressed. A household approach would also be fully consistent with the concern within much policy literature of impact at the household level.

This section has revealed the methodological inconsistency relating to how energy is consumed within homes. The nature of this inconsistency is a contradiction between two conceptions of consumption; one commonly adopted by downstream cap-and-trade schemes (which considers the individual as agent) and one commonly used in models of domestic energy consumption (which considers the household as unit of analysis). It has been argued that from the methodological perspective, the household provides an appropriate unit of allocation of emissions rights for residential energy demand that is consistent with existing analysis and corrects the methodological inconsistency.

4.2.3 Unjust outcomes: energy demand and income redistribution

Under a trading scheme the initial allowance (or quota) of permits does not determine the total amount of emissions that can be emitted by any individual or household. Additional permits can be obtained on the market to allow quantities of emissions over and above the initial allowance. The cost of obtaining additional permits to make up for an allowance deficit, or the income gained from selling surplus allowances, results in income redistribution. The policy outcome, or impact, of market instruments such as PCT is commonly measured in terms of income redistribution. In the case of PCT this involves measuring the change in income that would occur due to the trading of emissions rights. Policy-makers are concerned with the distributional impact of policy instruments such as PCT. Examining the redistributive effect (and the determinants of household energy demand more generally) reveals not only the expected income redistribution, but also the factors that might be considered as relevant differences for an alternative allocation regime.

Income redistribution under a PCT scheme covering domestic fuel and private transport emissions in the UK has been investigated, for example by Thumim and White (2008). This analysis reveals characteristics of households that gain under PCT: households allocated more permits than required to meet their energy use; and those that lose: households allocated less than required. Winners would be able to sell their excess permits to those requiring extra (the losers), receiving additional income in the process. As discussed in the previous section, due to the lack of data on individual energy demand, the pattern of income redistribution can only be calculated as a function of household emissions (not personal emissions) and therefore the analysis reveals the impact at the household, not individual, level.

The focus of the analysis to date has been on the socio-economic traits of groups and dwelling characteristics receiving a surplus or deficit of permits. As household emissions show a correlation with income (Druckman and Jackson, 2008; Roberts, 2008; Fahmy *et al.*, 2011; Büchs and Schnepf, 2013b; Preston *et al.*, 2013), a trade in permits would result in redistribution from households in higher income deciles to those in lower income deciles. Thumim and White (2008) found that 58 per cent of UK households would receive a surplus of permits compared to 42 per cent receiving a deficit, with 71 per cent of households in the bottom three income deciles receiving a surplus. This income redistribution from richer households to poorer households means that PCT is considered generally progressive (Thumim and White, 2008). In terms of household characteristics, winning households were more likely to contain more occupants and live in flats or terraced houses, and losing households were more likely to have fewer occupants and live in rural, detached dwellings (Thumim and White, 2008). Some of the significant characteristics emerging from this type of analysis are driven by other traits. For example, village and isolated dwellings were more likely to be heated by oil than those classified urban and fringe, with oil heating producing higher emissions than gas. The underlying factors can therefore be difficult to determine due to the complex and interacting relationship of individual variables (Thumim and White, 2008).

In their analysis of an EPCA system covering household energy and private transport fuels (with 50 per cent allowances allocated to children), Thumim and White (2008) rank the significant variables with respect to per adult emissions and allowance deficit/surplus (see Table 4.1 below). The ranking shows the number of adults as the most important variable, followed by number of vehicles, central heating type and number of rooms. The ten highest ranking variables are shown below. Their analysis is consistent with other models analysing the determinants of household energy demand (Druckman and Jackson, 2008; Büchs and Schnepf, 2013b).

Rank	Variable
1	Number of adults
2	Number of vehicles
3	Central Heating Type
4	Number of Rooms
5	Number of Children
6	Income (equivalised)
7	Tenure
8	Number of Appliances
9	Age of HRP[10]
10	Dwelling Type

Table 4.1 Significant variables for per capita emissions (Thumim and White, 2008)

The top ranked variable, *Number of adults* (household size) can be used as an example to argue that strict equality results in an outcome that may be considered unjust. In their analysis, Thumim and White (2008) present the mean allowance surplus or deficit against the number of adults occupying a dwelling, see Figure 4.1 below.

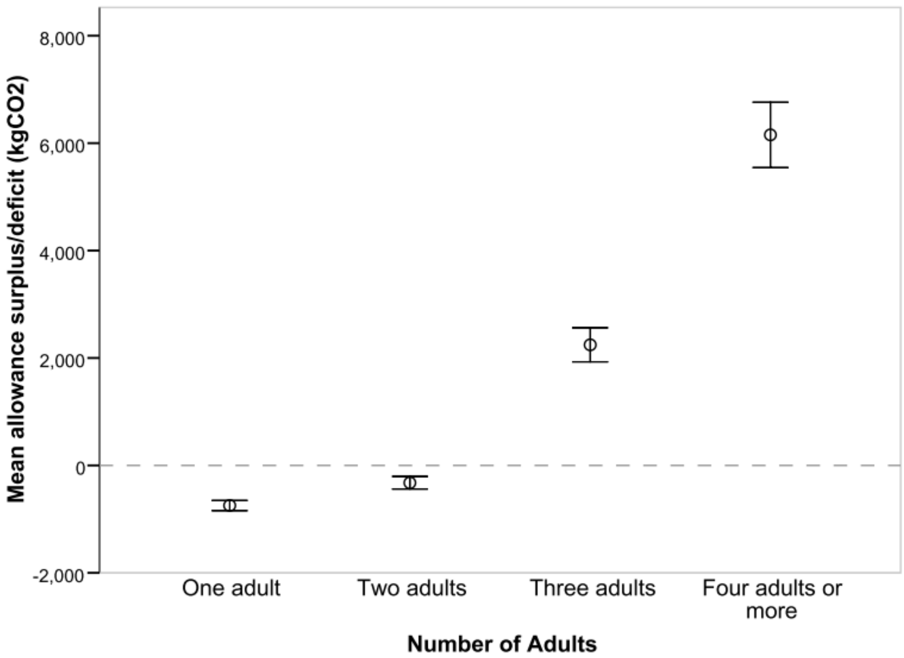

Figure 4.1 Allowance surplus/deficit and number of adults (Thumim and White, 2008)

Thumim and White found that for households of one or two adults the allocation received is below that required to cover their emissions, in other words they have a deficit of permits. For households of three and four, the

[10] Household Representative Person

allocation is greater than that required to cover their emissions, resulting in a surplus. The question that arises from acknowledgement of this relationship of household size and emissions is whether it is a just outcome that smaller households are disadvantaged compared to larger households? If the answer to this question is no, the example shows that EPCA, supported by simple resource equality, results in an unfair distribution.

4.2.4 Alternatives to EPCA

If EPCA leads to unjust outcomes what alternative allocation methods have been proposed or might potentially be used? In this section alternative approaches to EPCA are outlined, including:

1. Equal-per-household (EPHH) allocation
2. Differentiated household allocation based on dwelling energy performance
3. Grandfathered allocation based on historical energy demand

4.2.4.1 EPHH, different focus – same approach – inverse problem

Equal per household (EPHH), as proposed by Niemeier et al. (2008) in their Household Carbon Trading scheme proposal, suffers from a similar methodological problem to EPCA. Per-household emissions increase with the number of occupants, resulting in smaller households gaining advantage and larger households being disadvantaged under a system using an EPHH allocation. As with EPCA, the relationship between household size and emissions is ignored resulting in a differential impact across households according to the number of occupants. Figure 4.2 presents the similar, but opposite, impact of EPHH compared to two variants of equal-per-capita: EPCA (adults only) and EPCA+ch (with 50% allocated to children).

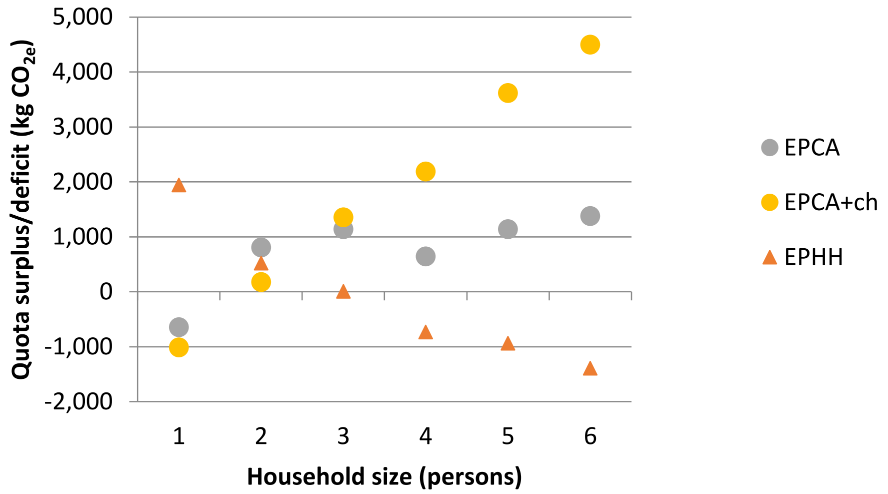

Figure 4.2 Median household quota surplus/deficit for EPCA, EPCA+ch and EPHH methods. Author's own modelling using LCF data (2009 - 2012)

4.2.4.2 Energy performance of dwellings

Another method with which to distribute emissions quotas could be based on dwelling energy performance certificates (EPC), with worse performing dwellings allocated a greater quota to reflect the fact that more energy would be required to achieve a fixed level of energy services. EPCs are created using the Standard Assessment Procedure (SAP) for calculating the energy performance of dwellings (BRE, 2010). However, while SAP provides a tool for rating the efficiency of the existing housing stock and the standard of new dwellings, it is has little to offer in the task of determining the actual 'in-use' energy demand of households for two reasons. First, SAP does not attempt to model overall energy demand, as occupancy, cooking and appliance ownership/use are ignored. The result is that nearly 20% of energy, 30% of emissions and 40% of the cost of household fuels are not covered by the SAP rating of a dwelling and are therefore in effect unregulated (Boardman, 2012). Indeed, modelling for DECC and Defra using physical attributes to predict household gas demand has been able to explain less than a third of the variation between high and low consumers (top and bottom consumption deciles) increasing to around 40% when household income and tenure are included in the model (Palmer and Cooper, 2013). Second, SAP efficiency ratings are essentially independent of dwelling size, with dwelling emissions rates calculated per unit of floor area (Henderson, 2008; BRE, 2010)[11]. This would have the effect that households occupying dwellings efficiently, living in smaller dwellings and producing fewer emissions, would not be rewarded compared to those occupying space less efficiently. Using the EPC to provide a differentiated household allowance is therefore insufficient if we are concerned with the efficiency with which dwellings are occupied, and that all household energy demand is included within the scope of a downstream cap-and-trade scheme.

4.2.4.3 Historic energy demand

Another method that might be considered would be a quota based on historic energy demand or emissions. This method, often referred to as grandfathering, would allocate larger quotas to households with higher historical emissions. Quotas would then reduce with each household receiving a quota reduced by the same proportion. This has been well critiqued in the context of other emissions trading schemes such as the EU emissions trading scheme (EU-ETS) and is widely seen as a problematic approach in terms of justice in that existing inequalities are maintained (for example see Caney, 2009).

While no downstream cap-and-trade scheme has yet proposed using grandfathering as an allocation method, in the context of household energy demand the principle has been used. In the case of the low-carbon retrofitting of the existing housing stock aggregate, sector-wide emissions targets have been set based on meeting an 80 per cent reduction by 2050 in line with the UK Climate Change Act (Gupta *et al.*, 2015). Given the adoption of the grandfathering principle elsewhere however, extending it to individuals (or households) under a PCT scheme would seem a possibility. Hyams (2009) critiques two arguments that have been made for the adoption of grandfathering: first, those who have historically used a certain proportion of the atmosphere as a store for emissions have appropriated it and are therefore justified in using the same (greater than average) share in the future; second, it is unfair to disproportionately burden those with carbon-intensive lifestyles

[11] It should be noted that high thermal performance of the dwelling envelope, as measured in SAP using the metric kilowatt hours per unit of floor area, is more difficult to achieve for smaller dwellings due to the higher exposed surface area to volume ratio.

with meeting greater reductions. Both arguments are dismissed by Hyams as, first, a misreading of the Lockean theory of appropriation (emissions degrade rather than improve the atmospheric resource) and, second, that those benefitting from extravagant, carbon profligate lifestyles at the expense of others should be called upon to curtail those lifestyles first.

4.2.4.4 Existing approaches are insufficient

All of the methods proposed so far fail to provide a satisfactory solution to the problem of allocating emissions rights quotas. I have shown how EPHH fails to address the relationship between household size and emissions, and that EPCA fails to address the non-linearity of the relationship between per-capita emissions and household size. I have explained that quotas based on dwelling performance exclude unregulated emissions and are therefore not sufficient in scope. Finally, I have presented existing critiques of grandfathering, claiming that this principle fails to give a compelling account of justice. These inadequacies can be summed up as limitations in understanding of the household - dwelling interaction; the relationship of that interaction to energy demand and emissions; and the redistributive implications. To better understand the relationship between household, energy demand and 'fair' quotas we need to further examine the issue of equality.

4.2.5 Equality of what?

The question that arises from acknowledgement of the relationship between household size and emissions is whether it is a just outcome that households are disadvantaged when compared to others due to size (e.g. as single households will be disadvantaged under an equal per capita scheme)? If the answer to this question is no, the example shows that EPCA supported by simple resource equality results in an unfair distribution. As the section above has demonstrated, there is empirical evidence to show that equality in the domain of household energy, whether viewed from the household or individual perspective, can only be realised through an unequal distribution of emissions rights: household size is indeed a structural reason for an unequal emissions allocation.

Moving from an equality of resources approach towards one focussed on wellbeing requires the consideration of other ethical questions; for example, if it is wellbeing that is to be equalised between individuals or households then how do we define wellbeing and how might it be measured? The scope of this work is not to provide an extensive evaluation of the ethical arguments, instead the following sections review the approaches to wellbeing that provide the analytical distinctions necessary to distinguish under and over-consumption in the domain of household energy demand.

4.2.5.1 Beyond welfarism

While a *resourcist* approach places more weight upon an objective valuation of the possession of commodities, a *welfarist* approach places more focus upon the subjective value that individuals attach to different bundles of resources; measured in terms of utility, personal satisfaction or desire fulfilment. Both resourcist and welfarist approaches have been challenged as not providing compelling accounts of human wellbeing: in a general context (Sen, 1984; Sen *et al.*, 1987) and specifically in the context of climate policy (Gough, 2015). What follows is a brief discussion of the ideas within this literature that are relevant to developing a wellbeing approach to allocating emissions rights in the context of downstream-cap-and-trade for household energy use.

Sen notes that assessing the wellbeing associated with the consumption of certain material goods requires four notions to be considered: a good (e.g. bread); the characteristics of that good (e.g. calories and other nutrients); the functioning of a person (e.g. living without calorie deficiency); and utility (the pleasure or desire-fulfilment from eating bread or from being nourished). He describes the limitations of orthodox approaches by their positioning within these four components. A welfarist ('utility') approach to wellbeing places desire-fulfilment at the centre of analysis whereas aresourcist approach focuses on the good itself. Sen argues that neither address what we are actually concerned with when thinking about well-being (or more specifically what Sen terms the standard of living); which is functioning, i.e. what a person is doing or achieving. These functionings are achieved with the use of goods and are a product of their characteristics but the distinction between means and ends is vital in understanding the standard of living (Sen, 1984). As Robeyns (2005) states, Sen's 'capability' approach is different to other philosophical approaches. The main concern of the approach rests not with income, consumption, or 'desire fulfilment' but with "…what people are effectively able to do and to be" (Robeyns, 2005, p.94).

For Gough, the two foundations of orthodox economic theory limit its validity for considering human wellbeing. The human qualities of bounded rationality and adaptive preferences, together with the effect of institutions on individual preference formation and the 'simply wrong' assumption of individuals being only motivated by self-interest, all challenge the applicability of preference satisfaction to the task of measuring human well-being (Gough, 2015).

4.2.5.2 The human right to subsistence

The view that it is wellbeing (not resources or commodities) that should be the basis of equality in the context of climate policy is well supported (Hayward, 2007; Caney, 2009). Hayward argues that emissions-rights themselves are important only in as much as they relate to the more fundamental ends that they enable within the context of a carbon intensive society.

> Those who are concerned particularly about the situation of the worst off globally invoke a human right to equal emissions per capita or to sufficient emissions for subsistence. Yet, while recognizing the moral force of their concern, I nevertheless maintain that we should deny that there is any human right to emissions. There is no human right to pollute; quite the reverse, there is a human right to live in an environment free of harmful pollution. What the worst off have a right to is secure access to the means to a decent life. Emissions are not inherently necessary to fulfil that right. (Hayward, 2007, p.432) p.432

Caney adopts Hayward's view that emissions rights themselves should not be the focus of a distributive principle. He argues that the principle of distribution should relate to the 'fair distribution of *energy use* (and its burdens) – not greenhouse gas emissions' (Caney, 2009, p.137). He suggests that although difficulties and controversy surround what constitutes a perfect (or maximally) just distribution of emissions, two principles can inform a minimally just distribution, anti-grandfathering and protection of basic needs. Grandfathering and any distribution that prevents people from meeting their basic needs are unjust (Caney, 2009, 2010).

The difference between human rights *as* emissions-rights and human rights as *enabled by* emissions-rights is precisely where Sen's capability approach draws important analytical distinctions. Further, Shue suggests that distinction should be made between emissions arising from meeting essential needs and those arising from non-essential activities - the two being quite morally distinct:

> The central point about equity is that it is not equitable to ask some people to surrender necessities so that other people can retain luxuries." (Shue, 1993, p.56)

The notion of subsistence and luxury emissions has much relevance for household energy, while some households cannot afford enough energy to keep warm, others are easily able to meet their energy needs (Roberts, 2008). Shue identifies that not all emissions are equal, and it follows that in the case of household energy emissions there is a moral argument for treating differently those emissions arising from meeting the energy demands for subsistence, and those arising from energy demands above such a level – what might be deemed 'over-consumption'. In the context of constrained emissions Gough (2015) argues that climate change mitigation must be tackled at the same time as confronting poverty, and that orthodox economic and subjectivist approaches are inadequate. Our notion of wellbeing, he argues, should distinguish between subsistence and luxuries, or needs and wants, as such concepts play a role in establishing moral grounding and setting of priorities. He states that our notion of wellbeing should be capable of measuring wellbeing across time and space and that "…only a concept of human needs can do the theoretical work required." (Gough, 2015, p.1)

4.2.5.3 Human needs

For Gough, "…'need' refers to a particular category of goals which are believed to be universalisable and if needs are not met, harm results. The contrast with wants – goals that derive from an individual's particular preferences and cultural environment – is central to our argument" (Gough, 2015, p.5). Basic needs are satisfied by goods, services, activities and relationships that vary across cultures and time, therefore, while basic needs are universal, 'satisfiers' are often relative (Doyal and Gough, 1991). Doyal and Gough point to the similarity of their approach with Sen's understanding of wellbeing being provided by the characteristics of goods. Like Sen, they describe commodities as having characteristics, a subset of which are described as 'satisfier characteristics' i.e. those "…contributing to the satisfaction of our basic needs in one or more cultural settings" (Doyal and Gough, 1991, p.157). A smaller subset, named ‘universal satisfier characteristics’ (USCs), are described as the “…properties of goods, services, activities and relationships which enhance physical health and human autonomy in all cultures” (Doyal and Gough, 1991, p.157).

For Gough, needs are objective, whereas for orthodox welfare approaches preferences are subjective. Needs are also satiable, therefore lists of basic needs and threshold levels can be conceived (Gough, 2015, p.12).

> How are appropriate thresholds to be decided and measured? In our case, the ideas of ‘appropriate’ and ‘adequate’ must be defined at the level of both basic needs and USCs…In principle, (need) satisfaction is adequate when, *using a minimum amount of appropriate resources*, it optimises the potential of each individual to sustain their participation in those constitutive activities important for furthering their critical interests. (pp.12-13, emphasis added)

The emphasis added to the quote above highlights Gough’s attention to responding to climate change. The responsibility to mitigate greenhouse gas emissions requires the provision of needs satisfiers using a constrained amount of resources.

Adequate housing as ‘intermediate need’

Doyal and Gough identify ‘adequate protective housing’ as one of the eleven ‘intermediate needs’ provided by USCs. Housing contributes to basic needs across all cultures by “providing protection from climate extremes, from exposure and from pests and disease-carrying vectors…it should be able to withstand the normal demands of weather, provide adequate sanitation, and in colder climates appropriate heating and insulation” (Doyal and Gough, 1991, p.196). Furthermore, adequate protective housing should avoid overcrowding which undermines the health and autonomy of occupants (Doyal and Gough, 1991, p.197).

On thresholds and the distributive principle

Given Doyal and Gough’s statement that with respect to standards with which to measure basic needs “…we endorse neither an absolute minimum standard nor a culturally relative one” (Doyal and Gough, 1991, p.159) how can the theory of human need be operationalised, and the concept of adequate provision be measured?

Due to the hierarchy of needs-satisfiers the question of which level of basic need-satisfaction does not apply. This is because the study is primarily concerned with just one of the eleven component intermediate needs that contribute to basic need satisfaction and is restricted in terms of spatial contextuality with the focus of this thesis being on the UK. While a small amount of sub-national variability in housing provision remains across the regions within the UK, the needs-satisfiers related to housing are assumed to be similar enough to warrant narrowing the scope of applying standards of measurement to 'specific satisfiers'. Specific satisfiers contribute to meeting intermediate needs (USCs) in Doyal and Gough's theory. They describe the question of measuring adequate provision as how intermediate need 'inputs' are related to outputs of physical health and autonomy (p. 161). They note the threshold nature of needs:

> "…a particular level of satisfaction for each intermediate need is required if human health and autonomy are to be optimised, but beyond that point no further additional inputs will improve basic need-satisfaction" (Doyal and Gough, 1991, p.162).

And specifically in the domain of housing, that:

> "…once a dwelling is safe, warm, not overcrowded and supplied with clean water and adequate sanitation, no further improvements – in space, amenities, luxury fittings and so forth – will enhance the *need* satisfaction of its inhabitants…these improvements may well meet subjective desires and enhance the satisfaction of wants, but they are irrelevant to the evaluation of need-based welfare" (Doyal and Gough, 1991, p.162)

Gough describes the distributive principle embodied within the human needs approach: "… the implied [distributive] goal is sufficientarian: to bring all individuals up to such a threshold" (Gough, 2015, p.12). Up to this threshold, Doyal and Gough note, "… the appropriate distributional principle is one of strict equality" (Doyal and Gough, 1991, p.237), however they also note that this does not require equality of access to needs-satisfiers due to the varying capacities of individuals to convert needs-satisfiers into needs-satisfaction.

Hyams rejects basic needs and capabilities approaches on the grounds that neither approach provides an account of how, once basic needs have been met, the remaining 'luxury' emissions should be distributed (Hyams, 2009, p.250). In response it should first be restated that in applying a needs approach it is satisfier characteristics that are of primary interest, not emissions. In the context of emissions from housing we are concerned with the adequate provision of heated space, hot water for washing and laundry, and other energy using services with household emissions quotas differentiated on this basis. Hyams contention is that the needs-capabilities approach is not concerned with, and therefore tolerates, a great deal of inequality within 'luxury' emissions. While, the distribution of 'luxury emissions is a secondary concern, in practice the same distributional principle can be applied to these emissions (and satisfier characteristics) as those meeting basic needs. The needs-based allocation method is not therefore required to distinguish between basic needs and luxury emissions for the purposes of allocating rights, In response to Hyams' objection, it should be acknowledged that in using this approach, a fair distribution of the luxuries related to energy is assumed to be the same as the distribution of basic needs.

4.2.5.4 The sufficiency principle in practice

Gough (2015) sees the theory of human needs as capable of providing a list of basic needs that possess a threshold level for being met. This principle of sufficiency aligns with a body of work known as 'Minimum Income Standards' (MIS), see Deeming (2005) and Bradshaw et al. (2008). The MIS "provides an explicit framework for selecting personal requirements needed or deemed necessary to maintain a particular predefined standard of living" (Deeming, 2005, p.620). The MIS approach has been applied extensively in the UK by the Joseph Rowntree Foundation to inform and provide sufficiency benchmarks for social policies such as benefits, tax credits, minimum wages and the affordability of housing (Bradshaw *et al.*, 2008). An extension of this work into the domain of climate policy is provided by Angela Druckman and Tim Jackson in their paper 'The bare necessities: How much household carbon do we really need?' (Druckman and Jackson, 2010). Druckman and Jackson use the MIS to construct a minimum consumption scenario and to model the greenhouse gas emissions that arise from meeting the MIS definition of standard of living. In doing so, they claim to identify "...how much of the carbon that is used in our current consumer lifestyle is necessary for a 'decent' life, and how much may be thought of as 'discretionary' and could potentially be eliminated." (Druckman and Jackson, 2010, p.1795). Part of this work dealt explicitly with assessing the household fuel required to "maintain the health and wellbeing of the householders and the fabric of the home" (Oldfield, 2008). Other work has examined the implications of constrained household emissions on acceptable living standards (Druckman *et al.*, 2011). The MIS approach was also followed by Rushby (2011), who implemented the housing element as the foundation for calculating emissions quotas under PCT.

Here, I have followed the example of Druckman and Jackson, creating a reduced consumption scenario. To achieve this I apply the minimum threshold approach of Gough's intermediate need for 'adequate protective housing' in order to determine the energy and emissions required to sustain a predefined minimum standard of living. By defining this requirement for a range of household types, the method can be used (as proposed by Rushby 2011), as the basis with which to produce a set of comparative household energy and emissions budgets to use in allocating emissions rights under a downstream cap-and-trade policy.

4.3 Summing up

This chapter has described the limitations of existing methods commonly proposed for allocating emissions rights under DCAT. The methods have been critiqued both in terms of methodology and ethical concerns. The 'needs' framework has been shown to be an appropriate framework within which a minimum threshold of energy services can be established. Before describing the needs-based differentiated household carbon allocation (dHCA) model in detail and the method with which it is tested against other allocation methods, one last problem requires attention: how to determine the energy and emissions required to maintain a minimum standard of living. I describe how existing tools for assessing the energy demand of dwellings can be applied to quantify Gough's 'adequate protective housing' and therefore adopted to provide measurement for the purposes of a differentiated household allocation.

5. Determining needs-based energy demand

5.1 Overview

The needs-based energy demand model described here is underpinned by a theory of the fair sharing of common household goods and services, specifically, those relating to the use of energy within the home (and therefore resulting directly or indirectly in the release of GHG emissions). The theory underpinning the model has been set out in the preceding chapter. The aim of the needs-based energy demand model is to provide a measure of the minimum energy services required by households of differing composition. Needs in this context are connected with energy required to provide space heating, domestic hot water, lighting, cooking and to power appliances. This minimum requirement is based on a set of idealised assumptions about the energy services required to fulfil the definition of 'adequate protective housing'. Standards and measurement frameworks are already well established for the delivery of 'adequate protective housing'. These frameworks are focussed on the energy performance of dwellings rather than the services required by occupants; however they can be adapted to provide a definition of a minimum provision of energy services by adding parameters and modifying some assumptions. Essentially the needs-based energy demand model developed in this thesis describes two parameters required for this task: the minimum floor space required by households of differing size (required to quantify the 'regulated' energy demand), and the 'unregulated' energy demand not considered in rating the energy performance of dwellings.

This chapter will begin by describing how the delivery of new 'adequate protective housing' is already controlled by standards and regulations in the UK. The regulations related to the provision of energy services will be presented along with a description of the methodological differences between this dwellings focussed regulatory framework and the human needs focussed approach of dHCA. The first part will conclude by setting out the concerns of adapting the existing regulatory framework to the task of defining the needs-based energy demand model. The second part will present in more detail the considerations of the two parameters required to adapt the existing energy modelling framework.

5.2 Complimenting an existing framework

5.2.1 Building regulations and energy performance

While debate about what exactly constitutes an acceptable minimum standard for housing will remain ongoing and design standards continue to evolve, existing regulatory instruments within the planning process and building regulations already provide the means by which new dwellings are judged to be fulfilling the provision of adequate housing. It is therefore unnecessary to start from first principles as such considerations are already well established in good design practice. It is acknowledged that in this study all dwellings are assumed to be conforming to a minimum standard with regard to these non-energy related capabilities (e.g. in terms of functional design, access for physically impaired occupants, security, fire safety etcetera).

The framework and methods with which dwellings are assessed for energy related provisions is also well established. The energy performance of new dwellings is regulated by Part L of the Building Regulations in England (HM Government, 2014): any new dwelling must meet minimum standards for energy efficiency and emissions of greenhouse gases. The services included under the regulations are: space heating, domestic hot water (DHW) and fixed lighting: referred to as ‘regulated’ energy and emissions (see 4.2.4.2). To meet the requirements a dwelling is assessed using the Standard Assessment Procedure (SAP) and given efficiency ratings; a dwelling fabric energy efficiency (DFEE) rating and dwelling Emission rating (DER) (BRE, 2010). Existing dwellings are also given ratings, which are known as Energy Performance Certificates (EPC), when being sold or let (Department for Communities and Local Government, 2014). In this way SAP provides ratings for comparing the efficiency of dwellings, using a standardised level of service provision.[12] Assumptions are made about the number of persons living in a dwelling and demand levels derived for each service such as: time period for heating; litres of hot water per day; and the power required for lighting (BRE, 2010).

[12] In much the same way that SAP provides ratings for dwellings, efficiency ratings, such as those found on refrigerators, measure and compare the performance of appliances under standardised tests. The energy used by appliances within homes is, however, not regulated under the building regulations. The energy and emissions related to these appliances is therefore referred to as ‘unregulated’.

While the energy assessment framework is focussed on rating dwellings and not the needs of the people living there, assumptions about the levels of energy services provided within a dwelling can also be thought of as threshold levels for Gough's 'adequate protective housing'. It follows that by considering the service levels assumed by SAP instead as minimum threshold levels, the procedure can be applied to defining the basic needs or 'subsistence' case by making a few additional assumptions. The task of comparing energy service demand from households is therefore made easier due to the existence of these regulation and assessment procedures. There are, however, some values within the dwelling assessment procedures that must be examined and adjusted to reflect the change in modelling focus, and parameters that must be added to adapt these tools for the purpose of creating a needs-based energy model. Before turning to this task the differing modelling perspectives will be examined in more detail.

5.2.2 Modelling perspectives

The SAP rating provides a measurement of the cost, energy efficiency and emissions intensity of delivered energy services. Energy requirements are modelled using an energy balance calculation that makes assumptions about the characteristics of the occupying household i.e. household size and composition, heating regime and appliance ownership (BRE, 2010). The BREDEM model, a more complex method closely related to SAP, allows the specification of household characteristics (such as household size and heating patterns) in addition to the dwelling characteristics (BRE, 2010). It therefore provides a more comprehensive approach to modelling using more information about the energy service demands of the occupying household. The method produces the same measurement metrics of efficiency and emissions intensity while better representing the in-use 'human factors'.

The dwelling-focussed methods such as BREDEM and SAP are orientated to modelling from a building physics perspective to estimate energy demand, emissions and related cost. These models represent the fixed physical configuration of dwelling fabric and systems that provide useful energy services, measuring the efficiency with which this is achieved. In essence, SAP measures the efficiency of an individual dwelling in providing energy services such as heated space and hot water in terms of cost, energy and emissions.

The metric of measurement for dwelling performance, both in terms of emissions rate and energy demand is by unit of floor area (BRE, 2010).

As stated in Chapter 4, the dHCA follows the methodology used by in the Fuel Budget Standard (Oldfield, 2008) as part of the Minimum Income Standard (MIS) work (Bradshaw *et al.*, 2008), and applies it to the problem of reducing emissions in the same way as Druckman and Jackson (2010) in their '*Bare Necessities'* study. In order to calculate the energy requirements of households and thereby emissions and costs in the MIS scenario, appropriately sized dwellings are allocated by household type (size/composition). The Fuel Budget Standard (Oldfield, 2008) details the selection of real dwellings to model household energy demand for the MIS study. In modelling the energy requirements some physical attributes were idealised. For example, dwellings were assumed to be fully insulated with cavity wall and loft insulation.

In these studies the focus has shifted away from modelling the physical system of a specific dwelling and towards focussing on the energy services required by a household to meet its needs. Furthermore, the nature of the assumptions made within the model has shifted from those made about the occupants (human) to those about the characteristics of the dwelling (physical). What is of interest, for the purpose of distributing emissions rights, is a method to compare the proportional demand for energy services of households of different sizes and/or composition. The method must align with the notion that energy is merely instrumental in meeting underlying needs.

In the needs-based demand model, energy needs will be evaluated in terms of the end-uses (or services) enabled by energy and not as an energy requirement in itself. In contrast to Oldfield's 'Fuel Budget Standard', such an evaluation will be made without reference to the efficiency of the dwellings or systems providing the energy services (Oldfield, 2008). In the dHCA scenario, the dwelling is only of concern in terms of the living space for which it is a container. In terms of methodology, the needs-based energy demand model (dHCA scenario) can be seen as moving higher in the level of abstraction of household needs than the approach used by Oldfield (2008) and Druckman and Jackson (2010). In contrast to SAP and BREDEM, the *Bare Necessities* study and dHCA models of demand can be understood as moving in the opposite direction: focusing on the end-use energy services that are required by a household and using assumptions about the occupied dwelling (and energy service delivery systems within) to estimate energy demand. Through the application of alternative assumptions and additional parameters, these household-focussed models represent the level of energy services required to meet a defined minimum level of *functioning* (Sen, 1984), or definitive list of *intermediate needs* (Doyal and Gough, 1991).

The perspective offered by the *Bare Necessities* and dHCA methodology can be visualised conceptually as moving in a different direction from the dwelling-focussed approach of SAP and BREDEM models of energy demand; the former providing a description of household energy service needs rather than the technical configuration of energy delivery systems within a dwelling. Figure 5.1 below illustrates these two perspectives.

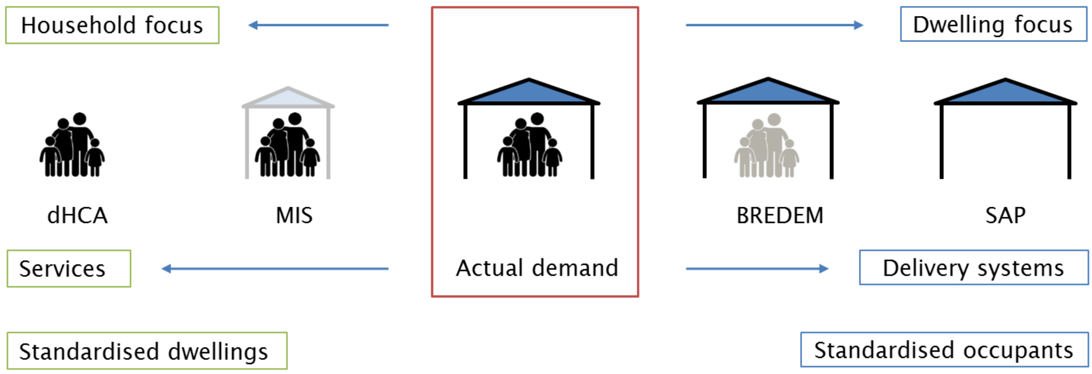

Figure 5.1 Conceptual diagram of household and dwelling-focussed household energy demand modelling approaches

In common with the *Bare Necessities* study, the dHCA model assumes that households occupy dwellings of minimum adequate size, and the energy performance of dwellings is assumed to be uniform across the housing stock. However, rather than assuming a specified standard of energy efficiency, the energy performance of dwellings remains undefined. The energy efficiency therefore becomes an output of the model as opposed to an input (see Chapter 6 for model description and dHCA model results).

5.2.3 Changing assumptions for the needs-based model

The simple, first generation dHCA method proposed here uses just one variable to differentiate household quotas: household size. Accordingly the needs-based model is therefore built on a number of assumptions:

i. That the minimum floor area required by a household can be calculated as a function of occupancy
ii. That the regulated emissions rate for dwellings per unit of floor area is constant across the dwelling stock and can be calculated as a function of floor area
iii. That the unregulated emissions rate for households is a function of occupancy, floor area and emissions factors for household fuels

As stated above, SAP is designed as a compliance tool: to calculate energy requirements of dwellings using standardised assumptions. If adopted for the purposes of defining a minimum living standard, the method does have three limitations: dwelling size, occupancy rate and unregulated energy demand. The metric of measurement for dwelling performance, both in terms of emissions rate and energy demand, is by unit of floor area. This means that for the metric to be meaningful we must add dwelling size to the measurement. This is entirely appropriate as the wellbeing provided to a household by the dwelling are intrinsically linked (by good design practice) to the living space contained within it. As described in the previous chapter, efficiency in living space is also shown empirically to be correlated to lower household emissions.

In order to determine the provisions adequate for a minimum, needs-based case, assumptions around the levels of energy service demand will need to be adjusted. The standard assumptions of occupancy rates contained within SAP are based upon the relationship between dwelling size and the number of occupants found in the existing distribution within the housing stock (Henderson, 2008). In this distribution, dwelling sizes are generally larger than the minimum required. Figure 5.2 below shows the existing distribution of dwelling sizes according to household size and compared to the commonly cited Parker Morris (PM) minimum standard (Ministry of Housing and Local Government, 1961). The chart shows that median dwelling sizes are larger than the PM standard for all household sizes of six persons and smaller. The assumptions are therefore unsuitable for use in a minimum standard scenario and modifications will therefore be necessary. The assumptions with respect to dwelling size are detailed in Section 5.3.2.

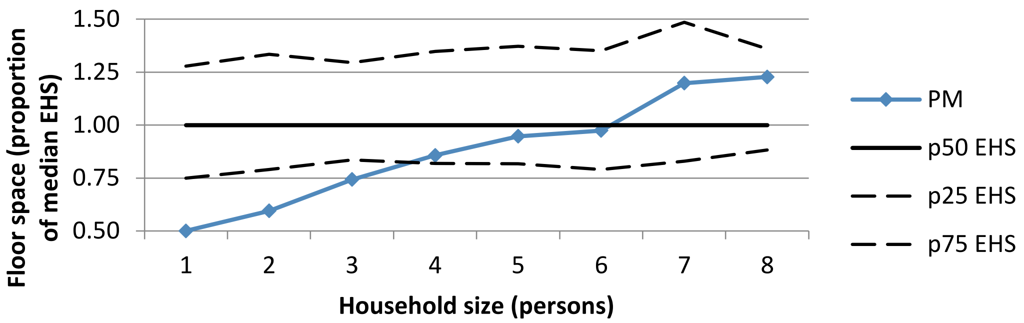

Figure 5.2 Existing distribution of dwelling size as a proportion of the median by household size, EHS data (2009 - 2012)

The tools for demonstrating compliance with the building regulations are also restricted in terms of scope. As described above, the 'unregulated' energy used by appliances is not subject to control and is therefore not included in the measurement of dwelling performance. Despite not being controlled by the building regulations, unregulated demand is within the scope of the dHCA and therefore the needs-based demand model will account for this energy use.

To reflect the scope of the existing regulations, the needs-based energy demand model will consider household energy service requirements in the two categories, outlined below:

1. Regulated energy and emissions – energy use covered by the building regulations for space heating/cooling, domestic hot water, fixed lighting, pumps & fans etc.
2. Unregulated energy and emissions – energy use not covered by building regulations and arising from cooking and electrical appliances.

Accepting the limitations noted above, it is proposed that existing metrics used by SAP will be used as a measure of the energy and emissions intensity of dwellings for the purpose of defining a standard of living. The two tasks remaining are: allocating living space (or dwelling size) to households; and determining the unregulated energy demand and emissions. Consideration of both are detailed in the following sections.

5.3 Regulated emissions and dwelling size

5.3.1 Rationale

This section describes how the measurement metrics produced by the SAP procedure allow the regulated component of household energy and emissions to be represented using dwelling size, or floor area, as a proxy. This allows the economies of scale present in the space and energy requirements to be taken into account and expressed very simply.

The SAP procedure provides a measure of the total energy demand and emissions arising from a dwelling in delivering the energy services required by the occupants. It is a measure of the performance of the complete energy system including: the fabric of the walls, floors and roof; the openings; and services such as heating, domestic hot water, ventilation and cooling systems. The metrics produced are expressed as single figures: for energy, in kilowatt hours per year (kWh/yr); and for emissions, in kilogrammes of carbon dioxide equivalent per year (kg CO_2/ year). For a dwelling of a given size, or floor area (in square metres), the measures can be expressed per unit of floor area per year: for energy efficiency (kWh/m^2/yr); and for emissions intensity (kg CO_2/m^2/year). (BRE, 2010)

Further, if - as stated in the previous section - it is assumed that energy efficiency and emissions intensity are constant across the housing stock, then dwelling size alone can be used as a proxy for the regulated component of energy and emissions. Of course, the assumption of a performance of the housing stock will introduce other inequalities into the dHCA method due to the effects of built form, age, fuels and other factors on efficiency and emissions intensity. The implications are discussed further in Chapter 7 (Section 1.1.1).

5.3.2 Determining a minimum dwelling size

The task of representing regulated demand in the needs-based model falls to defining an appropriate minimum dwelling size according to the number of members within a household. As described previously in this chapter, the methodology adopted in this thesis follows that used in the Minimum Income Standard (Bradshaw *et al.*, 2008) (Oldfield, 2008) and (Druckman and Jackson, 2010). This section will examine and compare alternative definitions of minimum acceptable dwelling size that are applicable to the dHCA and needs-based demand model.

The objective of this section is not to provide a systematic review of the literature on space standards for residential development but to provide an overview of frequently cited standards. The starting point for this section is the comprehensive review commissioned by the Greater London Authority (GLA) as part of a review of the London Plan, a long term strategic spatial development strategy. This research provided background for part of the London Housing Design Guide (Mayor of London, 2010). One of the draft policies included in the replacement London Plan provides for the introduction of minimum standards for dwellings. Details on the scope of the policy are given by the Greater London Authority, stating that the new dwelling space standard:

> … sets out minimum space standards for dwellings of different sizes. This is based on the minimum gross internal floor area (GIA) required for new homes relative to the number of occupants and taking into account commonly required furniture and the spaces needed for different activities and moving around, in line with Lifetime Home Standards. This means developers should state the number of occupiers a home is designed to accommodate rather than, say, simply the number of bedrooms. These are minimum standards which developers are encouraged to exceed. When designing homes for more than six persons developers should allow approximately 10 sq. m per extra person (Greater London Authority, 2009, pp.69-70).

Underpinning this policy was evidence on housing design standards submitted for the review (Mathieson, 2010). The evidence relied extensively on a report commissioned by GLA as a comprehensive review of the literature and trends in practice (Drury *et al.*, 2006). It provided a review of space standards and their potential role within the revised plan as a tool to introduce a 'safety net' of minimum space standards for new-build public housing.

5.3.3 Historical use of minimum space standards

The history of using standards to define the minimum requirements for public sector residential development stretches back nearly a century. Standards have been adopted by the different sectors of the house building industry in England using different mechanisms. For example, social housing developments are required to meet minimum standards for design in order to receive funding. Several committees have been created by the UK government in order to review and improve public housing provision. More recently the third sector, social housing funding (and regulatory) organisations and insurance providers have conducted research and produced their own guidance, some of which has been incorporated into mandatory statutory standards (i.e. building regulations) and into their own voluntary guidance or standards. (Drury *et al.*, 2006)

The review by Drury et al. (2006) of the implementation of space standards in housing reveals some development in how the minimum requirement for space has been theorised (see Figure 5.3 below). Drury et al. describe minimum space standards as beginning with a prescribed number of rooms provided by a dwelling, moving to the inclusion of additional requirements for room sizes, then to minimum floor space for the dwelling as a whole, and finally to functional- or activity-based requirements. They find that, over time, minimum space standards have become more sophisticated.

Figure 5.3 Evolution of minimum space standards (adapted from Drury et al.)

In their summary, Drury et al. (2006) suggest that as existing standards are updated, or new standards introduced, public sector housing provision improves, however these improvements fall away over time until the next set of standards are introduced. They suggest that the private sector, while affected by standards in the public sector, shows smaller changes. The authors also describe anecdotal evidence suggesting that dwellings in the private sector are typically built with floor areas of around 5-10m^2 below standards published for public sector developments. (Drury *et al.*, 2006)

The GLA investigation represents the most thorough review of space standards conducted in recent years. The space standards set out in the *London Housing Design Guide* therefore form an up to date set of standards with which to compare other seminal work such as the Parker Morris standards (Ministry of Housing and Local Government, 1961). Following their own research into minimum space requirements, the Royal Institute of British Architects (RIBA) endorsed the *London Housing Design Guide* standards in their report titled *The Case for Space* (RIBA, 2011):

> The London space standards are the best standards available at present in that they offer a much needed improvement on the size of homes currently being built in England. (RIBA, 2011, p.16)

There was however a caveat to this endorsement: that they were based on the Parker Morris standards, which represented an outdated view of contemporary living. The authors called for the 60 year old research on what constitutes adequate space for living to be fundamentally revisited. The report also highlighted that RIBA did not consider the standards best practice, expecting new homes to exceed the standards, confirming GLA's position that they should constitute a 'safety net' in terms of provision (RIBA, 2011). Adopting such values for floor space as a relative measure of household energy service needs should therefore be treated in the same manner as a 'safety net' threshold.

The housing charity Shelter also endorsed the minimum standards contained within the London Plan in lieu of a systematic review of space standards by the Government. They called for stronger action by improved building regulations to include "clear housing quality measures such as adequate inside and outside space and storage, which apply to **all** homes." (Shelter, 2013, p.1 emphasis added)

In 2015 the UK Government issued its own set of space standards for housing: the 'nationally described space standard' (Department for Communities and Local Government, 2015a). The standards are intended to replace the various space standards used by local authorities. The standards contain identical values to those contained in the London Plan for single storey dwellings designed to accommodate up to six persons, however, for dwellings of more than six persons the two standards differ: the DCLG guidance (Department for Communities and Local Government, 2015b) allows 9m^2 for each additional person compared to 10m^2 in the London Housing Design Guide (Mayor of London, 2010). While the standards differ slightly, the two are considered to be sufficiently closely aligned that only the set of values detailed in the London Housing Design Guide will be used for comparison.

Three different space standards were selected for comparison in this work. The selected standards are described below along with the justification for inclusion.

London Housing Design Guide (Mayor of London, 2010) – standards resulting from the GLA investigation. As noted above these standards represent the most significant recent review of historical standards and recently adopted design standards currently in practice.

Parker Morris standards (Ministry of Housing and Local Government, 1961). The Parker Morris standards are used in this comparison as they remain the most recent Government-led systematic review of the space requirements of families in England. The standards remain a benchmark against which other more recent standards are compared (see CABE, RIBA, and GLA etc.).

Minimum Income Standard (Bradshaw *et al.*, 2008). The Minimum Income Standard (MIS) requirements have been included in the comparison as the methodology used in their development is significantly different to the other two standards in the comparison; the MIS standard matched households with a set of existing dwellings from JRHF's housing stock. The requirements for living space were obtained using a blended methodology with input from both experts and ordinary people. The standards have subsequently been used in work on domestic energy demand reduction.[13]

[13] Although the dwelling sizes for the MIS standard are not publically available. Floor space values used here are reported in Rushby (2011).

5.3.4 Comparing standards

There are difficulties when comparing the minimum space standards and care needs to be taken when comparing across different built forms. For example, looking at the floor areas from the London Housing Design Guide in Figure 5.4 below, it can be seen that the minimum floor area required for a one storey flat (denoted 'GLA Flats') is lower than that of a two-storey house (denoted 'GLA 2 st. houses') designed for the same occupancy. Similarly a two-storey house requires less overall floor area than a three-storey house (denoted 'GLA 3 st. houses'). This is because two and three storey dwellings require additional space to accommodate stairs and additional circulation space over that required for flats/bungalows – this space is included within figures for net internal floor area but is not floor space that can be used for other purposes.

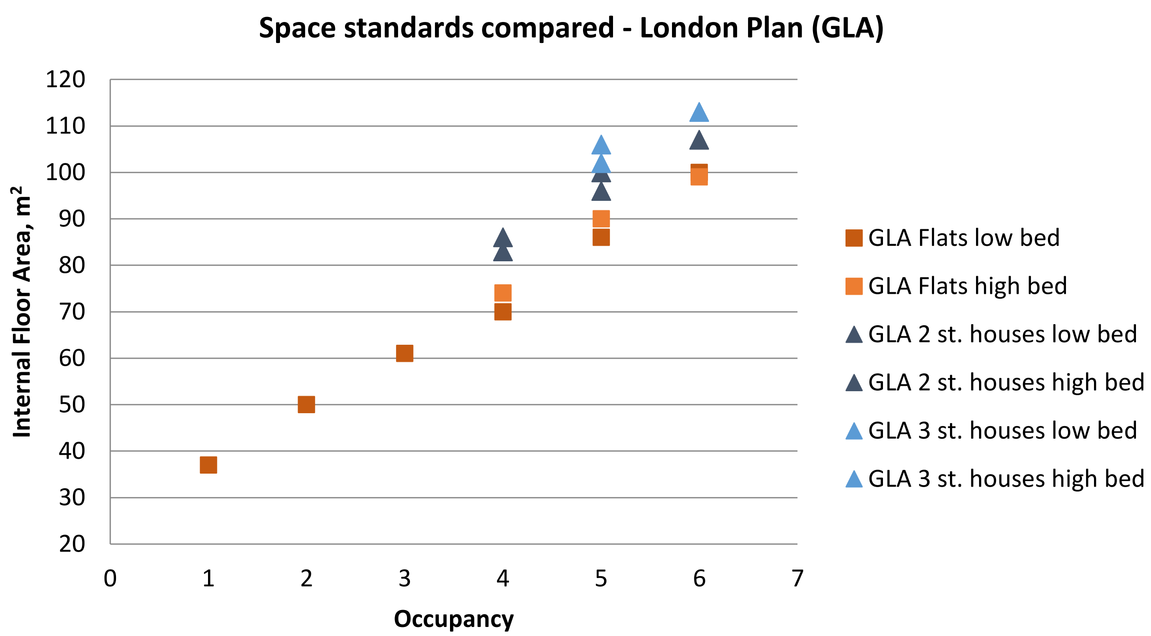

Figure 5.4 Minimum floor space for flats and houses, London Housing Design Guide

Therefore when comparing standards it is only appropriate to compare standards for similar built forms. For this reason the GLA London Housing Design Guide quotes minimum floor area requirements by number of occupants, number of bedrooms, and the number of storeys forming the dwelling. Considering only flats, the GLA standards contain two values for the floor area required for four, five and six bed-space dwellings.

Occupants	Bedrooms	Type	Bedrooms	Gross Internal Floor Area (GIA) m^2
1	1	1b1p	Low	37
2	1	1b2p	Low	50
3	2	2b3p	Low	61
4	2	2b4p	Low	70
4	3	3b4p	High	74
5	3	3b5p	Low	86
5	4	4b5p	High	90
6	3	3b6p	Low	95
6	4	4b6p	High	99

Table 5.1 Minimum floor area for flats, GLA London Housing Design Guide (Mayor of London, 2010)

Values have been grouped for further analysis by the number of bedrooms. For each occupancy level the row corresponding with the lowest number of bedrooms has been denoted ‘Low’ and the value corresponding with the highest number of bedrooms has been denoted ‘High’. This allows for individual analysis of the two sets of minimum floor areas. Figure 5.5 below shows the floor area required for flats by the Parker Morris and GLA standards. Comparing the standards it can be seen that the GLA standards are more generous.

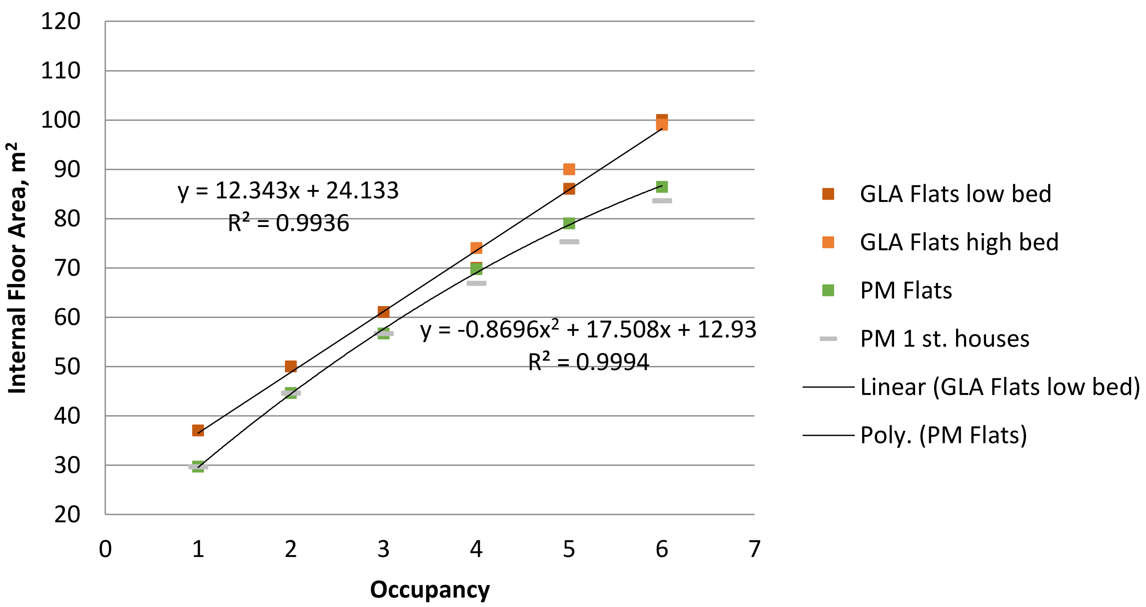

Figure 5.5 Minimum floor space standard for flats compared, GLA and Parker Morris

Comparing minimum floor areas for houses shows that the GLA standards are more generous than Parker Morris, see Figure 5.6 below. Where figures from the London Housing Design Guide have given two values for the same number of occupants, the values have again been split by provision of bedrooms. Two values for two storey houses are also quoted in the Parker Morris standard for four and five occupant homes (Ministry of Housing and Local Government, 1961). The values given are differentiated for dwellings in centre-of-terrace or end-of-terrace (and semi-detached) built form.

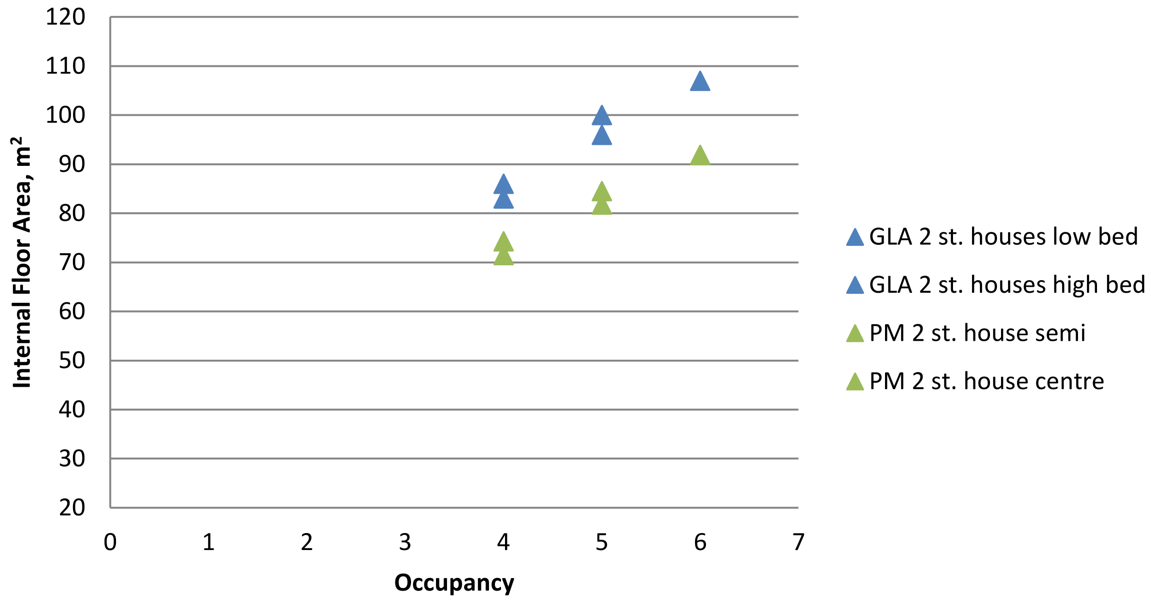

Figure 5.6 Minimum floor space standard for two-storey houses compared, GLA and Parker Morris

Adopting the GLA standards for single storey dwellings (flats) provides a good fit to a linear relationship between occupancy and minimum required floor area for up to six occupants, see Figure 5.7 below. RIBA have drawn attention to the fact that new houses in England and Wales are the smallest in Western Europe (RIBA, 2011). Comparing GLA standards to example standards from Germany used in the RIBA report, it can be seen that the minimum space provision is around 10m^2 lower for the London Housing Design Guide.

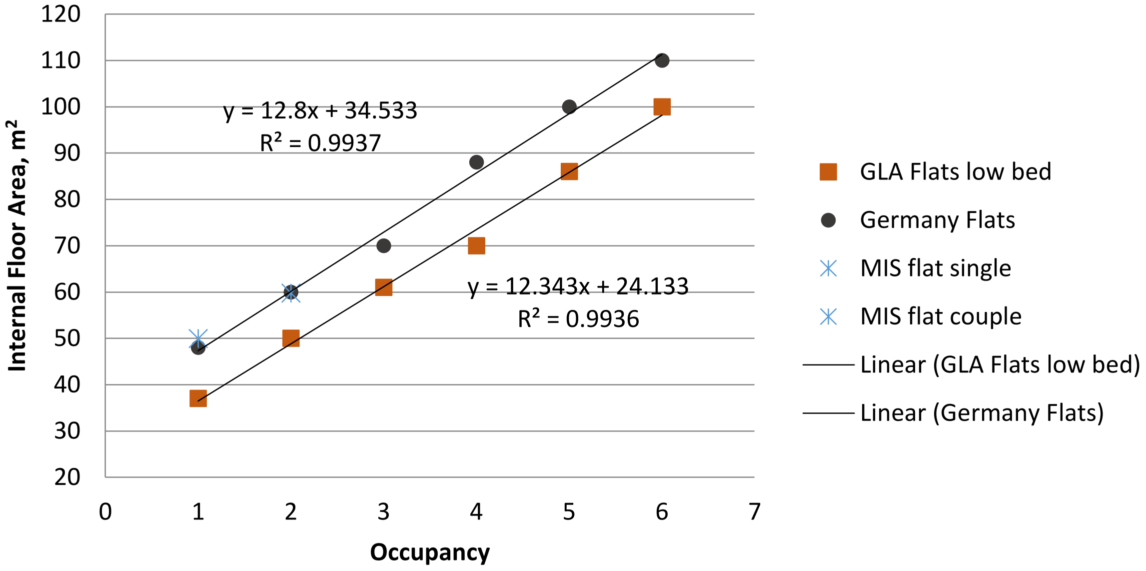

Figure 5.7 Minimum floor space standard for flats compared, England and Germany

Adding in another comparison, from MIS, for one and two person households, the MIS size requirements are closer to the German standard. The other households within the MIS study use two storey houses so it is inappropriate to compare with the values provided for flats in Germany (from RIBA study). The values for two-storey houses can be used to compare the GLA and MIS standards, shown in Figure 5.8 below.

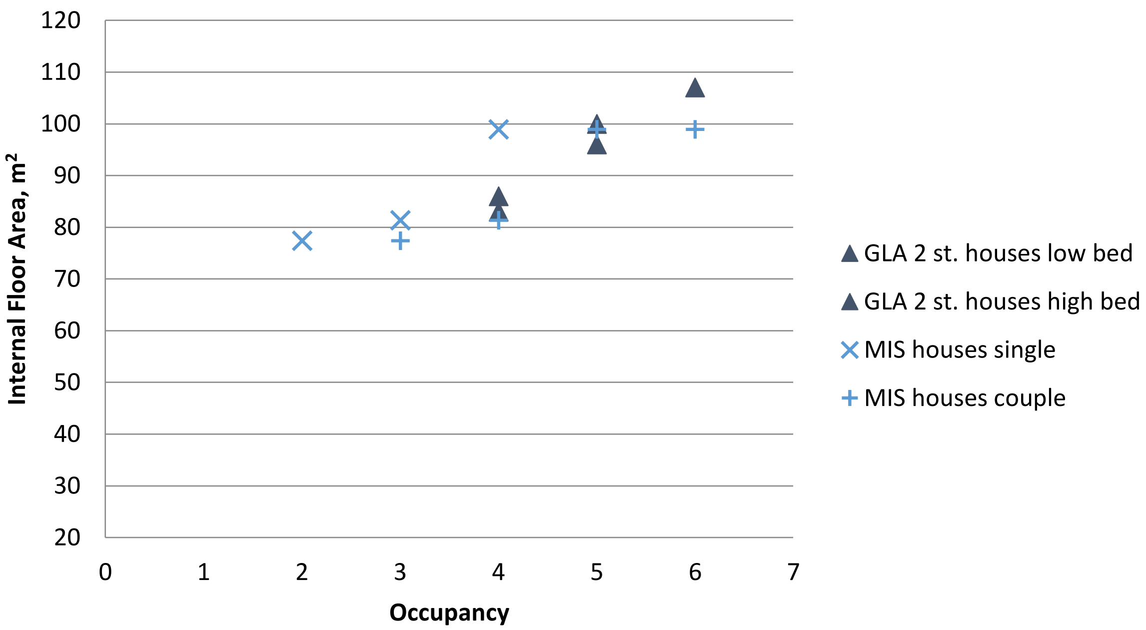

Figure 5.8 Minimum floor space standard for houses compared, GLA and MIS

The comparison with the MIS study serves to highlight the differences in minimum floors areas obtained by using two different methods.

5.3.5 Standard adopted and methodological implications

The measure of floor area adopted for use in the needs-based demand model is the London Housing Design Guide standard (GLA values). The justification for using this data is that it provides the most up-to-date set of minimum dwelling sizes and involved a comprehensive review of the development and use of these standards in the UK. These dwelling sizes have been selected in preference to the MIS dwelling sizes. The reason is that they use a systematic method to optimise dwelling sizes whereas the MIS study does not optimise dwelling size, instead using existing dwellings. The floor area values for one-level flats provide a complete set for comparison (with all other built forms requiring additional floor area over and above) and will form the basis for the floor area element of the model. Adopting this set as the basis of the floor area calculation element of the dHCA method embeds the following methodology:

- The model will adopt an idealised occupancy-based, not bedroom-based, relationship to floor area
- Households containing more than six occupants are allocated 10 sq. m for each additional person
- As with the London Housing Design Guide, the dwelling sizes do not discriminate between adult and child occupants: children are allocated an identical amount of floor area as adults

5.3.6 Floor area calculation

By adopting the London Housing Design Guide (GLA) values for 1-level flats, a simple linear relationship between the number of occupants and minimum required floor area can be derived from lines of best fit. It should be noted that the relationship changes for households with more than six household occupants. Using this relationship the floor area of dwellings is calculated with the following equations:

For occupancy <= 6:

Determining needs-based energy demand

$$GIA_{Occ} = (12.343 \times Occ) + 24.133$$

Equation 5.1 Gross internal area calculation (six or fewer occupants)

For occupancy > 6:

$$GIA_{Occ} = [10 \times (Occ - 6)] + 98.191$$

Equation 5.2 Gross internal area calculation (greater than six occupants)

Where: GIA is the minimum gross floor area

Occ is the number of occupants living in the household

Using the formulae above generates the following values for floor areas:

Number of occupants	Gross Internal Floor Area (m^2)
1	36.5
2	48.8
3	61.2
4	73.5
5	85.8
6	98.2
7	108.2

Table 5.2 dHCA model generated floor areas

The calculation for minimum floor area requirements reflects the economies of scale available in the resources required to support adequate living requirements: the first person requiring 36.5 square metres of living space, the next five requiring only an additional 12.3 square metres each, and any additional persons requiring only 10 square metres.

5.4 Unregulated emissions

As noted previously, unregulated emissions refer to the emissions arising from household energy demand not controlled by the Building Regulations. The Standard Assessment Procedure (SAP) does however include an extension used to calculate a value for unregulated emissions: Appendix L. Floor area, occupancy and emissions factors for fuels are used in this method to calculate the energy and emissions associated with this category. (BRE, 2011)

The procedure provides a method for demonstrating that the total CO_2 emissions arising from a dwelling (or group of dwellings), including both regulated and unregulated categories, can be reduced to zero using on-site renewable energy generation (BRE, 2011). A dwelling meeting this criteria for energy and emissions would be defined as a ‘Net Zero CO_2 emissions’ home, or Code Level 6 (Department for Communities and Local Government, 2010a).

5.4.1 SAP method

Using the method described in SAP, energy demand is calculated for appliances and cooking as a function of floor area and the number of occupants. The results for each are then added to give the total unregulated demand. The emissions factors for household fuels are then used to convert energy demand to emissions (see assumption statement iii, in 5.2.3 above). Unregulated energy demand of a household for appliances, E_A (measured in kWh), is calculated using the following equation (BRE, 2011):

$$E_A = 207.8 \times (TFA \times N)^{0.4714}$$

Equation 5.3 Unregulated energy demand (appliances)

Where: N is the number of occupants living in the household

TFA is the total gross floor area of the dwelling in square metres

Unregulated emissions from cooking, E_C (measured in kg/m²/year), are calculated using the following equation (BRE, 2011):

$$\frac{(119 \times 24\,N)}{TFA}$$

Equation 5.4 Unregulated emissions (cooking)

The assumptions behind the equation are not stated and so the basis for calculation is unclear. Clarification is available within additional guidance offered by Zero Carbon Hub in the appendix to their technical guide: *Modelling 2016 using SAP2009* (2011). The guidance separates the emissions calculation for cooking equipment fuelled by electricity, gas or a combination of both fuels. From the equations it is possible to derive the constants and coefficients for each appliance for both fuels, see Table 5.3 and Table 5.4.

	Constant	Coefficient	Equation
Oven + hob	481.0	96.30	481.0 + 96.30*N*
Hob only	280.5	48.15	280.5 + 48.15*N*
Oven only (derived)	200.5	48.15	200.5 + 48.15*N*

Table 5.3 Energy demand coefficients for gas cooking appliances, derived from Zero Carbon Hub (2011b)

	Constant	Coefficient	Equation
Oven + hob	275.0	55.0	275 + 55*N*
Oven only	137.5	27.5	137.5 + 27.5*N*
Hob only (derived)	137.5	27.5	137.5 + 27.5*N*

Table 5.4 Energy demand coefficients for electric cooking appliances, derived from Zero Carbon Hub (2011b)

While a little more detailed, the modelling is still crude (for example where appliances use a mix of fuels, the overall demand has simply been halved), this offers a little more information on which to base the dHCA model. Using the derived formulas shown above it can be seen that the unregulated emissions arising from cooking are also dependent on the type of fuel used. The estimated emissions do not vary a great deal, therefore, for simplicity, the model will assume all electric cooking. The unregulated energy demand from cooking (E_c) can therefore be calculated using the following equation:

$$E_c = 275 + 55N$$

Equation 5.5 Unregulated energy demand (cooking)

To convert to emissions arising from the calculated demand, the demand is multiplied by the emissions factor for electricity (BRE, 2011).

$$Emissions_{Unreg} = (E_A + E_C) \times Fuel\ Emissions\ Factor$$

Equation 5.6 Total unregulated emissions

5.4.2 Modified SAP method

While the HCA method is not concerned with the definition of a 'Net Zero' emissions home, the formula for calculating unregulated emissions is relevant to this investigation. There is however a problem with applying the formula to the dHCA model, namely the occupancy rate assumed within SAP for a given dwelling size.

The SAP procedure uses a rate based on a survey of the actual distribution of occupancy within the housing stock (Henderson, 2008). Unfortunately this distribution is of little use for the dHCA model scenario which assumes a significantly different occupancy profile where the dwelling stock is assumed to be more densely occupied. The contrasting occupancy rates are shown in Figure 5.9 below.

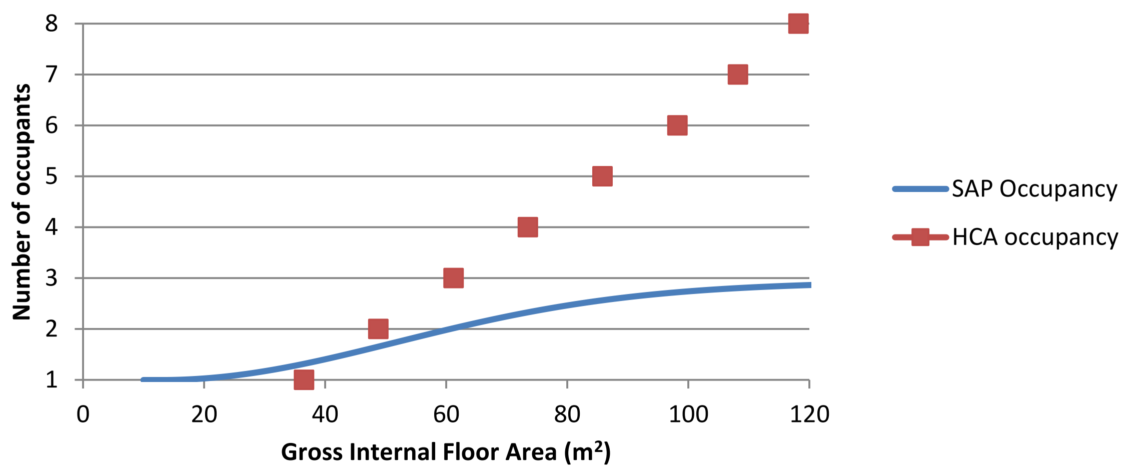

Figure 5.9 Occupancy calculated by dwelling size using SAP and dHCA methods

One option for modelling unregulated emissions would be to adapt the SAP formula, adjusting the occupancy to suit the dHCA distribution. The table below shows the resulting emissions levels from calculating the unregulated demand using the three examples quoted in the Zero Carbon Hub guide. Values have been calculated using both SAP and HCA occupancy rates and using 2009-2012 fuel factors (0.206 and 0.591 $kgCO_{2e}$/kWh for gas and electricity respectively).

HCA occupancy				SAP occupancy			
N_{HCA}	i. Elec oven, elec hob	ii. Gas hob, elec oven	iii. Gas oven, gas hob	N_{SAP}	i. Elec oven, elec hob	ii. Gas hob, elec oven	iii. Gas oven, gas hob
1	864	834	788	1.32	967	935	887
2	1292	1256	1203	1.66	1190	1156	1106
3	1693	1651	1592	2.01	1416	1380	1327
4	2082	2034	1968	2.33	1625	1587	1532
5	2464	2409	2338	2.56	1808	1768	1712
6	2841	2780	2702	2.72	1962	1922	1864

Table 5.5 Estimates of emissions arising from cooking calculated using SAP method with SAP and dHCA occupancy

For the SAP method, household occupancy, N is calculated as follows:

Where $TFA \leq 13.9$, N=1

Where $TFA > 13.9$:

$$N = 1 + 1.76 \times [1 - \exp(-0.000349 \times (TFA - 13.9)^2] + 0.0013 \times (TFA - 13.9)$$

Equation 5.7 Occupancy calculation (SAP method)

Using modified values for occupancy in the SAP method gives greater emissions for all households with occupancy of two or more people. The results for both methods are shown in Table 5.6.

			Household Emissions (unregulated), $kgCO_2$/year		
HCA occupancy	Floor area, m^2	SAP occupancy	HCA occupancy	SAP occupancy	Difference
1	36.5	1.3	864	967	103
2	48.8	1.7	1292	1190	-102
3	61.2	2.0	1693	1416	-277
4	73.5	2.3	2082	1625	-457
5	85.8	2.6	2464	1808	-657
6	98.2	2.7	2841	1962	-879
7	108.2	2.8	3186	2070	-1116
8	118.2	2.9	3527	2166	-1361
9	128.2	2.9	3865	2252	-1612
10	138.2	2.9	4200	2333	-1867

Table 5.6 Unregulated emissions calculated using SAP method with SAP and dHCA occupancy

Due to the opaque assumptions within the SAP method, it is not clear what the implications of adjusting the occupancy level within the SAP method might be for the accuracy of the calculation. Therefore an alternative approach is considered.

5.4.3 Alternative method

Another approach to defining a simple relationship of alternative household size and unregulated demand method would be to use data on appliance use to generate an alternative model. Defra commissioned research relevant to this problem: a study of the household electrical use of 251 owner-occupied households in England (Zimmerman *et al.*, 2012). Although the study consisted of a relatively small sample, it provides useful comparative data for unregulated demand. The small sample size is problematic due to the limited cases for larger households. Households with 1 or 2 occupants provided 63% of the sample; households with between 3 and 5 occupants provided 35% of the sample; and those households with 6 or more occupants represented only 3% of the sample (Owen, 2012). While the study achieved a close correlation to national data in terms of household size, a consequence of the small sample is that there are relatively few higher occupancy households represented in the dataset, just 7 or 8 households with 6 members or above.

Despite the limitations the study shows that for most groups of appliances contributing to unregulated energy demand, the demand per person decreases as the number of household members increases, for example for cooking and dishwasher use (Zimmerman *et al.*, 2012). This provides further evidence that the equal-per-capita assumptions of standard PCT approaches are wrong to focus on individuals. The relationship does not appear linear for most contributing items - reducing dramatically for the first additional occupant and with subsequent reductions diminishing thereafter. The small number of cases in the data for higher occupancy households means that defining a robust relationship for all groups of appliances is not possible. Noting this limitation, the data will be used to describe a simple relationship with which to estimate unregulated demand per person. This will be compared to the results obtained using the SAP method.

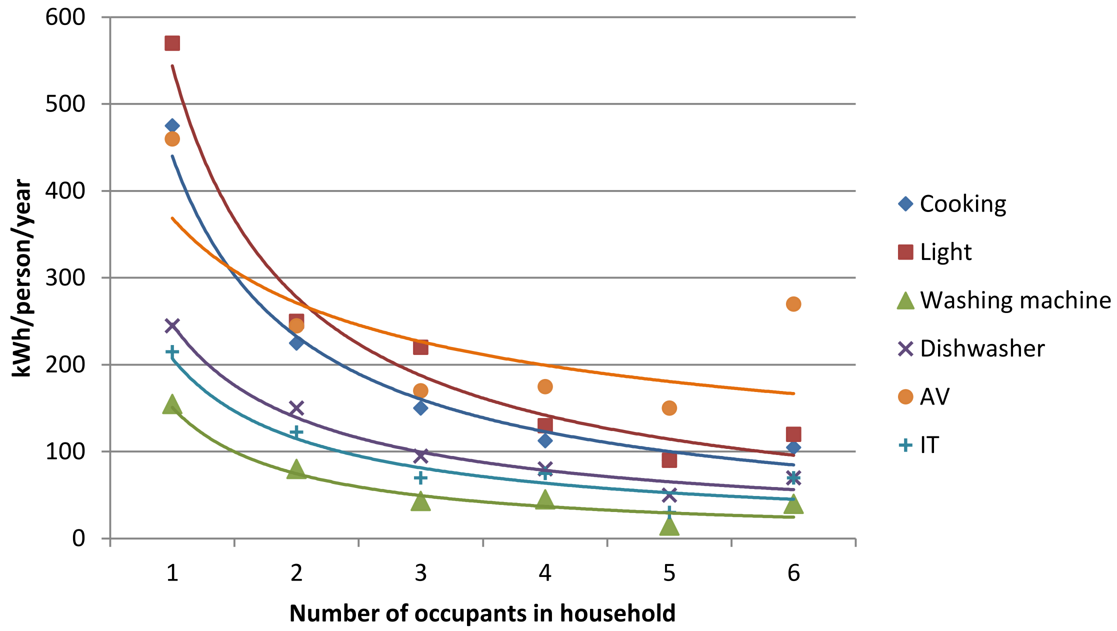

Figure 5.10 Energy demand of household appliances by type. Author's own disaggregation of data from Zimmerman et al. (2012)

The average power demand per person by appliance group and by number of household members was used to build an initial model. An idealised equation to fit to the total demand was added to the graph of values shown in Figure 5.11. This allows estimation of power demand for households larger than those included in the study.

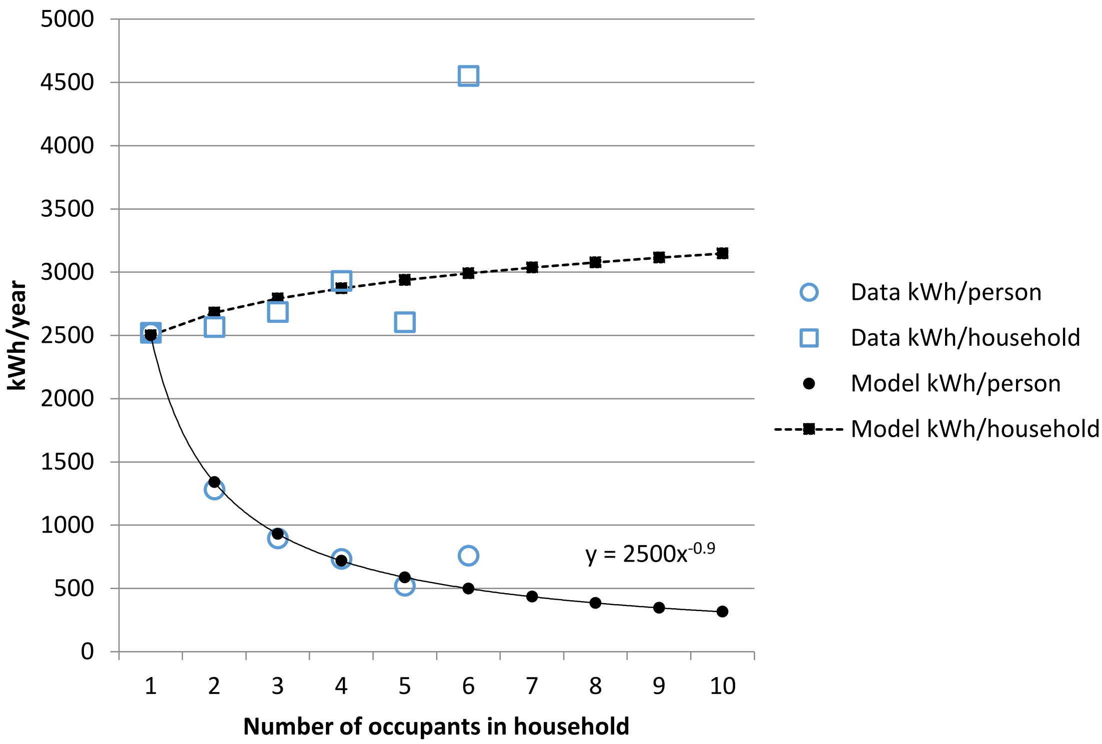

Figure 5.11 Unregulated energy demand by number of occupants, EST data and modelled

The total annual unregulated energy demand, in kWh, arising from a household, of size N is calculated using the following equation:

$$E_{A+C} = N \times (2500 \times N^{-0.9})$$

Equation 5.8 Total unregulated energy demand

Where: N is the number of occupants living in the household

Figure 5.12 shows the unregulated energy demand by household size calculated using both the SAP method, using both sets of values for occupancy, and using the calculation method described above (named the HCA method).

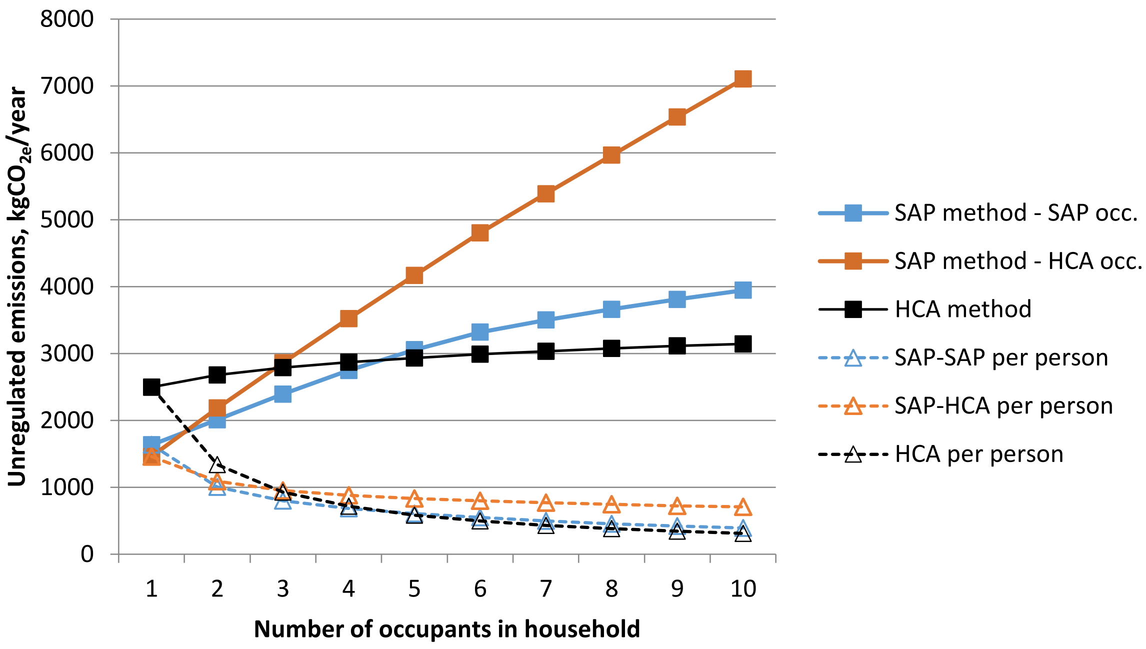

Figure 5.12 Unregulated household emissions – calculation methods compared

For all methods the demand per person reduces as the number of occupants in a household increases. Both series of values calculated using the SAP method are dependent on floor area *and* occupancy, with the HCA series dependent only on occupancy. Substituting for the needs-based scenario occupancy in the SAP method, in place of the assumed occupancy rate, results in higher demand for all households with two or more occupants. The HCA method results in higher values for one and two-person households and lower values for households with five or more occupants. The simple dHCA approach was chosen as it provides a method using just one variable: household size. The method therefore aligns with the method used for the regulated component. It was chosen over the SAP method as it is independent of the type of fuel used for cooking and also due to the assumptions of dwelling size made by the SAP method: as noted above, this reflects a much lower occupancy density than the needs-based scenario.

Alternative methods exist for generating unregulated demand such as bottom-up end-use modelling of appliances. Examples of this approach are: Yao and Steemers (2005) who model demand based on household occupancy patterns; Richardson et al. (2010) using ‘active’ occupancy and activity profiles; and Capasso et al. (1994) who synthesize appliance load profiles with household socio-demographic attributes. For this exploratory study however, the more complex methods noted above would have proven too time consuming to integrate within the needs-based energy model. These bottom-up models do align more closely with the dHCA methodology however and should be considered for the next generation needs-based demand model.

5.5 Summary

This chapter has described the formalisation of a needs-based energy services demand model. It has been shown that such a model is complementary to existing regulatory standards (although requiring some amendments to the assumptions within models). The two parameters required to compliment the SAP procedure for use in this task have been described. By applying minimum floor space requirements (a proxy for the regulated component of demand) and a simple calculation to quantify unregulated demand, this model provides the relative household demand required as input for the dHCA allocation model.

The dHCA model will therefore create a differentiated household emissions quota based on a set of household emissions using standardised minimum service levels in notional dwellings of minimum floor area and of uniform performance levels. The dHCA method is expected to result in a different distribution of emission quotas across groups of households. Single-person households would be expected to fare better under dHCA than EPCA and larger households better under dHCA than EPHH.

6. Household emissions modelling and analysis

6.1 Overview

This chapter presents the work completed to meet the empirical objectives of the research; to test the impact of the dHCA method relative to other proposed methods for allocating emissions rights under DCAT. The section following this overview provides a review of similar studies in the literature and a description of the methodology used for the empirical analysis. The next three sections will describe in detail the microsimulation modelling undertaken in this work. The final section will present the results obtained and analysis.

Comparison of the impact of different allocation methods was undertaken using a static arithmetic microsimulation model. This consisted of three parts: the first, modelling of household emissions from expenditure data; the second, modelling of household emissions quotas using four methods; and finally, calculation of residual quota surplus or deficit for each method. Figure 6.1illustrates the steps within the microsimulation with reference to the relevant sections of this chapter in parenthesis.

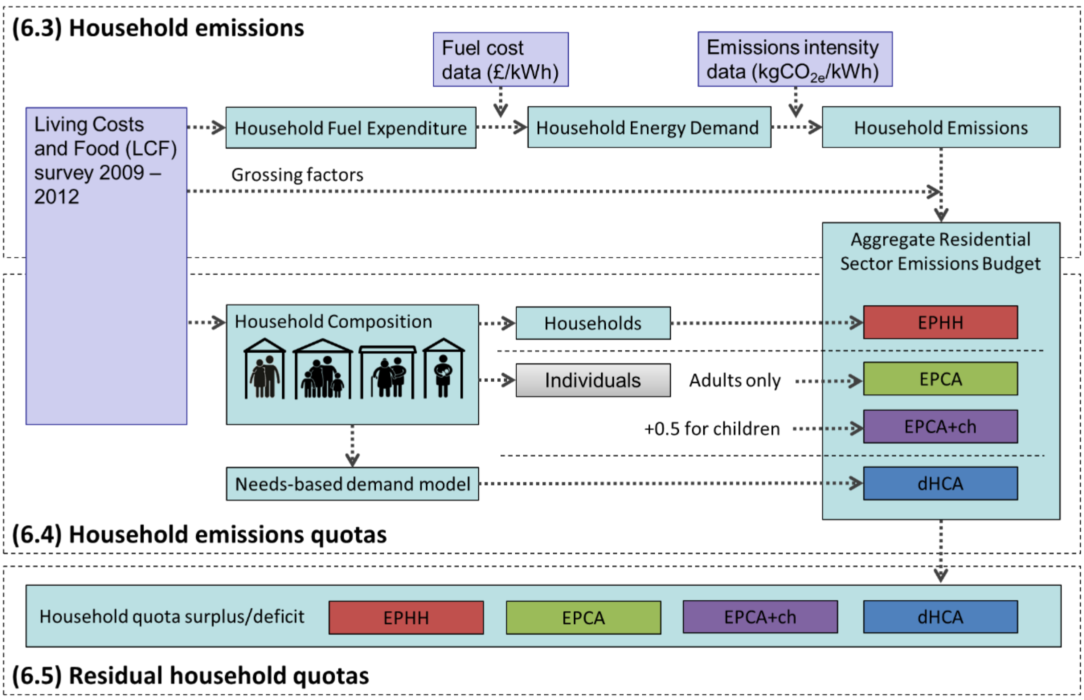

Figure 6.1 Overview of microsimulation modelling

Data management and analysis was performed using the statistical data analysis software Stata (version 13.1). Household emissions quotas for each of the four methods were calculated using a model created in Microsoft Excel. Data was exported from Stata into Excel to populate the household and population elements for the quota modelling (section 6.4).Once calculated, the household quota levels were imported back into Stata for the calculation of residual quotas (section 6.5) and analysis (see Section 6.6).

The microsimulation model is used to simulate the change in residual household carbon quota (or surplus/deficit) when adopting different emissions allocation methods under DCAT. Using a static model for the analysis precludes any change of behaviour of individual agents within the model (Bourguignon and Spadaro, 2006). The metric of comparison between allocation methods is the residual household quota (household quota minus household emissions). There is an assumption that any change in residual quotas (or quota surplus/deficit) results in a proportional change in the welfare of households and that this change affects all households equally (Bourguignon and Spadaro, 2006): i.e. a change of 1tonne/CO_{2e} affects a similar change in welfare for a single-person household and a family of four. This assumption is obviously false, however we can consider how equal changes in quota surplus and deficit would have differential impact on households with different characteristics.

6.2 Methodology

There are a few examples within the literature of deriving household energy demand and associated greenhouse gas emissions from survey data on expenditure in the UK. The studies described below all commonly use household expenditure obtained from a large-scale survey conducted by the Office for National Statistics (ONS). This survey is currently called the Living Costs and Food Survey (LCF), a module of the Integrated Household Survey (IHS). The LCF replaced the Expenditure and Food Survey (EFS) in January 2008, which itself replaced two separate surveys from 2001-2002; the Family Expenditure Survey (FES) and the National Food Survey (NFS). All of these surveys have provided information to government and wider society on patterns and changes in household spending in Britain since the 1950s. The surveys are used to provide information for economic and social indicators such as the Retail Prices Index (RPI) and analysis of taxation and benefit policies.

Dresner and Ekins (2004) combined the data from two rounds of the FES (1999-2000 and 2000-2001) to investigate the social implications of environmental taxation on household energy. The focus of their analysis was on the redistribution of household income and the mitigation of adverse effects through different strategies. Further analysis of the traits of winning and losing households was not carried out. The study uses a simple treatment of the costs and emissions intensity of household fuels: "The carbon dioxide emissions were calculated using the appropriate conversion factors for the carbon dioxide emissions for each kilowatt-hour of gas or electricity consumption." (p.12) For households with electric central heating, an off-peak factor of 0.62 was used to account for the reduced cost per unit of dual-tariff electricity (p.21).

Druckman and Jackson (2008) used a single round of the EFS (2004-2005) to calculate household energy demand. They then created a model to produce small area estimation of emissions using a 'conditional mean value replacement approach' based on household typology. The variables used were: age of household representative person (HRP), economic status, dwelling tenure and built form. Using their Local Area Resource Analysis (LARA) they produce a spatially disaggregated model of household emissions. They analyse the traits of high and low emitting clusters of households within groups according to ONS national output area classification (OAC). The authors also produce a further study on wider consumption of goods and services by incorporating a 'quasi-multiregional input-output model' for indirect emissions into the LARA model. The focus of their analysis is how emissions support high level functions (e.g. space heating; food and catering; clothing; health and hygiene; recreation and leisure etc.) and how the emissions associated with these categories varies according to socio-economic factors (2009).

Thumim and White (2008) merged three consecutive EFS datasets (2003-4, 2004-5, 2005-6) in order to increase the sample size. They use the resulting dataset to estimate energy demand and emissions in order to analyse the distributive impacts of a PCT scheme covering household energy and private transport fuels. Their analysis consists of three parts:

i. Multiple linear regressions to identify and investigate variables influencing degree of allowance credit/deficit.
ii. CHAID analysis[14] to segment survey based on combinations of variables identified in (i).
iii. Investigation of the characteristics of groups created in (ii) identifying trends and exceptions relevant to assessment of social distributional impacts.

The modelling by Thumim and White includes sophisticated treatment of the costs and emissions intensity of household fuels, using a lookup table with regional price variation.

Gough et al. (2011) link expenditure from the EFS (2006) to an input-output model of the UK economy (REAP – Stockholm Environment Institute) to estimate both direct and indirect emissions from households. REAP is two-region input-output (less complex than multi-region input-output (MRIO). N= 6164. Their analysis focuses on income and household size and composition (categorised). They treat all household occupants as equal (see Gough, 2011, pp.7) and per-capita values are derived by dividing the household total by the number of occupants (children are treated as adults). Regression analysis is carried out for a range of social factors such as dwelling tenure, employment status, household composition and age of HRP. Due to the large scope of emissions covered, calculation of the energy component is less thorough than others, and using REAP does not adjust for regional price variation.

Fahmy et al. (2011), Preston et al. (2013) and Patsios et al. (2013) all provide details of contributions to the Joseph Rowntree Foundation (JRF) climate change and social justice programme. The scope of their analysis extends to all direct emissions sources, including those from household energy, private transport, public transport and aviation. The authors create a synthetic dataset by combining four rounds of the EFS (2004-2007) alongside data from the National Travel Survey (NTS) and Air Passenger Survey (APS) using an advanced statistical method; Multiple imputation using the Markov-chain Monte Carlo technique (Fahmy *et al.*, 2011). The statistical analysis of the synthesised dataset (N=24,207) that follows reveals significant differences in mean annual

[14] Chi-Squared Automatic Interaction Detector (CHAID) analysis is used to examine the relationship between a dependent variable and a set of interacting predictor variables (Thumim and White, 2008)).

emissions (CO_2) of groups defined by socio-economic variables. The variables: dwelling type, household type, household size and number of bedrooms are shown to account for between 10 and 17 per cent of the overall variation in emissions from household fuels. In the executive summary of their report, Fahmy et al.identify the potential extension of their work aligning closely with the scope of this thesis:

> Although beyond the scope of this report, it would also be interesting to investigate the use of 'Minimum Income Standards' approaches to equivalising carbon emissions. This could enable an understanding of the levels of carbon emissions required to meet acceptable living standards. (Fahmy *et al.*, 2011, pp.12)

Büchs and Schnepf (2013b) combine four years of expenditure data (EFS 2006 & 2007, and LCF 2008 & 2009) to estimate direct and indirect emissions in terms of CO_2 (N=24,446). They provide a thorough statistical analysis of socio-economic household characteristics on the three separate emissions domains (home energy, transport and indirect) and also total household emissions. The authors also compare three methods of estimating household emissions using expenditure survey data (Büchs and Schnepf, 2013a).

Using household expenditure data for modelling fuel purchases, energy demand and greenhouse gas emissions is problematic. The infrequency of household energy purchases results in 'false-zeros'. This leads to an over representation of households with no apparent consumption of household fuels. This creates a limitation for analysis using this data in that it is not reliable at the household level. The limitation is noted for this study and therefore analysis will only be provided for groups of households. This approach to analysis, using households grouped by characteristics, is used in many of the examples noted above. The studies detailed above are summarised in Table 6.1. These examples document the extensive use of expenditure data to estimate household energy demand and greenhouse gas emissions.

Study	Data source	Scope	Energy/emissions calculation method	Analysis
Dresner and Ekins (2004)	EHCS 1996 FES 1999-2001	'Direct' HH energy	Price and emissions factors for household fuels.	Relationship of income to energy demand/emissions. Income redistribution due to carbon taxation.
Büchs and Schnepf (2013b)	EFS 2006, 2007 LCF 2008, 2009 (n=24,446), NTS[15], APS[16]	'Direct' HH energy Transport (private and public) + 'Indirect'	Direct: price and emissions factors for household fuels (regional variation accounted for). AA fuel price statistics for petrol diesel. Indirect: REAP input-output model	Regression of socio-economic factors
Druckman and Jackson (2008)	EFS 2004/05 (n~7000)	'Direct' HH energy	Price and emissions factors for household fuels. Local Area Resource Allocation (LARA) model – estimates emissions for households in socio-economically homogenous local areas (ONS output area classification) based on socio-economic characteristics.	Comparison of emissions according of 7 OAC supergroups (giving associated characteristics)
Druckman and Jackson (2009)	FES (year not stated)	'Direct' HH energy Transport (private and public) + 'Indirect'	As above plus input-output model for indirect. Uses LARA model (see above).	Comparison of emissions of 7 OAC supergroups Analysis of emissions related to functional use categories by OAC supergroup.
Fahmy et al. (2011)	EFS 2004-2007 (n=24,207) NTS 2002-2006 APS 1999-2008	'Direct' HH energy Transport (private and public)	Price and emissions factors for household fuels.	Regression on socio-economic factors.
Gough et al. (2011)	EFS 2006	'Direct' HH energy Transport (private and public) + 'Indirect'	REAP input-output model. Per capita emissions (household divided by all occupants) – children treated as equal to adults.	Analysis focuses on income and household size and composition. Regression analysis on social factors such as dwelling tenure, employment status, household composition and age of HRP.
Thumim and White (2008)	EFS 2003-4, 2004-5 and 2005-6	'Direct' HH Energy Transport (private)	Price and emissions factors for fuels (regional variation accounted for) (see pp. 77). AA fuel price statistics for petrol/diesel. Per adult emissions (hh/no. adult occupants) children ignored?	Analyse redistribution under PCT. Regression analysis on allowance surplus/deficit provides socio-economic characteristics of households in winning and losing groups.

Table 6.1 Studies estimating UK household emissions using expenditure survey data

[15] National Travel Survey (NTS)
[16] Air Passenger Survey (APS)

6.3 Estimating household energy emissions

6.3.1 Data sources and modelling process

This section presents an overview of the modelling of household energy demand and associated greenhouse gas emissions including: details of data sources and preparation, the calculation processes, new datasets and outputs. In this element of the empirical work [the modelling of household emissions using the LCF data], I received assistance in the form of Stata code and Excel spreadsheets produced for work undertaken under the Economic and Research Council (ESRC) project: "Who emits most? An analysis of UK households' CO2 emissions and their association with socio-economic factors". The grant number was RES-000-22-4083. Büchs, M. (Principle Investigator), Schnepf, S. and Bardsley, N. (Co-investigators). These files were used primarily to ensure that the modelling for this thesis was aligned methodologically and compatible with the analysis, with a view to extending the modelling and analysis over a longer time period.

The LCF survey data is representative of the UK population (Office for National Statistics, 2013a), therefore the modelling of household energy demand can provide emissions data on two levels: at the household level and, using weighting and grossing factors within the LCF data, at the aggregate level (for total emissions from the residential sector). The aggregate quantity is used as an input into the household quota model and is distributed by each of the four allocation methods. This provides an internal consistency check for integrating the two parts of the microsimulation: the aggregate quantity of household emissions calculated from the LCF expenditure data should equal the aggregate quantity of emissions allocated by each of the allocation methods.

As shown by the review of previous studies above there are several alternative methods with which to calculate household emissions. The alternatives arise where additional data is required to convert expenditure on fuels into quantities purchased. The additional data is illustrated within the boxes with dashed outlines in Figure 6.2 below.

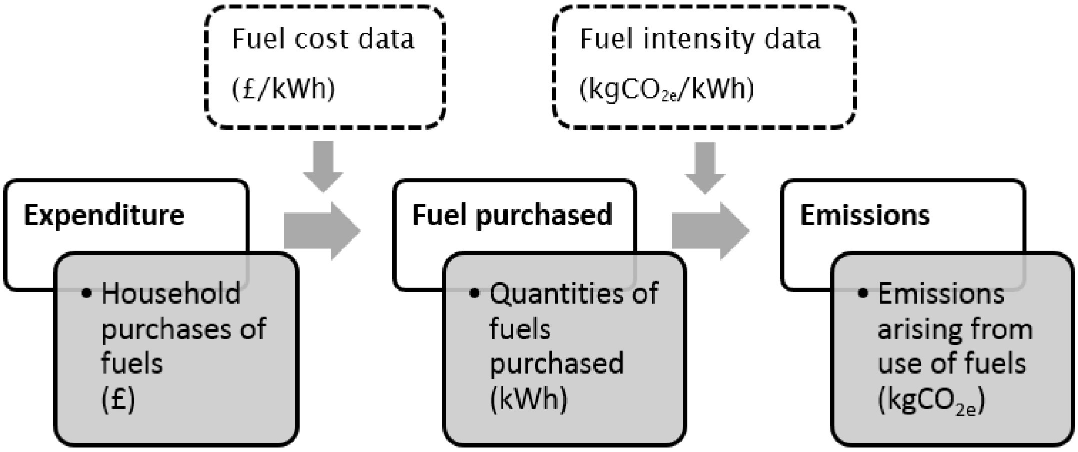

Figure 6.2 Household emissions calculation flow chart (simplified)

The complexity of this step of the calculation, will be determined by the fuel cost data adopted. For a simpler analysis, as for example Gough et al. (2011), a single price can be applied to fuels to convert expenditure to quantities of fuel purchased. Here equivalisation may be required to adjust for energy price inflation across the LCF survey years. A more rigorous approach is achieved through price matching for fuels across geographical regions (Druckman and Jackson, 2008; Büchs and Schnepf, 2013b; Patsios *et al.*, 2013).

Before calculation of the household quotas could be performed, the input data from the LCF survey was prepared. This preparation also processed the LCF datasets for use in estimating household energy demand and greenhouse gas emissions. The preparation is detailed in the next section.

6.3.2 LCF file preparation and harmonisation

The LCF survey was chosen as it is designed to be representative of the UK population and therefore, with weighting applied, the sample can be used to produce estimates of the total quantities of fuels used and the emissions arising from residential energy use for the whole of the UK. It is also suitable for use in providing the distribution of the population in terms of household composition, supplying the population and household inputs into the dHCA model. To create a larger sample size for analysis, four years of LCF survey data have been combined. The combined dataset provides increased numbers of observations for larger households and households with other characteristics of interest. The merged dataset contains 22,369 households. The sample size for each year is shown in Table 6.2 below.

Year	UK	England	Data source
2009	5,822	4,404	Office for National Statistics and DEFRA (2011)
2010	5,263	4,387	Office for National Statistics and DEFRA (2012)
2011	5,691	4,779	Office for National Statistics and DEFRA (2013)
2012	5,593	4,939	Office for National Statistics and DEFRA (2016)
Total	22,369	18,509	

Table 6.2 LCF datasets and sample size by year (households)

The relevant expenditure and social variables for each year of the survey were harmonised prior to merging them into a single dataset. This process generally involved ensuring that the variables detailing items of household energy expenditure were consistent across the individual survey years. Following the data harmonisation and merging, the resulting dataset was used to produce the household and population data required for modelling household emissions quotas. This exported data is referred to as the 'household matrix' (see section 6.4.1).

6.3.3 Households and population

The dHCA model requires data on the distribution of household composition through the population. This matrix is used within the dHCA model to produce estimates of aggregate totals of adults and children which are required to calculate the level of emissions rights quotas for the other allocation methods. A module of code was written in Stata to produce the household matrix from the LCF survey data: frequencies of households by composition (see also dHCA model description in section 6.4).

The aggregate household estimates obtained from each LCF survey year have been compared to estimates obtained from other data sources and are shown in Figure 6.3 below. Estimates obtained from the EHS and 2011 census (Office for National Statistics, 2013b) are also displayed. For the UK, the LCF produces estimates of household numbers that are lower than the figures from the 2011 census. For England, the LCF provides aggregate totals that are more variable than those obtained from the EHS, with the average for the four-year period marginally higher than the 2011 census.

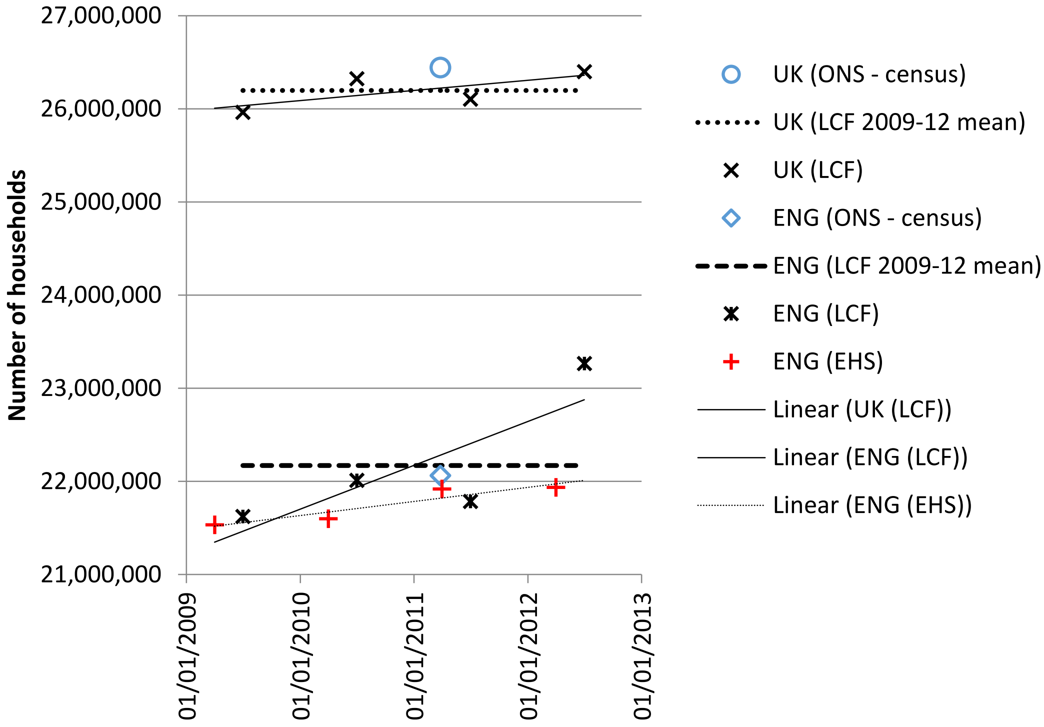

Figure 6.3 **Household estimates by data source for England and UK (2009 – 2013)**

The resident population measured by the 2011 census provides separate figures for residents living in both households and in communal establishments. The figures adopted for this comparison are for persons resident in households and excludes those in communal establishments. This is the appropriate figure to use as the LCF and EHS only survey households.

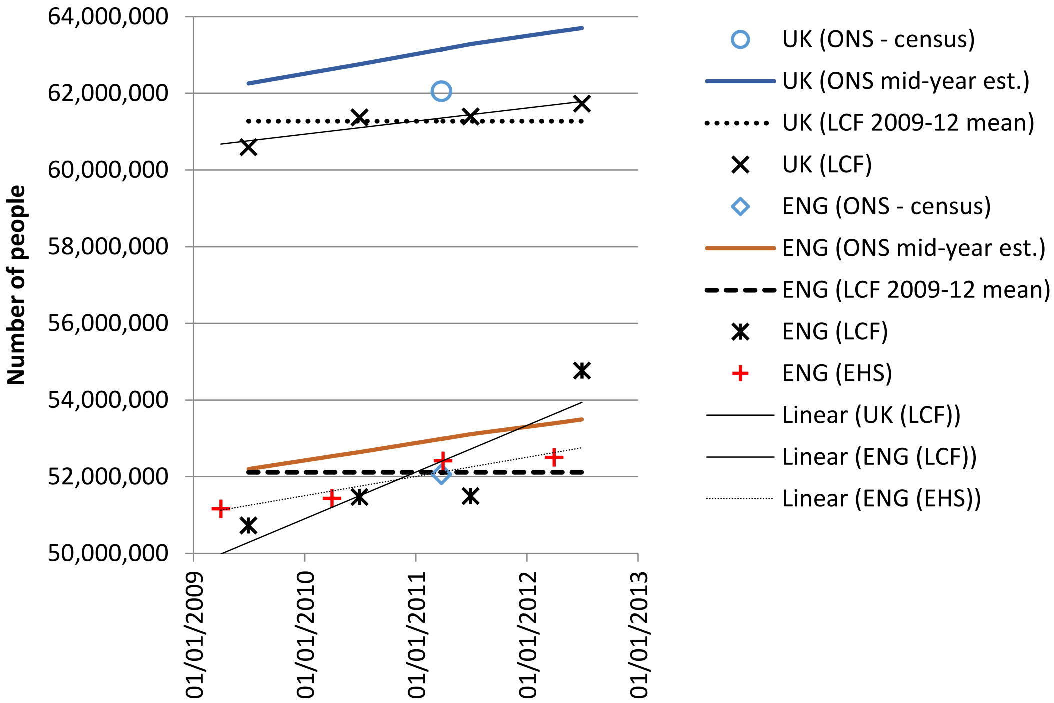

Figure 6.4 Population estimates by data source for England and UK (2009 – 2013)

Mid-year population estimates for 2009 to 2012 provide figures for all residents only: including those living within communal establishments (Office for National Statistics, 2013c). The mid-year estimate for 2011 is therefore higher than the figure for the 2011 census and would be expected to be consistently higher than the other estimates in the comparison. The mid-year estimates provide a comparative trend line for the increasing population. It can be seen from Figure 6.4 above that the trend in the UK aggregate population estimate obtained from the LCF is comparable to the trend found in the mid-year estimates, although lower than the census estimate. Considering just England, the LCF data shows a steeper trend but with the four-year average closer to the census estimate. For England, the EHS provides estimates of population that are more consistent with the census figures, both for the 2011 estimate and the trend line for mid-year estimates.

6.3.4 Fuel price data

In order to estimate the quantities of fuel purchased from expenditure, unit prices for each fuel were required. As the LCF survey sample spanned four consecutive years, and due to the volatility in the prices of some household fuels, sources of data on unit prices across the whole survey period were used. Time intervals varied according to the source used, with the minimum interval of annual average prices adopted (an exception was wood fuel which was interpolated/extrapolated for annual price from two values for 2009 and 2012).

Data on fuel prices was gathered from a number of sources and for the main household fuels account for price variation across geographical regions, time and payment method. The data sources are summarised in the Table 6.3 below.

Fuel	Source	Time interval	Regional	Payment method
Electricity	DECC	Annual	Yes[1]	DD,C & Prepay
Gas (mains)	DECC + S.T.[2]	Annual	Yes[1]	DD,C & Prepay[2]
Gas (bottled)	Sutherland Tables (S.T.)	3mth -6mth	Yes[3]	No
Oil	Sutherland Tables	3mth -6mth	Yes[3]	No
Coal	Sutherland Tables	3mth -6mth	Yes[3]	No
Wood fuel (logs)	SAP (BRE)	Annual (interp/extrap)[4]	No	No

[1] Unit prices are adjusted to account for discrepancy between DECC and LCF regional boundaries.
[2] Unit prices for Northern Ireland were not available by payment method, therefore a flat rate across payment types has been adopted.
[3] Sutherland Table region data is matched to government region.
[4] Unit prices for wood fuel interpolated and extrapolated from 2009 and 2012 values quoted by SAP.

Table 6.3 Summary of fuel price data sources by fuel

Unit prices for electricity and gas were taken from Tables 2.2.3. and 2.3.3. respectively of the Quarterly Energy Prices (QEP) publication (Department of Energy and Climate Change, 2012). Although quarterly prices are available for the UK as a whole for each fuel, regional prices are only available as annual averages, these are adopted to correspond with each LCF survey year. The unit prices include standing charges and are based on average annual consumption of 15,000 kWh for gas and 3,800 kWh for electricity. The regions used in this publication relate to distribution regions. The distribution regions consist of 14 Public Energy Supplier (PES) regions for electricity and 12 Local Distribution Zones (LDZ) for gas (Büchs and Schnepf, 2013a). The regional price data published by DECC for electricity and gas was adjusted to take into account differing regional boundaries to those taken by the LCF survey. Büchs and Schnepf adopt a system for adjusting the DECC average regional unit price to correct for this. Their system uses data of the quantity of electricity and gas meters installed at district level and matches each district to the correct LCF government region by postcode. The proportion of meters within each government region that fall within each of the distribution regions were then used to weight the unit prices (Büchs and Schnepf, 2013a, 2013b). This system was also adopted for the emissions modelling in this study.

For electricity, households with electric central (or primary) heating were assumed to hold dual tariff accounts. These households received a reduction factor of 0.7 to the unit cost of electricity to account for 'off-peak' heating demand and the reduced unit cost of off-peak tariffs (see Patsios *et al.*, 2013).

The DECC data does not cover Northern Ireland for gas, therefore unit price data from the Sutherland Tables was adopted for this region. The Sutherland Tables give two unit prices for gas; one for the first 2000 kWh and one for the balance. As gas demand varies over the course of the year, the average unit price also varies due to the changing ratio of the two unit prices. The average unit price has therefore been adjusted to take average quarterly demand into account. This was carried out in using the method employed by Büchs and Schnepf (Büchs and Schnepf, 2013a, 2013b). The proportions are shown in Table 6.4 below.

	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Av. quarterly demand (kWh)	7,200	3,600	1,800	5,400
Proportion - First 2000 kWh	0.2778	0.5556	1.0000	0.3704
Proportion - Balance	0.7222	0.4444	0.0000	0.6296

Table 6.4 Quarterly price correction of Northern Ireland gas

Data extracted from the Sutherland Tables was used for mains gas (Northern Ireland only), bottled gas, oil and coal. The price data supplied by the Sutherland Tables is given in 7 regions including the Republic of Ireland. The 6 UK regions were matched to government regions in the LCF. The process of matching these regions for unit prices of fuels covered by the Sutherland Tables was considered less critical due to the lower quantities of these fuels used, see Figure 6.5 below.

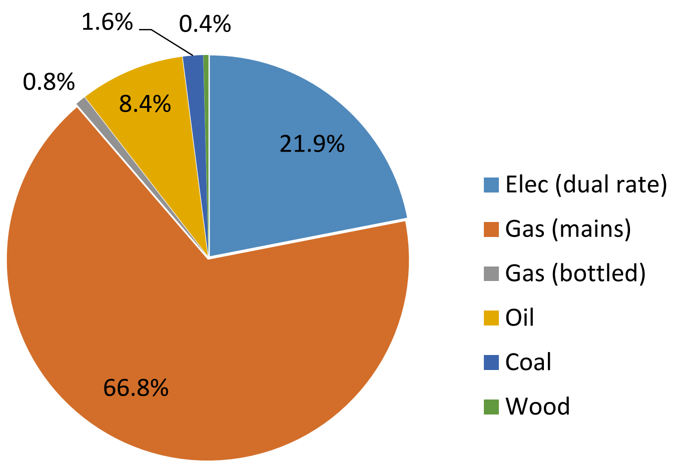

Figure 6.5 Total UK household energy demand by fuel type, LCF 2009 to 2012

Finally, wood fuel prices were adopted from the values used in SAP. Due to the lack of regional price data and the small quantities reported to be purchased in the LCF, interpolating and extrapolating from the values for 2009 (BRE, 2009) and 2012 (BRE, 2014) was deemed to be sufficient.

6.3.5 Fuel unit price matching

The fuel unit price data described in the section above was matched and applied to each household in the LCF dataset using the month and year of the survey response, the region and payment method. Not all variables were used for every fuel in the matching process, for example wood fuel was not matched using region and gas and electricity were not matched using survey month. See Table 6.3 above for the matching criteria applicable for each fuel.

The DECC price data for electricity and gas quotes unit prices by region and by payment type; direct debit, credit and prepayment. To attribute the unit price to each household, responses to the LCF survey on payment type were first matched to the DECC payment methods. Once matched, the DECC payment method and region were used to allocate the corresponding unit prices to gas and electricity. Gas prices for Northern Ireland do not vary for payment type due to the single unit price provided by the Sutherland Tables. Table 6.5 below shows the mapping of LCF survey responses on payment methods (variables a128 and a130) to DECC payment types.

LCF Code	LCF 2009	LCF 2010 to 2012	Payment method (DECC)
0	Not recorded	Not recorded	n/a (gas only)
1	Direct debit	Direct debit	Direct debit
2	Standing order	Standing order	Direct debit
3	Monthly/quarterly bill	Monthly/quarterly bill	Credit
4	Pre-payment (keycard or token) meters	Pre-payment (keycard or token) meters	Pre-payment
5	Included in rent	Included in rent	Credit
6	Frequent cash payment	Frequent cash payment	Pre-payment
7	Fuel direct/direct from benefits	Fuel direct/direct from benefits	Credit
8	Fixed annual bill	Fixed annual bill	Credit
9	Other	Other	Credit
10		Paid direct by someone outside the household (except DWP)	Credit
88	Not applicable	Not applicable	n/a (electricity only)
99	Don’t know	Don’t know	Credit

Table 6.5 Gas and electricity payment methods

Where households responded that the payment method was ‘unknown’ or ‘not applicable’ but recorded an expenditure (or rebate), a default DECC payment type of ‘Credit’ was applied.

The resulting proportions of households settling their accounts by each payment type are presented with figures published by DECC in Figure 6.6. DECC figures are taken from Table 2.5.2. of the Quarterly Energy Prices publication (Department of Energy and Climate Change, 2014b).

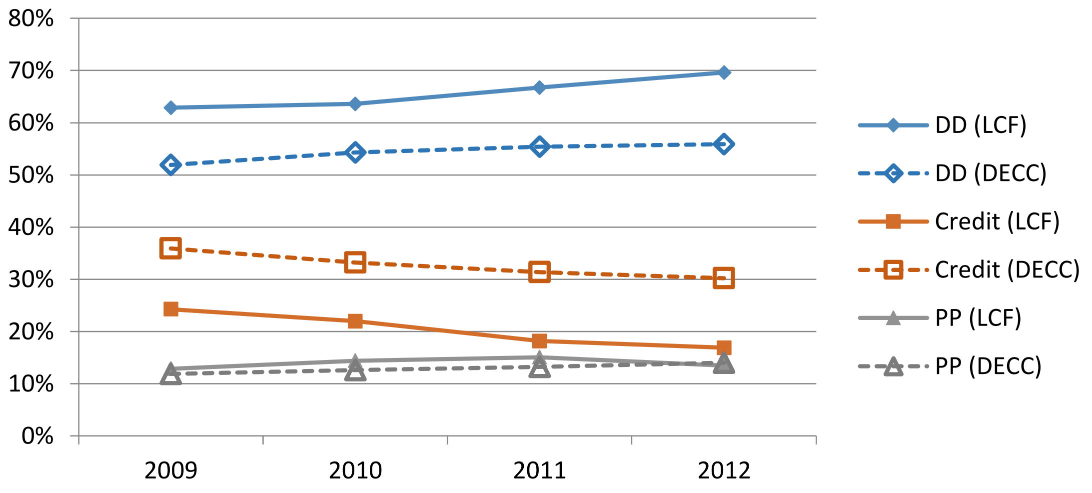

Figure 6.6 Gas payment methods compared, LCF and DECC

Payment method	2009	2010	2011	2012	Average
direct debit	62.86%	63.61%	66.74%	69.62%	65.71%
credit	24.26%	21.98%	18.17%	16.90%	20.33%
prepayment	12.88%	14.41%	15.09%	13.48%	13.97%

Table 6.6 Gas account payment method, LCF survey 2009 to 2012

Payment method	min	max	LCF Average	DECC Average	Difference
direct debit	62.86%	69.62%	65.71%	54.4%	11.3%
credit	16.90%	24.26%	20.33%	32.7%	-12.3%
prepayment	12.88%	15.09%	13.97%	12.9%	1.0%

Table 6.7 Gas account payment methods compared, LCF and DECC

Again, the proportions of households settling their electricity accounts by each payment type are presented in Figure 6.7, Table 6.8 and Table 6.9 below along with figures published by DECC. DECC figures are taken from Table 2.4.2. of the Quarterly Energy Prices publication (Department of Energy and Climate Change, 2014b).

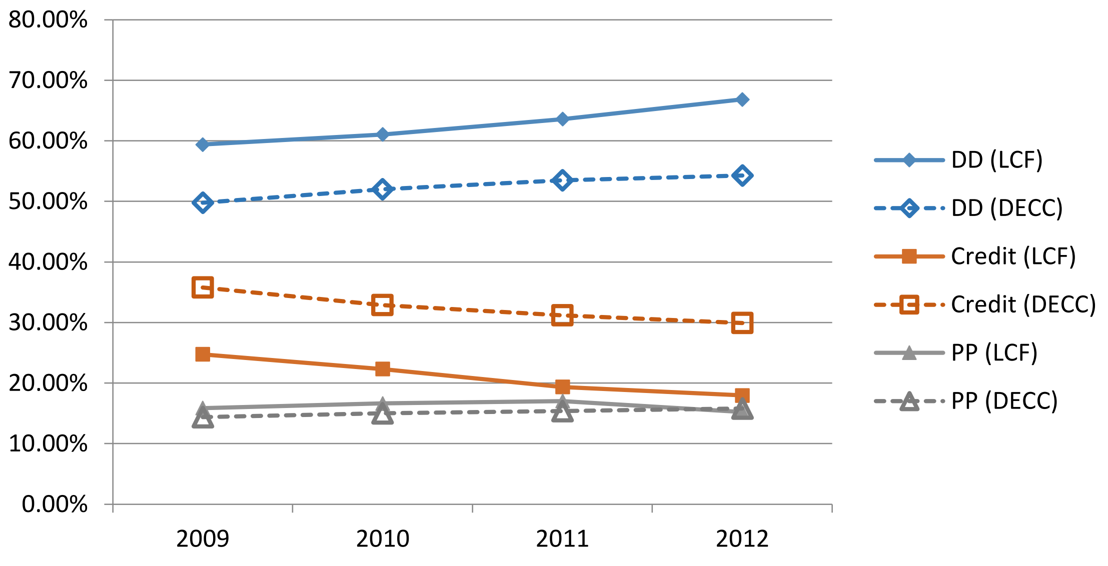

Figure 6.7 Electricity payment methods compared, LCF and DECC

	2009	2010	2011	2012	min	max	LCF Av. (all)
direct debit	59.37%	61.04%	63.59%	66.83%	59.37%	66.83%	62.71%
credit	24.76%	22.33%	19.37%	17.96%	17.96%	24.76%	21.10%
prepayment	15.87%	16.63%	17.05%	15.21%	15.21%	17.05%	16.19%

Table 6.8 Electricity account payment method, LCF survey 2009 to 2012

Table 6.9 below presents the variation of payment types for differing electricity tariffs: standard and dual (Economy 7). Households with electric central heating assumed to be dual tariff.

	LCF Av. (all)	LCF Av. (dual)	LCF Av. (std.)	DECC Av. (std.)	Diff. (all)	Diff. (dual)	Diff. (std.)
direct debit	62.71%	50.59%	63.67%	52.4%	10.3%	-1.8%	11.3%
credit	21.10%	29.01%	20.47%	32.5%	-11.3%	-3.4%	-12.0%
prepayment	16.19%	20.41%	15.85%	15.2%	1.0%	5.3%	0.7%

Table 6.9 Electricity account payment methods compared, LCF and DECC

For both fuels, the payment method mapping results show the proportion of accounts settled by direct debit increased over the period 2009 to 2012. The proportion of credit accounts decreased over the same period. Both of these trends are reflected in the DECC data. For the prepayment method, the proportion of households increased for both electricity and gas in the period 2009 to 2011 but decreased in 2012. DECC figures show the upward trend continuing into 2012.

While the trends in payment method found in the LCF match the DECC data well, the matching process does not produce figures consistent with DECC. For the period 2009 to 2012 the average mismatch between payment methods for gas is +11.3 per cent for direct debit, -12.3 per cent for credit and +1.0 per cent for prepayment. For electricity, the mismatch is +10.3 per cent of households for direct debit, -11.3 per cent for credit and +1.0 per cent for prepayment. Recoding ‘standing order’ payments as credit, rather than debit, reduces the discrepancies by 2 percentage points across direct debit and credit payment types for both gas and electricity and has been completed for the modelling. The matching process adopted by this study produces comparable results to those found by Büchs and Schnepf (2013a) for 2009.

6.3.6 Fuel quantities calculations

The Stata code uses the fuel unit price data and weekly expenditure contained in the LCF to calculate the quantity of different fuels purchased by each household. The totals for each fuel are then aggregated to provide estimated aggregate totals for all UK households. For results and comparison with other data sources on residential fuel consumption refer to section 6.3.9.

6.3.7 Emissions factors and household emissions

Merging the data required to perform the greenhouse gas emissions calculation was simpler than for the fuel price data as a single source of data was adopted. The emissions factors used in the calculation of emissions estimates are taken from Defra's Greenhouse Gas Conversion Factor Repository (Defra, 2014b). The factors use Scopes 1 to 3 (full fuel cycle). Emissions factors based on the gross calorific values for energy content of gas (mains and bottled), coal and oil have been adopted. This is in line with DECC and Defra guidance on greenhouse gas emissions reporting (DECC, 2014; Defra, 2014a) although other studies have used net calorific values; see Patsios et al. (2013). For all household fuels except electricity, fixed emissions factors (2012 values) have been used for the entire period 2009 to 2012. Emissions factors for electricity have been adopted for each individual year within the period due to the effect of changes in the generating fuel mix on emissions intensity per kilowatt hour (kWh).

Care has been taken to adopt emissions factors consistent with the units of the fuel price data i.e. where fuel price data provided is in weight units per £ expenditure, the emissions factor adopted has been expressed in kg CO_{2e} per unit weight of fuel. For some fuels, purchase units differed in size from the units for emission factors and were subsequently factored within the Stata code for consistency. The emissions arising from the use of each fuel is calculated within Stata. All fuels are then aggregated to provide total emissions for each household for all fuels. From the household total, a per-capita value is calculated. Estimated aggregate totals for all UK households are also calculated to provide the sectoral emissions budget allocated by the emissions quota modelling.

6.3.8 Household expenditure

The weekly expenditure recorded by the LCF has been used to calculate mean household annual expenditure on a range of domestic fuels. The results are illustrated in Figure 6.8 below.

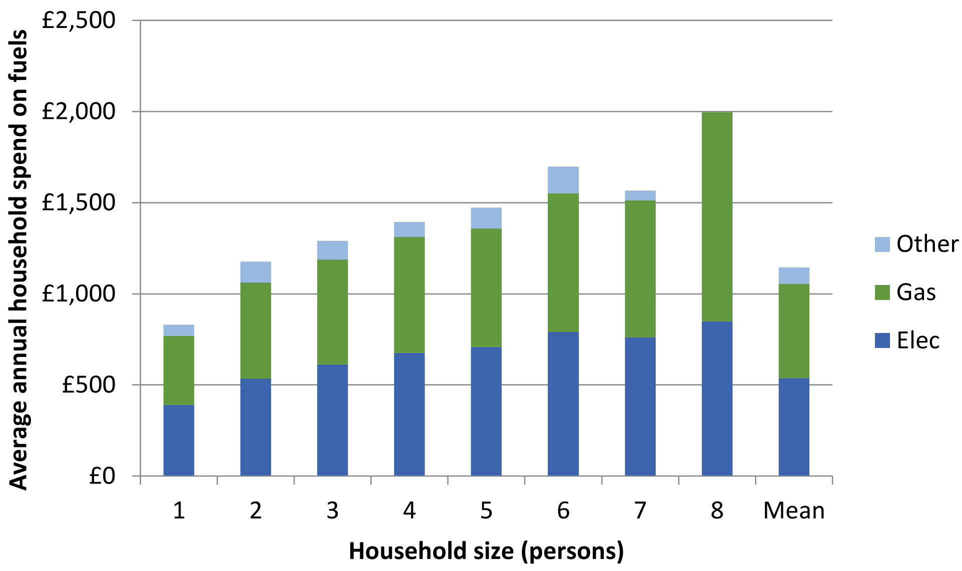

Figure 6.8 Mean annual household expenditure on fuel of UK households, based on LCF data (2009-2012)

Electricity contributes the largest component of household expenditure on fuels with an average annual spend of £537. Annual gas cost averaged across households is £516 and spend on other fuels £93 per annum.

6.3.9 Fuel quantities

Following calculation of expenditure on each fuel type, the Stata code merges price data for fuels and calculates the fuel quantities for each household. In adopting variable unit prices this process excludes price effects from the fuel quantities calculation, although mismatch of billing period and price will still be present.

The unit price of electricity was reduced for households with electric central heating (indicated in the LCF dataset by variable *a150*). Two figures are presented below for annual electricity demand to show the effect of including the simple correction for electrically heated households. The resulting 43% increase in electricity demand for this group of households leads to a 4% increase in the mean demand of the whole sample (see Figure 6.11 below).

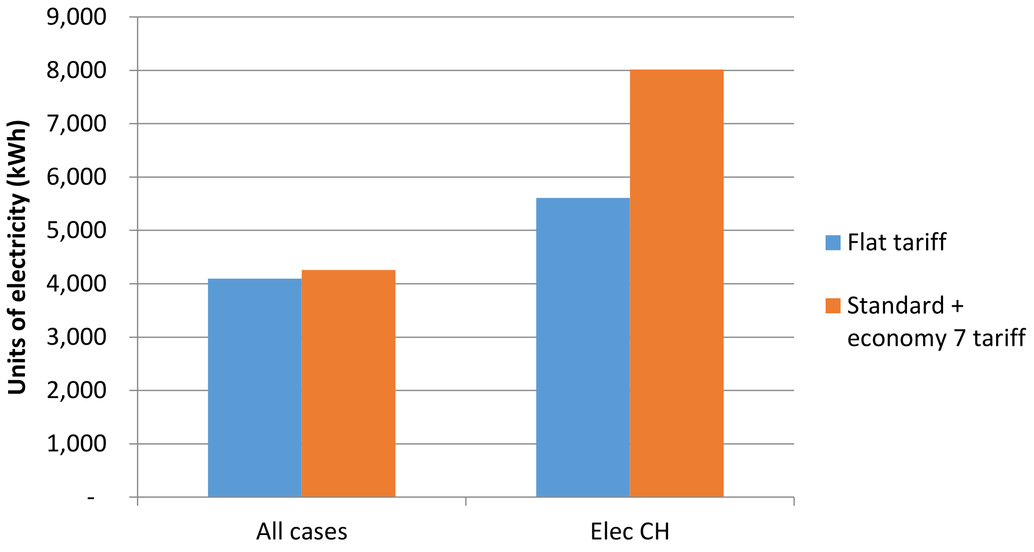

Figure 6.9 UK mean annual electricity demand estimates, author's own modelling of LCF data (2009-2012)

The dual-tariff assumption has been applied to the electricity demand estimates and therefore all of the results that follow include the electric central heating correction. The household quantities are aggregated to provide annual totals for each fuel type for each year of the LCF survey. These quantities have been converted to Terawatt-hours (TWh)[17] in order to compare to sector wide fuel demand statistics published by DECC in the Housing Energy Fact File (Palmer and Cooper, 2013, Table 2a). Unlike other DECC statistics, these figures are not weather corrected and consequently provide a direct comparison for the total aggregate household fuel consumption estimated using the LCF survey data. Figure 6.10 below presents the yearly consumption estimates from the LCF modelling compared with the figures from DECC.

[17] The conversion was performed using DEFRA conversion factors (DEFRA, 2014b)

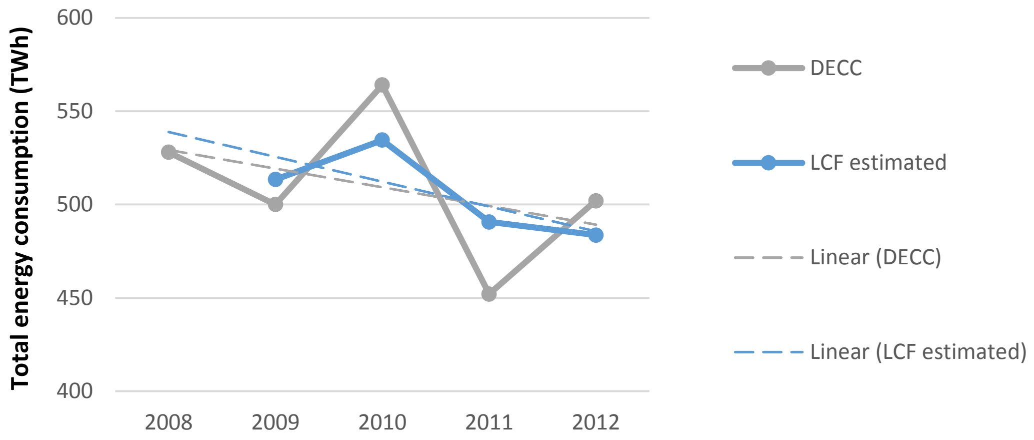

Figure 6.10 Modelled aggregate UK household energy consumption, based on LCF data (2009 to 2012) compared to DECC housing energy statistics (Palmer and Cooper, 2013)

6.3.10 Reduced scope of model

In order to draw comparisons between the scenario presented in the dHCA model and the existing housing stock, data is required about the dwellings occupied by households. This data is not included within the LCF survey and so additional data is used from the English Housing Survey (EHS). The EHS contains variables describing both household and dwelling attributes. As the survey only extends to households within England the scope of the allocation method has been restricted to allow use of both the LCF and EHS in the analysis. Limiting the scope of the carbon allocation scheme to England also recognises that legislative responsibility for climate change has been devolved to the regions in England, Wales, Scotland and Northern Ireland. The methods described could be adapted for use in each administration, thus allowing for regional variations in housing and energy to be incorporated. The residential sector budget allocated by the household emissions quota model has been reduced to reflect the reduction in scope and uses estimated emissions of households within England only. For the modelling of household emissions quotas and subsequent analysis, the four years of emissions are combined. This is to provide consistency with the combining of the LCF datasets to provide a larger sample. The output from the household emissions modelling is the aggregate residential sector emissions budget ($Agg.Budget$).

6.4 Modelling household emissions quotas

The quantities of emissions permits allocated by the four methods are modelled in Microsoft Excel. This section provides details of the calculation of household quotas for each of the allocation methods.

6.4.1 Household composition

Each of the allocation methods to be simulated requires the use of population statistics, household statistics or the distribution of population among households (household composition) in order to calculate emissions quotas. To provide these statistics in a common format that is applicable to all methods a matrix was used. The household matrix (H) was populated using analysis of the LCF dataset and provides the number of households in the UK population of each composition (i.e. number of adults and children). As the LCF is representative of the UK population, the sum total of matrix values (populated with weighted figures), multiplied by one thousand, should be expected to equal the total number of UK households. Multiplying the each of the values by the relevant household composition gives the population of adults and children (under the age of eighteen).

UK household matrix (,000's households)- output from Stata (LCF 2009-12 - mean) - Adults 18+									
		Number of children in household							
		0	1	2	3	4	5	6	7
Number of adults in household	0	0	1.372973	1.172729	0	0	0	0	0
	1	7557.657	699.5804	442.8561	153.8816	35.68426	10.1914	2.541776	0
	2	8651.246	2217.24	2144.994	640.1747	133.4474	35.67735	7.149898	0.659724
	3	1651.532	540.8495	224.3353	45.68419	11.90541	8.689095	0.642531	0
	4	553.3606	137.0371	58.26584	14.10207	2.755324	0.655477	0	0
	5	116.8163	29.05636	9.514802	5.369959	0	0	0	0
	6	25.49186	7.454168	0	0.783937	0	0	0	0
	7	5.237975	0	4.297698	0	0	0	0	0
	8	3.200215	3.712363	0	0	0	0	0	0

Table 6.10 Household composition matrix (H) UK 2009 – 2012 mean, weighted LCF survey data (2009 – 2012)

The residential sector emissions budget available to each method is equal to the aggregate household emissions estimated from the LCF data (grossed-up by applying LCF survey weighting for households) and detailed in Section 6.3.

This quantity provides the aggregate residential sector emissions budget to be distributed by each of the four allocation methods and is referred to as Agg. budget in the notation that follows.

6.4.2 Equal per household (EPHH)

The Equal-per-household allocation (EPHH) method is simply the residential sector emissions budget divided by the number of households in England. The total number of households is given by the sum of the values contained in the household composition matrix. Therefore the Equal-per-household quota, $EPHH$:

$$EPHH = \frac{\text{Agg. budget}}{\sum_{i,j=1}^{11} H_{ij}}$$

Equation 6.1 Equal-per-household (EPHH) quota

6.4.3 Equal per capita (EPCA)

Similarly the Equal-per-capita (EPCA) method shares the residential sector emissions budget equally among adults (aged 18 and over). The adult population is given by the sum of the product of each cell in the household composition matrix and the number of adults in each household (i). The Equal-per-capita quota, $EPCA$ is calculated thus:

$$EPCA = \frac{\text{Agg. budget}}{\sum_{i,j=1}^{11} H_{ij}\ \ i}$$

Equation 6.2 Equal-per-capita (EPCA) quota

To calculate the household quota, the $EPCA$ is multiplied by the number of adults in each household (i), giving $EPCA_{hh}$:

$$EPCA_{hh} = EPCA\ i$$

Equation 6.3 EPCA household quota

6.4.4 Equal per capita with children (EPCA+ch)

The EPCA calculation is adjusted to calculate an adult quota under a scheme allowing a proportional allowance for children (EPCA+ch). The child allocation proportion (CAP) describes the proportion of the adult quota allocated to children. The value substituted for (CAP) in the following equations is 0.5 for consistency with previous studies (see model assumptions). The equations allow any proportional child allowance to be used.

Equal-per-capita adult quotas, $EPCAch_{adult}$:

$$EPCAch_{adult} = \frac{\text{Agg. budget}}{\sum_{i,j=1}^{11} H_{ij} \;\; i + \left(CAP \;\sum_{i,j=1}^{11} H_{ij} \;\; j\right)}$$

Equation 6.4 Equal-per-capita (EPCA+ch) adult quota

Equal-per-capita child quotas, $EPCAch_{child}$:

$$EPCAch_{child} = CAP \; EPCAch_{adult}$$

Equation 6.5 Equal-per-capita (EPCA+ch) child quota

The household quota, is given by multiplying each for the number of adults (i) and children (j) in each household, giving $EPCAch_{ij}$:

$$EPCAch_{ij} = EPCAch_{adult} \, i + \; EPCAch_{child} \, j$$

Equation 6.6 EPCA+ch household quota

6.4.5 Differentiated Household Carbon Allowance (dHCA)

This section will describe how the elements above combine to form the calculation procedure. The process and inputs for the calculation are illustrated in Figure 6.11 below.

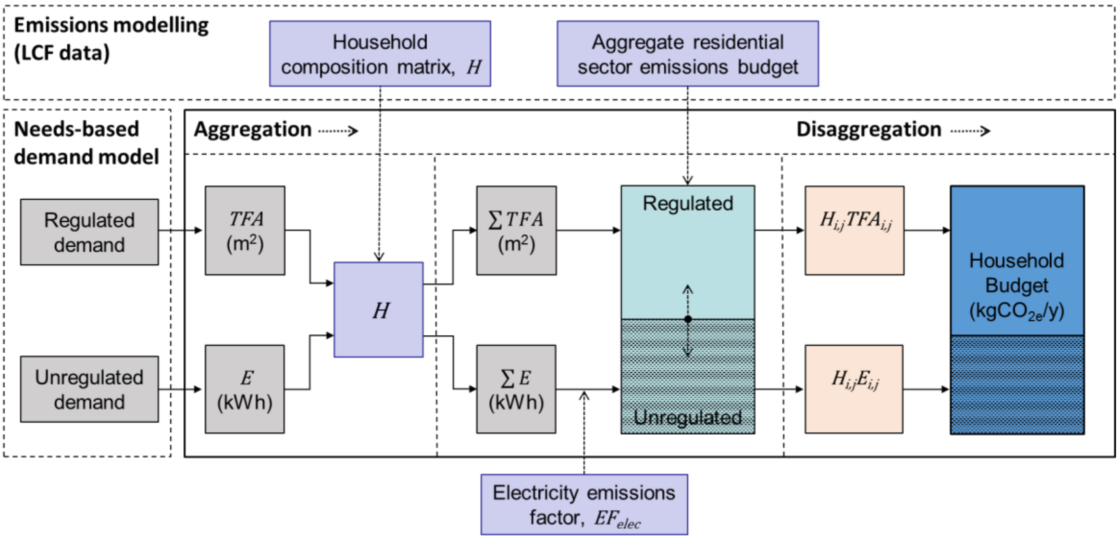

Figure 6.11 dHCA household emissions quota model, process and inputs

The background, assumptions and values underpinning the needs-based energy demand model used for the dHCA allocation method are detailed in the previous chapter. The remainder of this section details how the needs-based model and values are used to calculate household emissions quotas.

6.4.5.1 Hypothetical household energy demand

The needs-based energy demand model provides the dHCA with differentiated household requirements in the two components as detailed in the previous chapter; the proportional regulated energy demand ($Demand_{reg}$), and the unregulated energy demand ($Demand_{unreg}$). The two components are calculated for each occupancy rate in the household matrix and values stored in two additional matrices of the same format. Hypothetical regulated demand is measured by proxy as the floor area deemed to be the minimum that a household can be expected to occupy and is discussed in detail in the previous chapter. The living space for each household is calculated using the equations set out in section 5.3.6 and stored in matrix TFA. Regulated demand for a household of i adults and j children is given the notation $(TFA)_{ij}$ with units of square metres (m^2).

The hypothetical unregulated component of household demand is measured directly as energy demand in kWh. The value for each household occupancy rate is calculated using the method described in section 5.3.5 and stored in matrix E. Each value is given the notation $(E)_{ij}$ and is expressed in kilowatt-hours (kWh).

6.4.5.2 Hypothetical aggregate demand

The hypothetical aggregate demand is calculated as the product of values from the household needs-based energy demand model, matrices TFA and E, and the total number of households for each occupancy rate, stored within matrix H (see section 6.4.1). The hypothetical demand remains split into the two elements regulated and unregulated.

For households of i adults and j children, aggregate regulated demand for that household type:

$$Demand_{reg} = (H)_{ij} \times (TFA)_{ij}$$

Equation 6.7 Hypothetical regulated demand

Therefore, total aggregate regulated demand (all households):

$$Agg.demand_{reg} = \sum_{i,j=1}^{11} H_{ij} \times (TFA)_{ij}$$

Equation 6.8 Hypothetical regulated demand (aggregate)

Likewise, total aggregate unregulated demand (all households):

$$Agg.demand_{unreg} = \sum_{i,j=1}^{11} H_{ij} \times (E)_{ij}$$

Equation 6.9 Hypothetical unregaulated demnd (aggregate)

6.4.5.3 Regulated – unregulated emissions ratio

As all of the hypothetical unregulated demand is assumed to be electric - the value for emissions intensity of electricity (EF_{elec}) acts to fix the amount of the budget taken by unregulated energy demand in the allocation calculation (h). Fixing the unregulated emissions element in this way biases the calculation toward unregulated demand – where emissions intensity of energy supplied to meet unregulated demand will on average be higher than that supplied to meet regulated demand. As emissions intensity of electricity reduces over the decarbonisation period the bias will change. Other factors will alter this bias too, for example increased efficiencies in heating systems.

The model fixes the unregulated allocation as the product of emissions intensity and demand, whereas the regulated demand remains unfixed (dependent on the emissions intensity of an undefined mix of household fuels). The higher the emissions factor for electricity, the larger the proportion of overall budget taken up in meeting the unregulated demand. As the amount of unregulated demand varies between households according to a different relationship than regulated demand, the emissions factor effectively shifts the bias of the calculation between the two demand categories.

6.4.5.4 Aggregate budgets

The aggregate budgets for the two elements of household demand can be calculated following the application of the emissions intensity factor.

The unregulated budget is calculated thus:

$$Budget_{Unreg} = \sum_{i,j=1}^{11} H_{ij}\ (E)_{ij} EF_{elec}$$

Equation 6.10 Unregulated budget

The regulated budget is calculated by subtracting the unregulated budget from the overall available HCA budget (while unregulated budget is fixed):

$$Budget_{reg} = \text{Agg. budget} - Budget_{unreg}$$

Substituting for $Budget_{unreg}$

$$Budget_{reg} = \text{Agg. budget} - \sum_{i,j=1}^{11} H_{ij}\ (E)_{ij} EF_{elec}$$

Equation 6.11 Regulated budget

6.4.5.5 Differentiated Household Carbon Allocation (dHCA)

Household allocation for a single year and with an occupancy rate of i adults and j children $(dHCA)_{ij}$ is calculated thus:

$$(dHCA)_{ij} = \left[\left(\text{Agg. budget} - \sum_{i,j=1}^{11} H_{ij}\ (E)_{ij} EF_{elec}\right) \times \left(\frac{(TFA)_{ij}}{\sum_{i,j=1}^{11} H_{ij}\ (TFA)_{ij}}\right)\right] + \left[\sum_{i,j=1}^{11} H_{ij}\ (E)_{ij} EF_{elec} \times \left(\frac{(E)_{ij}}{\sum_{i,j=1}^{11} H_{ij}\ (E)_{ij}}\right)\right]$$

Equation 6.12 Household budget

6.4.5.6 Regulated emissions target

The target dwelling emission rate (DER) for a given budget year, averaged over the whole dwelling stock, in $kgCO_{2e}/m^2/year$ is calculated with the following equation:

$$DER = \frac{\text{Agg. budget} - \sum_{i,j=1}^{11} H_{ij}\ (E)_{ij} EF_{elec}}{\sum_{i,j=1}^{11} H_{ij}\ (TFA)_{ij}}$$

Equation 6.13 Regulated emissions target

6.5 Calculation of residual quotas (surplus/deficit)

Using the household emissions calculated from the LCF data and output of household allocation levels from the dHCA model, this stage of the analysis simply calculates the level of allowance surplus and deficit for each household i.e. the household's estimated emissions subtracted from the quota allocated by each method. The calculation is performed for the following allocation methods modelled by the dHCA:

i. Household Carbon Allowance (HCA); differentiated (dHCA)

ii. Household Carbon Allowances (HCA); equal-per-household allocation (EPHH)

iii. Personal Carbon Allowances (PCA); equal-per-capita allocation (EPCA) for adults only.

iv. Personal Carbon Allowances (PCA); equal-per-capita allocation (EPCAc) with an allowance for children.

6.6 Results

6.6.1 Overview

The primary aim of this analysis was to examine how the four allocation methods produce different distributions of residual household quota levels and to assess the performance of the proposed dHCA method in mitigating the distributional issue related to household size while maintaining the emissions reduction incentive. These aims are achieved by examining the estimated residual quotas of clusters of households according to a selection of household characteristics. This section will describe the results of the emissions modelling using the LCF survey data and the household quotas from the four different carbon budget allocation methods. A brief description of the distribution of household emissions is presented before describing the variables that define the household characteristics that are of interest. A detailed comparison of the residual household quotas follows. Full tabulated results are provided in Appendix 1.

6.6.2 Residential sector emissions

The aggregate emissions calculated from the LCF data are compared to DECC's end-user statistics for the residential sector (Department of Energy and Climate Change, 2014a) and also to the UK carbon budget[18] (Committee on Climate Change, 2010). Table 6.11 provides a comparison for the emissions for the period 2009 to 2012.

	2009	**2010**	**2011**	**2012**
UK (calculated - LCF) Mt CO2e	155.8	160.2	144.9	144.4
25% of UK carbon budget (interim)	143.0	141.6	140.2	138.8
DECC end-user figures	138.0	151.0	124.2	139.2
LCF % above carbon budget	9.0%	13.2%	3.4%	4.1%
LCF % above DECC figures	12.9%	6.1%	16.6%	3.7%

Table 6.11 UK residential ghg emissions 2009 - 2012, comparison of DECC end-user figures and estimated from LCF data

[18] The residential sector budget is taken as 25 per cent of the overall UK interim budget under the Climate Change Act (HM Government, 2008) as published in the 4th Carbon Budget rreport (Committee on Climate Change, 2010). It is represented as reducing year-on-year as opposed to the five-year period format of the published budgets.

Aggregate emissions estimated from the LCF expenditure survey are consistently greater than DECC's figures. The LCF estimates are between 3.7 per cent (2012) and 16.6 per cent (2011) higher than the DECC figures indicating that the LCF emissions are over estimated but follow a similar trend. The LCF estimates are also higher than the residential sectoral share of the UK carbon budget for the same period. To provide internal consistency for the redistribution and impact analysis, the LCF estimates are adopted as the budget levels for each year so as ensure that an overall quota surplus or deficit is not introduced.

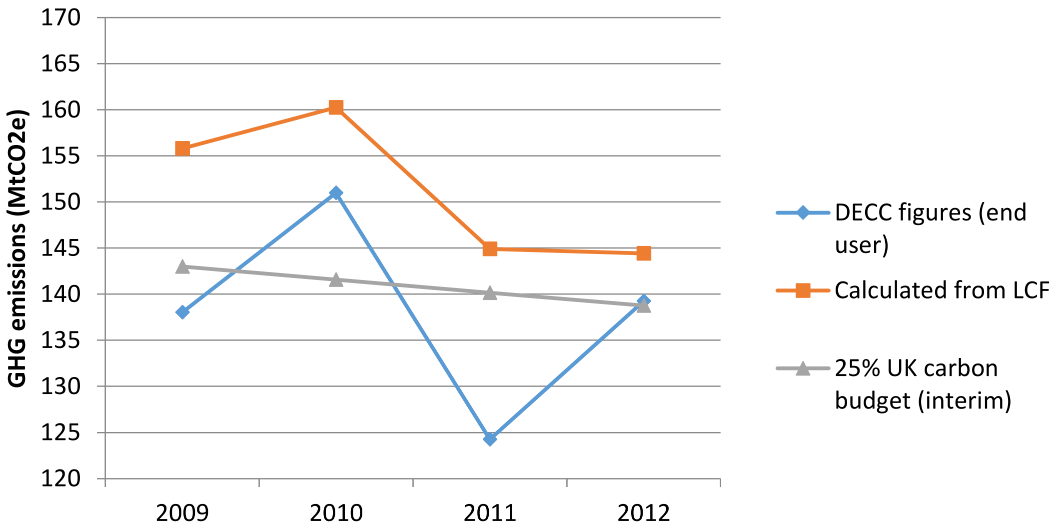

Figure 6.12 UK residential sector greenhouse gas emissions compared. Author's estimated using LCF data, DECC end-user statistics and apportioned UK carbon budget (linear reduction)

Looking at the variation of residential emissions for both the LCF estimated and DECC figures over the 4-year period, shown with residential carbon budget levels in Figure 6.12, there is an obvious problem with a strictly enforced budget reducing year-on-year. The high variability of emissions between years indicates that a banking and borrowing system would be required to allow for high consumption years. Figure 6.13 illustrates the relationship between annual winter temperature and annual heating degree days, the latter being correlated to residential space-heating demand and emissions (Palmer and Cooper, 2013).

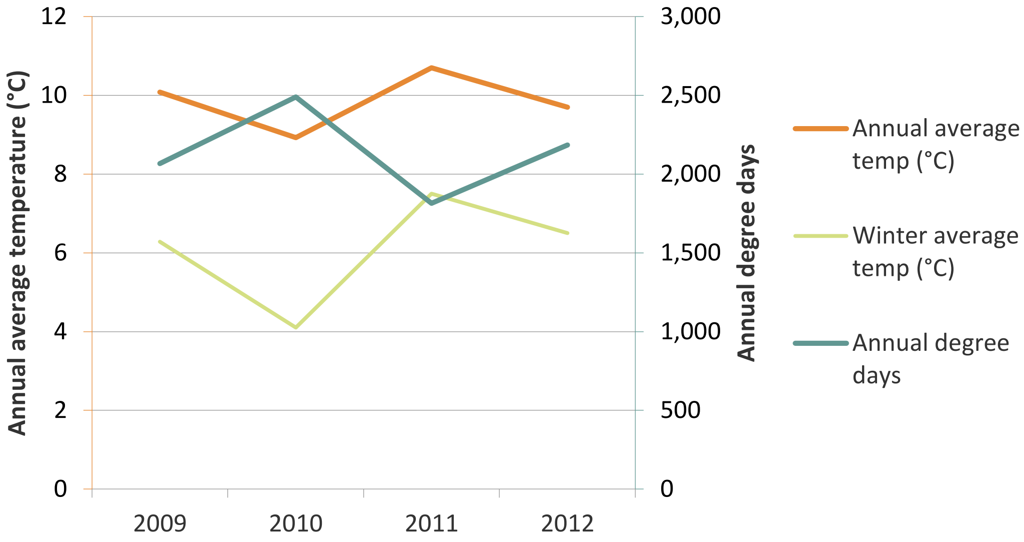

Figure 6.13 Average UK air temperatures and annual degree days 2009 – 2012 (Palmer and Cooper, 2013, Chart 5a curtailed)

6.6.3 Distribution of household emissions

The distribution of household emissions (shown in Figure 6.14 below) is positively skewed, with a long tail of households with high emissions. The chart reveals two artefacts of using expenditure data to estimate household emissions: the first is a number of households with negative emissions; the second a large number of households with zero household emissions apparent as a step in the cumulative frequency line at zero on the x-axis and the first peak in the 'kdensity' line. The kdensity function estimates the observations for a given value of household emissions and provides a smoothed histogram that better illustrates the peak in observations with zero emissions that is otherwise hidden by using a 'binned' histogram.

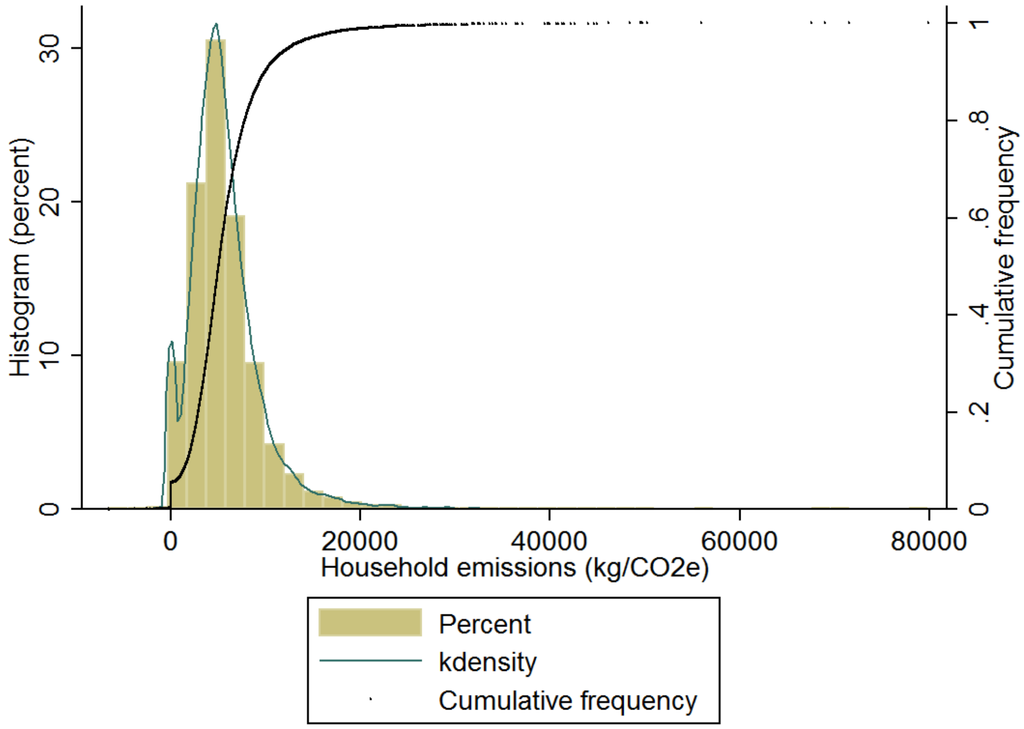

Figure 6.14 Histogram and cumulative frequency plot of household emissions estimated from LCF data (2009 – 2012)

Negative household emissions occur where credit from a fuel account is refunded to a household in the form of a rebate. This 'negative' expenditure on energy results in a corresponding negative value for emissions. Zero expenditure on household fuels can occur for two reasons; zero consumption or infrequency of purchase. In both examples, zero and negative expenditure, the error is corrected for by higher consumption in other households within the sample where the expenditure covers more fuel that would have been consumed within the data collection period. The sample is therefore representative overall and within groups (given enough observations) but not at the individual household level.

6.6.4 Household emissions

The characteristics used in the analysis are described by a selection of socio-economic variables available within the LCF dataset and are listed in Table 6.13. These characteristics have been shown in previous analyses to have significant correlations with energy use and emissions. For example: income and household composition (Druckman and Jackson, 2008); income (Roberts, 2008); income, dwelling size, tenure and central heating fuel (Büchs and

Schnepf, 2013b). Each of the variables have been tested for their association with the dependent variable (household emissions). Sub-groups defined by the independent variables were tested using the non-parametric Kruskal Wallis test in Stata. The LCF survey provides evidence that all of the independent variables considered in this analysis (shown in Table 6.12) are associated with household emissions and are significant at the 1% level (*Pr<0.01*).

Variable	Stata variable name	Type	Range	Equality of medians test
Dependent variables				
GHGtotalHH	*GHGtotalHH*	Continuous		
Independent variables				
Income (decile)	*TRincome10*	Ordinal	1 to 10	Pr = 0.000
Household size	*a049*	Ordinal	1 to 9	Pr = 0.000
Adults (number of)	*adults*	Ordinal	0 to 8	Pr = 0.000
Children (number of <16)	*TRchild16*	Ordinal	0 to 7	Pr = 0.000
Children (age)	*TRchildages*	Categorical	0 to 4	Pr = 0.000
Number of rooms in dwelling	*a111p*	Ordinal	1 to 10	Pr = 0.000
Age (working/pensioner)	*TRworking*	Categorical	0 to 9	Pr = 0.000
Pensioner status	*p365p*	Categorical	0 & 1	Pr = 0.000
Tenure (rented/owned)	*TRtenure*	Categorical	1 to 5	Pr = 0.000
Output area classification	*oac1d*	Categorical	1 to 7	Pr = 0.000
Central heating fuel	*chfuel*	Categorical	1 to 7	Pr = 0.000

Table 6.12 Variables from the LCF dataset used to define household clusters for analysis

To begin, descriptive statistics are presented for household emissions according to two independent variables of interest: household size and household income.

6.6.5 Household size

It can be seen from the results shown in the graph in Figure 6.15 and Table 6.13 (both below) that household emissions increase with household size, with the relationship holding consistently across survey years i.e. emissions for the year 2009 and 2010 are higher than for 2011 and 2012.

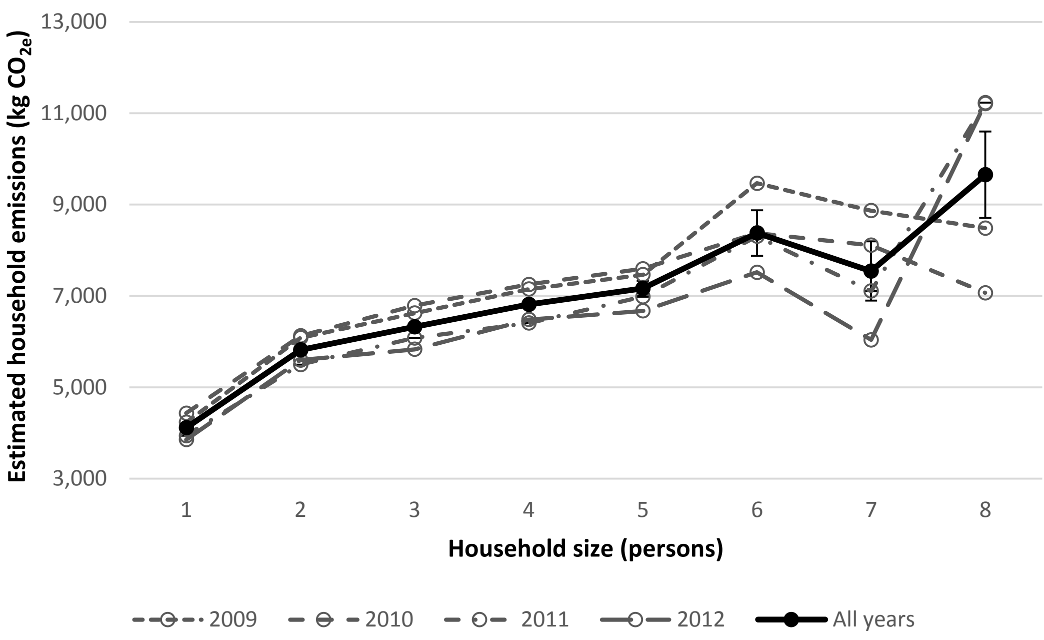

Figure 6.15 Estimated mean annual household emissions by household size and survey year, modelled using LCF data (2009 – 2012)

The increase in household emissions is greatest for the first additional household member with an increase in emissions from one person to two person households of 1819 kg CO_{2e} on average. Subsequent members (up to six person households) add smaller quantities of emissions to the household total, demonstrating the expected economies of scale related to energy use in shared households. There is an anomaly in the general trend for households of seven persons, however, as observed from the standard error bars, the lower number of observations for households with six or more members decreases the confidence of the household emissions statistics.

Household size (persons)	N	mean	sd	se(mean)	median	Lower quartile	Upper quartile
1	5066	4115	3172	44.6	3697	2322	5239
2	6992	5815	4343	51.9	5115	3564	7053
3	2921	6320	4217	78.0	5592	3964	7922
4	2421	6817	3939	80.1	6384	4528	8560
5	799	7165	4671	165.3	6550	4503	9207
6	214	8377	7303	499.2	6976	5125	10271
7	66	7546	5294	651.6	7262	4008	10230
8	21	9652	4430	966.7	8770	7100	13204
All	18507	5646	4180	30.7	4987	3268	7127

Table 6.13 Annual household emissions ($kgCO_{2e}$) summary statistics by household size, modelled using LCF data (2009 – 2012)

The skewed nature of the distribution of household emissions is apparent across household sizes, and as a result medians are consistently lower than means. Figure 6.16 displays both mean and median emissions by household size. Error bars show ± 1 standard deviation from the mean and dashed lines show the interquartile range.

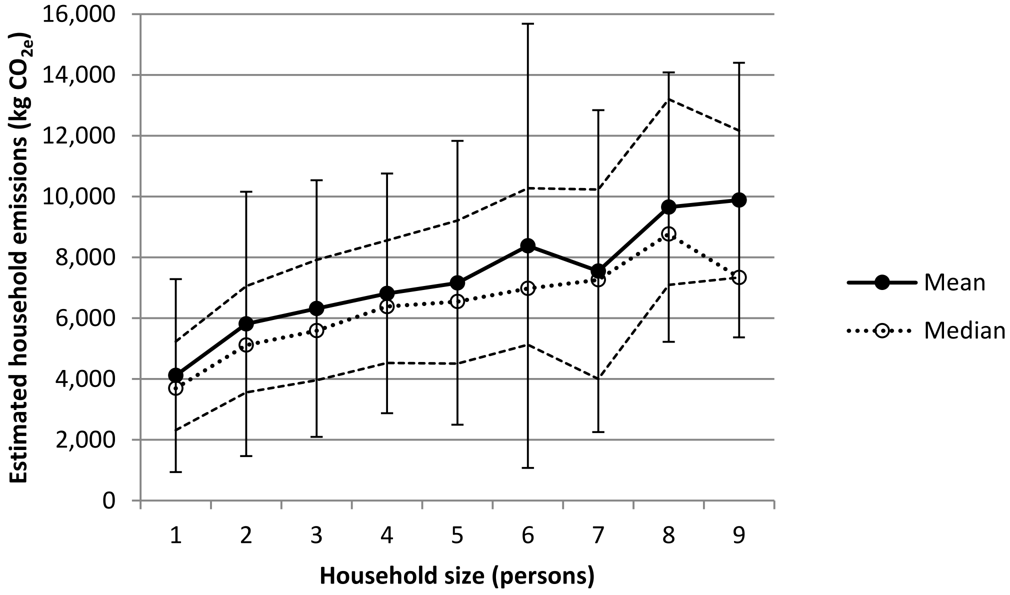

Figure 6.16 Estimated mean and median household emissions by household size, modelled using LCF data (2009 – 2012)

6.6.6 Household income

Household energy demand and emissions have been found in previous studies to be strongly associated with income (Roberts, 2008). The measure used in this analysis is the OECD equivalised household income scale. The link between household emissions and income is again confirmed (see Table 6.15).

In this analysis, the LCF sample has been divided equally into income deciles using equivalised household income. The minimum and maximum levels of income for each decile are shown in Table 6.14.

Equivalised household income decile	Minimum income (£)	Maximum income (£)
1	£0	£7,087
2	£7,089	£9,596
3	£9,597	£11,922
4	£11,922	£14,388
5	£14,390	£17,249
6	£17,250	£20,406
7	£20,408	£24,440
8	£24,441	£30,163
9	£30,165	£40,071
10	£40,072	-

Table 6.14 Income levels for equivalised household income deciles (OECD equivalence scale), LCF data (2009 – 2012)

Again, mean household emissions for each income decile are higher than the median indicating that the distribution of household emissions is positively skewed across all income deciles. Figure 6.17 displays mean and median emissions by income decile.

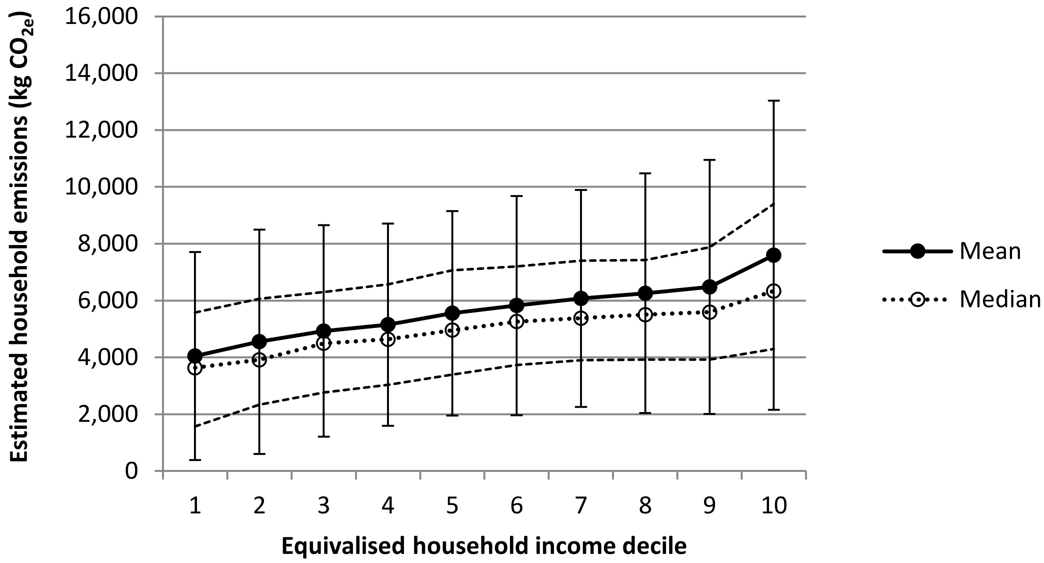

Figure 6.17 Estimated mean and median household emissions by equivalised household income decile, LCF data (2009 – 2012)

The estimated average household emissions for the lowest income decile are 4070 kg CO_{2e}, with the median approximately 10 per cent lower at 3649 kg CO_{2e}. For the households in the highest income decile, the estimated mean emissions were 93 per cent higher than the lowest income households at 7895 kg CO_{2e}. The median was 79 per cent higher than the lowest income households with a value of 6546 kg CO_{2e}. Summary statistics for all household income deciles are shown in Table 6.15.

Equivalised household income decile	N	mean	Standard deviation	Standard error (mean)	median	Lower quartile (p25)	Upper quartile (p75)
1	1786	4052	3660	86.6	3631	1569	5581
2	1846	4551	3948	91.9	3915	2340	6066
3	1868	4928	3720	86.1	4494	2760	6294
4	1911	5153	3558	81.4	4637	3033	6568
5	1884	5551	3597	82.9	4958	3391	7070
6	1875	5824	3856	89.0	5260	3727	7202
7	1861	6071	3821	88.6	5376	3900	7408
8	1841	6259	4214	98.2	5500	3920	7421
9	1812	6480	4471	105.0	5594	3928	7877
10	1823	7593	5438	127.4	6335	4297	9396
All	18507	5646	4180	30.7	4987	3268	7127

Table 6.15 Estimated emissions (kgCO_{2e}) by equivalised household income decile, summary statistics based on LCF data (2009 – 2012)

6.6.7 Household emissions quota surplus/deficit

The final stage of the modelling procedure was to calculate the household emissions quota surplus/deficit, or the 'residual' quota. This is the estimated household emissions subtracted from the household quota allocated by each of the four methods outlined in Section 6.4. Figure 6.18 below shows that each of the four distributions all appear very similar and are all negatively skewed, exhibiting long tails of quota deficit.

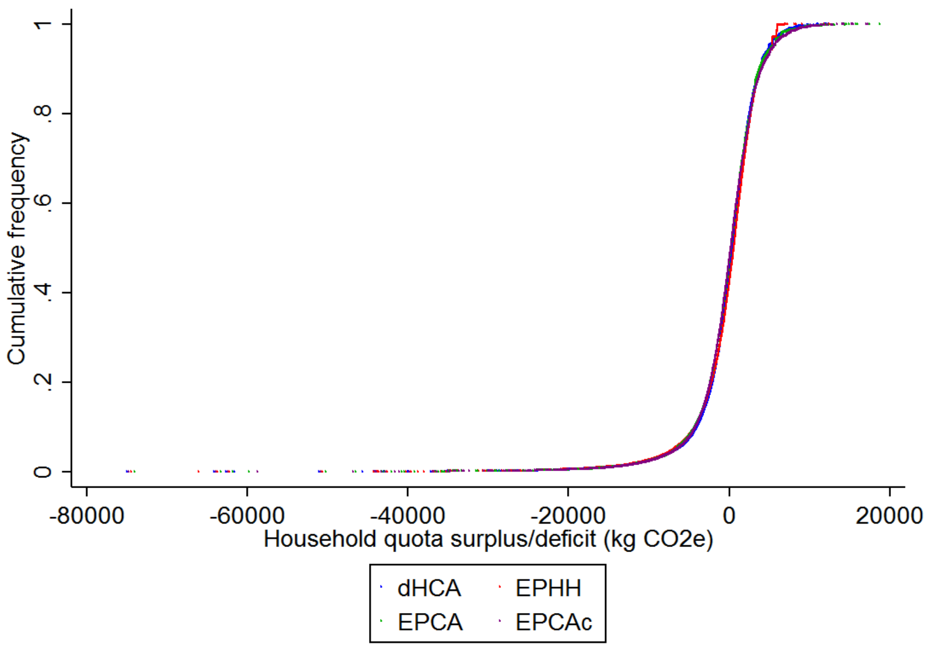

Figure 6.18 Cumulative distribution plots of household quota surplus/deficit levels

Statistics for the quota surplus and deficit distribution for each allocation method are summarised in Table 6.16. The mean residual household quotas (not to be confused with median) for all methods show that the allocation model is internally consistent, i.e. allocating the same quantity of emissions across households as the aggregate estimate for each year. The slight deviation of values away from zero can be attributed to rounding errors; 1 kg CO_{2e} per household per annum is approximately 0.02 per cent of mean household emissions. Median residual quota values are positive, due to the negatively skewed distribution, and range from 277 kg CO_{2e} (EPCA+ch) to 648 kg CO_{2e} (EPHH). The values at the 25th and 75th percentiles reveal that that the dHCA method has the smallest central spread of the four allocation methods.

	mean	se(mean)	min	max	median	p25	p75	IQR[1]
dHCA	0.80	29.90	-74876	12070	480.77	-1395	2123	3518
EPHH	0.61	30.65	-74491	12466	648.46	-1460	2364	3824
EPCA	1.28	31.29	-74060	18799	332.09	-1697	2266	3963
EPCA+ch	0.98	31.45	-74767	17315	277.45	-1720	2304	4023
Notes: [1] Inter-quartile range (p75-p25)								

Table 6.16 Summary statistics household quota surplus/deficit (kgCO_{2e}), England 2009 - 2012

The mean household quota surplus (shown in the first column of the table above) can be attributed to rounding errors. The values represent 0.011 percent of mean household emissions for the EPHH method and 0.023 percent for the EPCA. To test whether the residual quota distributions were significantly different from each other, a series of Wilcoxen signed rank sum tests were conducted. This test was used in place of the t-test due to the non-normal (positively skewed) distribution of household emissions. The dHCA result was tested against the three other methods. The results are summarised in Table 6.17 showing the number of standard deviations between the medians (Z value) and probability against chance (P value).

	Signed rank test	
Test	Z value	P value
dHCA = EPHH	-2.572	0.0101
dHCA = EPCA	30.667	0.0000
dHCA = EPCA+ch	-4.702	0.0000

Table 6.17 Summary table of statistical tests of distribution of residual quotas

The LCF sample provides strong evidence that the resulting distribution of residual household quota differs across allocation methods for all households. As the four allocation methods use varying functions of household size to distribute quotas, the pattern of residual quotas is not uniform across households or by allocation method. The remainder of this chapter will present analysis of the distribution of quota surplus and deficit across households grouped according to the variables described in the overview. Statistical tests have been carried out for each sub-group to test for significant differences between allocation methods.

6.6.8 Residual household quotas in detail

This section presents comparative analysis of the distributions of residual household quotas resulting from the four allocation methods modelled:

1. **d**ifferentiated **H**ousehold **C**arbon **A**llocation (dHCA)
2. **E**qual-**P**er-**H**ouse**H**old (EPHH)
3. **E**qual-**P**er-**C**apita **A**llocation (EPCA) adults only, and
4. **E**qual-**P**er-**C**apita **A**llocation with **ch**ildren (EPCA+ch).

Statistical tests have been carried out for each sub-group to test for significant differences between allocation methods.

6.6.8.1 Household income

Household emissions have been shown to be positively correlated with income (see section 6.6.6). As a result we would expect to see an inverse relationship when examining income with respect to residual household quotas. This is confirmed by the results presented below. All four allocation methods provide median quota surplus for the lowest income decile and deficit for the highest, and exhibit an inverse relationship of quota surplus to income. Figure 6.19 below shows the median household quota surplus and deficit across income deciles.

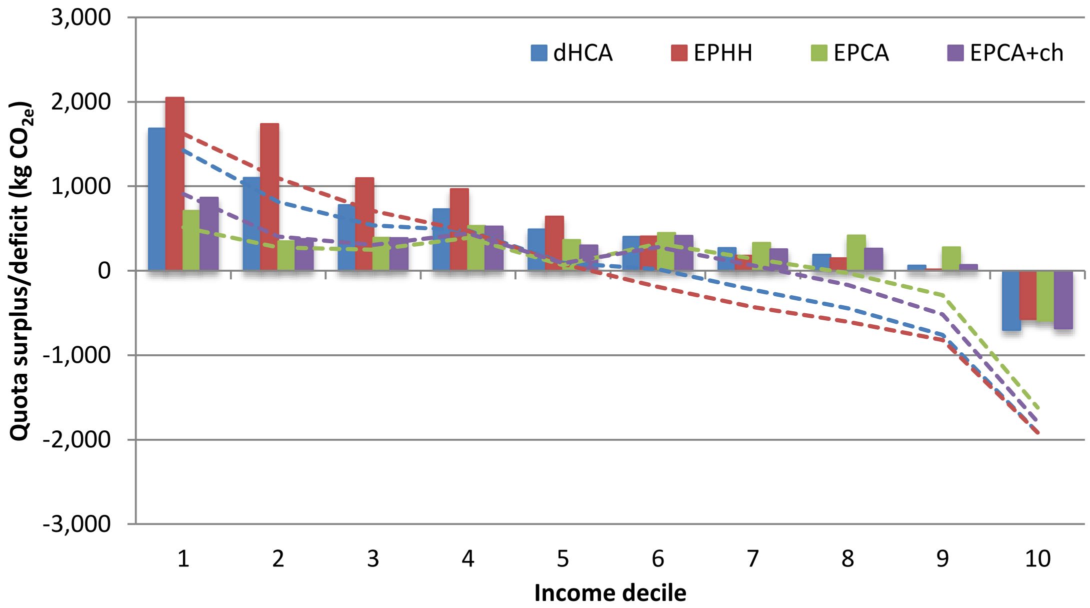

Figure 6.19 Estimated median quota surplus/deficit by equivalised income decile, modelled using LCF data (2009 – 2012)

As median values of residual household quotas are higher than the mean values and due to the wide variation between and within deciles, the pattern of redistribution across the income range is somewhat obscured. The mean values have therefore been added to Figure 6.19 as dashed lines to more clearly show the redistribution effect of emissions quotas across income deciles.

The results show that with respect to household income all allocation methods are generally progressive; redistributing from households in higher income deciles (quota deficit) to households in lower income deciles (quota surplus). The EPHH method displays the most redistributive effect, with dHCA showing slightly less impact. The two EPCA methods have the least effect.

6.6.8.2 Household size

We would expect to observe a clear difference in the relationship of household size to residual quotas between the allocation methods. The results confirm this with the two variants of EPCA displaying a positive association between household size and residual quotas while EPHH shows the reverse. The figure below presents median (bars) and mean (dashed lines) household quota surplus or deficit for groups of households determined by the number of occupants (household size). Error bars show the interquartile range.

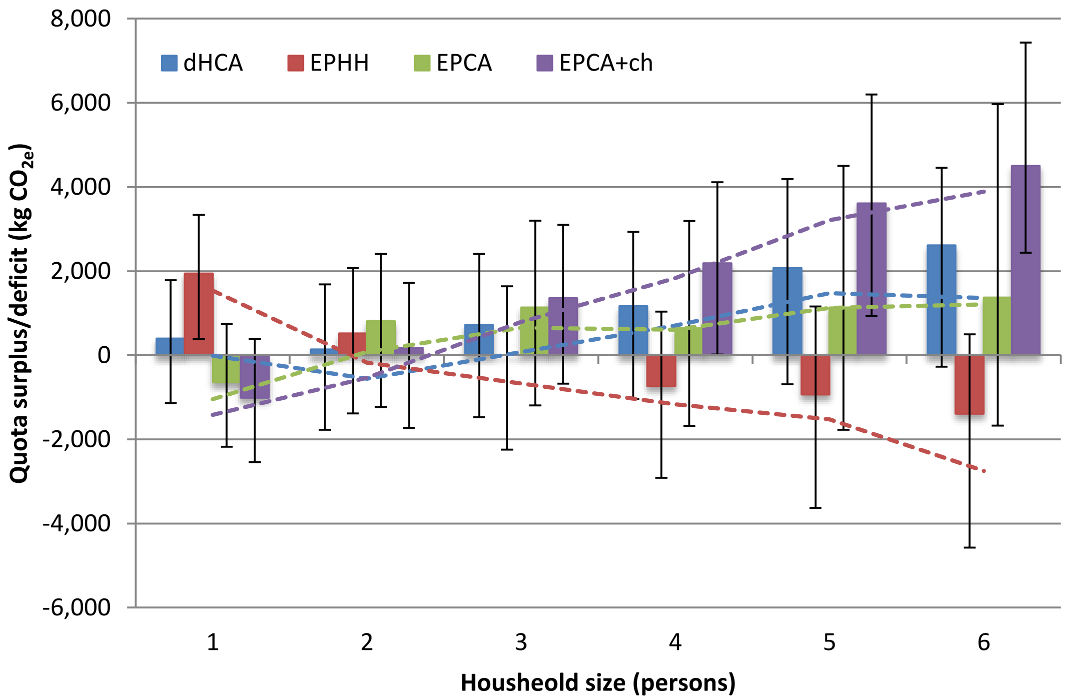

Figure 6.20 Median household quota surplus/deficit by household size

Under the EPHH allocation method, single-person households (with fewer than average occupants) receive a surplus at the median, while larger households receive a deficit that increases with the size of the household. The opposite is true for EPCA+ch with a surplus for larger households and to a lesser extent EPCA.

The aim of the dHCA method was to provide an alternative method to alter the relationship between household size and quota levels. For single occupant households the two variations of EPCA result in a median quota deficit, whereas EPHH gives a surplus at the median. The dHCA method sits between with a small surplus. The dHCA method also has the lowest impact on one person households with both mean and median values closest to zero for this method.

Two-person households generally fare best under EPCA, with EPHH second. dHCA and EPCA+ch provide small surplus at the median but with mean deficits. While two-person households receive a smaller surplus that one-person households under dHCA, the method does display a positive relationship between household size and residual quota for larger households. The increasing median surplus values lie between those for EPCA and EPCA+ch.

Households with three or more occupants are worst-off under EPHH, with quota deficits growing with household size, and best under EPCA+ch. EPCA remains relatively flat for three to six occupants compared to EPCA+ch and dHCA.

While the distribution of the number of households in each income decile is equal, the distribution across household size is not. Table 6.18 contains the number of households represented by each group of households by size.

Household size (number of persons)	Number of obs in LCF	Percentage of households	Cumulative percentage
1	5,066	28.7	28.7
2	6,992	35.6	64.3
3	2,921	16.3	80.6
4	2,421	13.2	93.8
5	799	4.5	98.3
6	214	1.2	99.5
7 or more	94	0.5	100.00

Table 6.18 Distribution of households by size, LCF data (2009 – 2012)

According to the LCF survey, nearly 94 per cent of all households in England comprised four persons or fewer for the period 2009 to 2012, with 29 per cent single-person households. The proportion of households by size should be considered when taking into account the impact of each allocation method.

6.6.8.3 Dwelling size

Figure 6.21 below presents the results for residual household quota by dwelling size. Dwelling size is measured using the proxy of the number of rooms in sole use by the household, thereby excluding shared spaces.

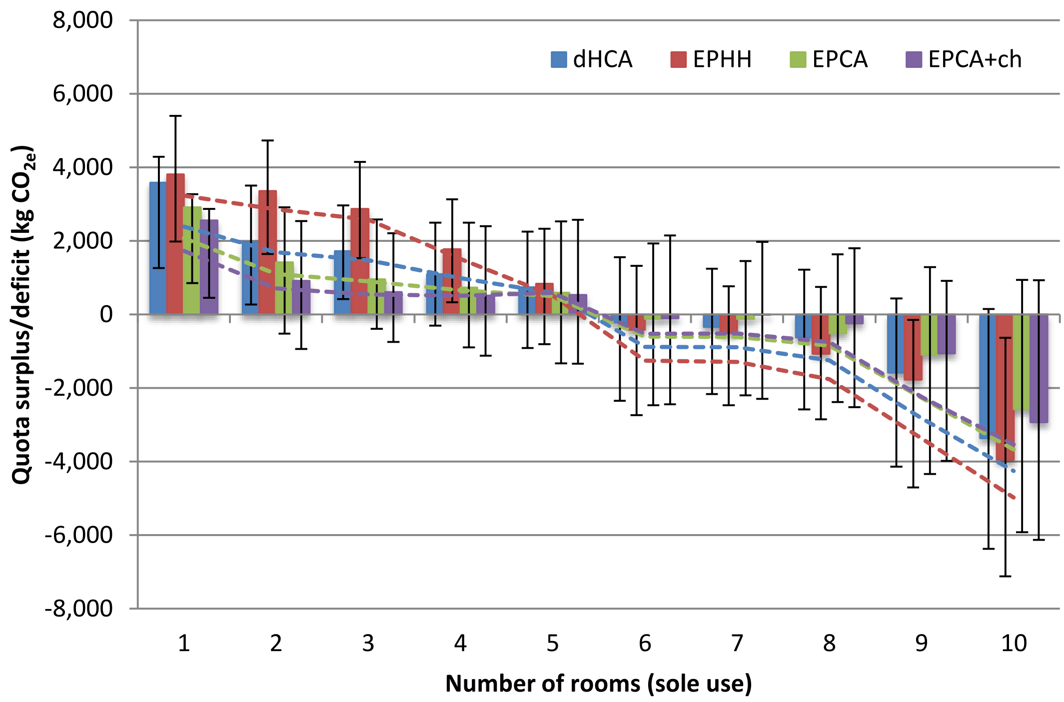

Figure 6.21 Median household quota surplus/deficit by number of rooms, modelled using LCF data (2009 – 2012)

As dwelling size is positively associated with household emissions we would again expect all allocation methods to display a negative correlation between dwelling size and median residual quota levels.

Under all four allocation methods smaller homes receive a surplus and larger homes a deficit. The most redistributive method, with largest surplus and deficit values across dwellings, is the EPHH method, followed by dHCA with the two variants of EPCA being the least redistributive.

6.6.8.4 Common household types

Further than the relationships by 'basic' household characteristics such as income, household size and dwelling size, we are interested in the differential impact across different household types with combinations of these and other significant characteristics.

Analysis was performed of several common household types defined by composition and age (also as a general proxy for working status). Three groups of households were defined: working age without children, pensionable age without children and working age with children. The groups were then sub divided into households with a one adult (single) or two adults (couple). Working age households contain adults between the ages of 18 and 65 for men, and 18 and 60 for women. Pensioner households contain only adults over 60 years of age for women and 65 for men. For pensioner couple households both members were of pensionable age or older.

Table 6.19 shows the number of cases in each of the six household types and the proportion of households represented. These households taken together represent just below 80 per cent of the households covered by the LCF survey.

Household description	Frequency	Proportion of households
single, working age, no children	2,445	13.79
couple, working age, no children	3,088	17.45
single, pensioner, no children	2,621	14.90
couple, pensioner, no children	2,312	10.17
single, working age +children	1,016	4.53
couple, working age +children	3,581	18.63
Total	**15,063**	**79.46**
All cases	18,507	

Table 6.19 Frequency of household types, LCF data (2009 – 2012)

Looking at the household quotas allocated by the dHCA method for these six household types, the **mean** dHCA quota values varied as follows:-
For single person households, dHCA allocates a smaller quota than EPHH (by 1549 kg but larger than EPCA and EPCA+ch by 1037 kg and 1408 kg respectively.
For two-person households, dHCA provides a smaller allocation than the three other methods: EPHH by 387 kg, EPCA by 867 kg and EPCA+ch by 126 kg.

For single-parent households, dHCA provides the largest quota, 500 kg larger than EPHH, 3083 kg larger than EPCA and 1053 kg larger than EPCA+ch.
For two-parent households, 1682 kg larger than EPHH, 1202 kg larger than EPCA and 521 kg smaller than EPCA+ch.

The chart below illustrates the difference in quota levels by allocation method. Values above zero indicate that the method allocated a larger quota than dHCA, and below zero smaller quotas.

Figure 6.22 **Variations in quota levels (relative to dHCA) by method, modelled using LCF data (2009 – 2012)**

Figure 6.23 below shows the median quota surplus and deficit levels for each household type, in which we can see the pattern above appear.

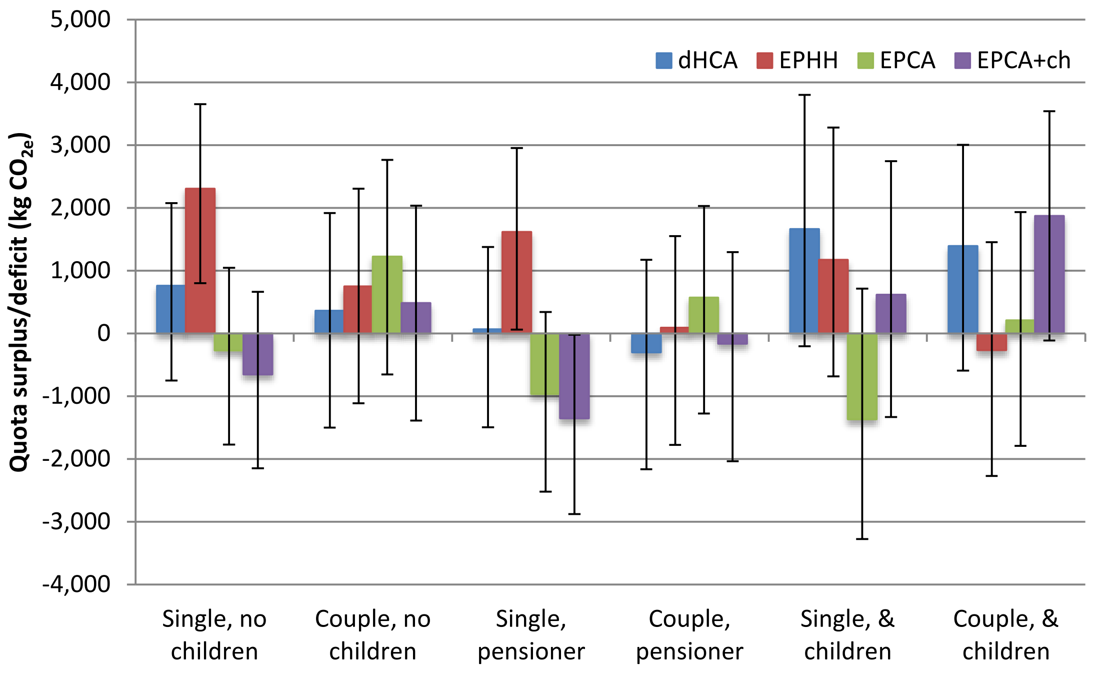

Figure 6.23 Median quota surplus/deficit by household type, modelled using LCF data (2009 – 2012)

The dHCA method clearly exhibits a different distributive effect across these household types when compared to the other allocation methods. Single adult households are generally positively affected with a change from EPCA to dHCA, and two-adult households generally negatively affected. The distribution of emissions within these broad household types is also determined by other variables, for example, there is a large variation within each group according to equivalised household income.

6.6.8.4.1 Working age households, no children

For single-adult households, dHCA results in higher median quota levels than both variants of EPCA but lower than EPHH. For households occupied by two adults the dHCA methods provides the lowest median quota levels.

Dividing each household type into income quintiles reveals that the effect of income is to increase residual quota levels for lower quintiles and reduce levels for higher quintiles. For single, working-age households in the 1st quintile, all allocation methods result in a median quota surplus with EPHH the highest (3156 $kgCO_{2e}$) and EPCA+ch the lowest (233 $kgCO_{2e}$). For the 5th quintile, all methods except EPHH result in a median quota deficit; EPHH (1687 $kgCO_{2e}$) and EPCA+ch (-1336 $kgCO_{2e}$).

For couple households of working age, all allocation methods result in a median quota surplus for all income quintiles up to and including the 4th. For this household type EPCA provides the highest surplus; from 1841 $kgCO_{2e}$ in the 1st quintile reducing to 515 $kgCO_{2e}$ in the 5th. The dHCA method provides the lowest median residual quotas reducing from a 1000 kg surplus to a 327 kg deficit in the 5th quintile.

6.6.8.4.2 Pensioner households

The distribution for single pensioners is similar in pattern to households of working age, however the increased emissions of this group results in lower surpluses and higher deficits. Again, dHCA results in higher quota levels than both variants of EPCA but lower than EPHH. In the 1st quintile, only EPHH and dHCA methods result in a median quota surplus (2191 and 656 $kgCO_{2e}$ respectively). At the 5th quintile, only EPHH results in a median quota surplus (784 $kgCO_{2e}$). The EPCA+ch method provides the lowest median residual quotas with a deficit increasing from 747 kg surplus in the 1st quintile to 2188 kg in the 5th quintile. For couple pensioners, the pattern also follows that of working age households but with all methods resulting in a median quota deficit in the 5th income quintile. For this household type, EPCA produces in the most favourable quotas and dHCA the least, closely followed by EPCA+ch.

6.6.8.4.3 Households with children

For single adult households with children (Figure 6.24), dHCA provides the highest mean quota surplus of the four allocation methods with a median surplus across all income quintiles (2390 reducing to 814 $kgCO_{2e}$). EPHH also provides a median quota surplus for all income quintiles. EPCA+ch provides a surplus for the 1st to 4th quintiles. The EPCA method results in a median deficit for all income quintiles (358 increasing to 2057 $kgCO_{2e}$).

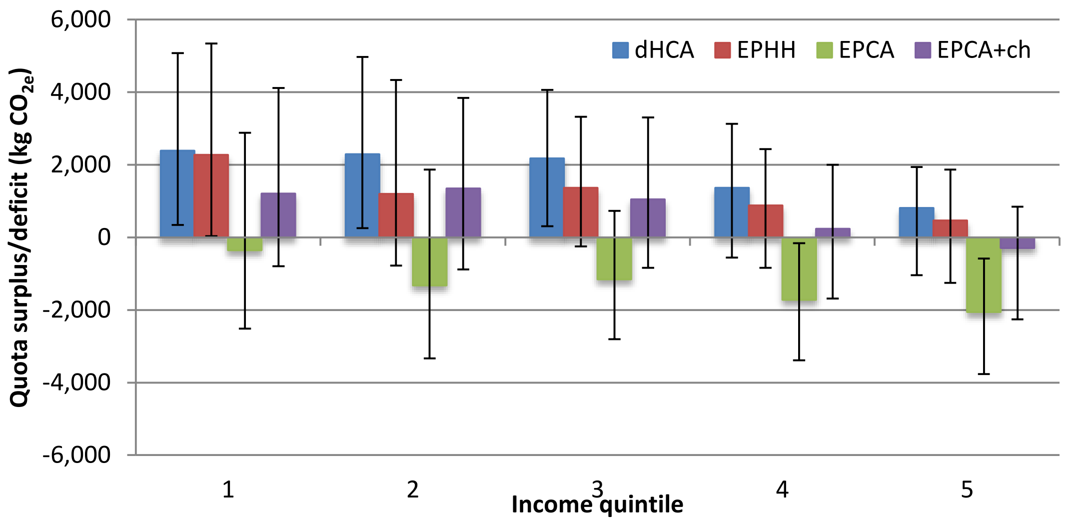

Figure 6.24 Quota surplus/deficit levels (single parent households) by income quintile

For couples with children, EPCA+ch provides the highest mean quota surplus of the four allocation methods, with dHCA second. Both methods produce a median surplus across all income quintiles. EPHH provides the least favourable quotas for this group.

For single parents with one child, the allocation method most likely to be favourable would be EPHH followed by dHCA. For single parents with 3 or more children, dHCA is more likely to be favourable, followed by EPCA+ch. For two-parent families, the pattern of redistribution is more consistent in terms of the number of children. EPCA+ch is most favourable, closely followed by dHCA. EPHH is the least favourable for this household type.

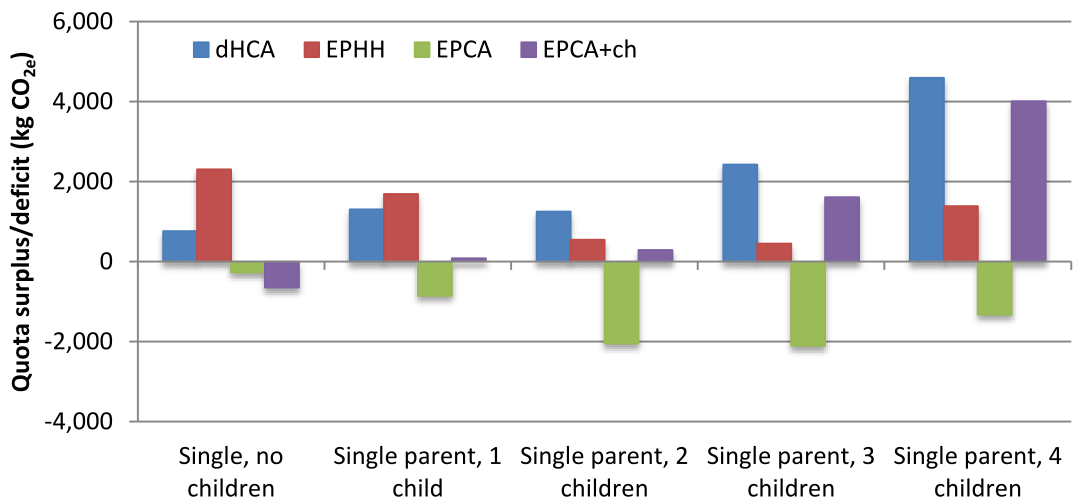

Figure 6.25 Quota surplus/deficit levels (single parent households) by no. of children

6.6.8.5 Other grouping variables

6.6.8.5.1 Tenure

Presented in Figure 6.26 below are quota surplus and deficit values for households grouped by tenure. All allocation methods result in median values for quotas in surplus for rented homes with levels varying by allocation method and type of landlord (local authority/housing association versus private). Values for householders with a mortgage are a small surplus with the exception of the EPHH allocation method with a small deficit at the median. Householders owning their homes outright are most likely to have a quota deficit for the dHCA, EPCA and EPCA+ch allocation methods. These results indicate that the dHCA method produces distributional effects in line with the other allocation methods and does not produce the largest quota surplus or deficit in any of the tenure categories.

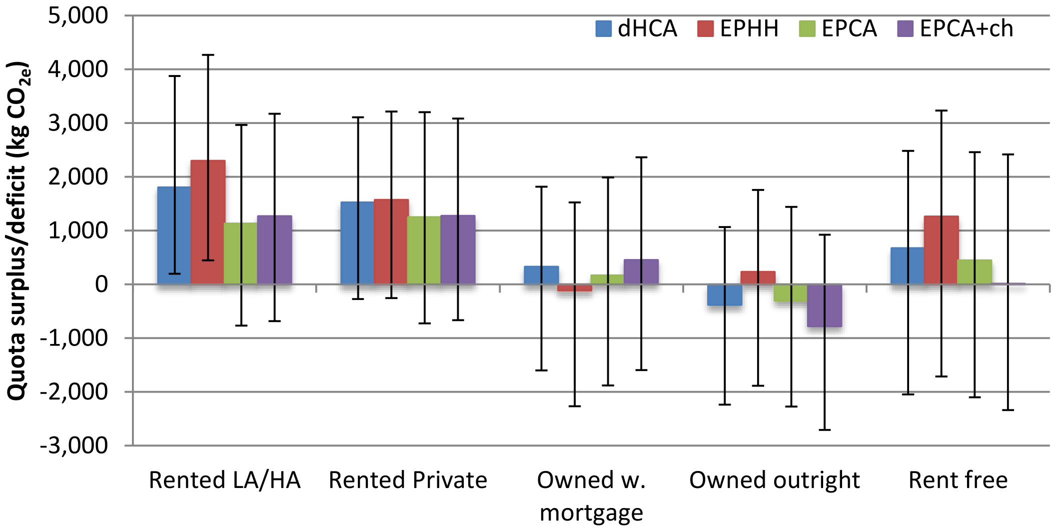

Figure 6.26 Median household quota surplus/deficit by tenure for English households, modelled using LCF data (2009 – 2012)

Fuel	N	Proportion of households	In btm quintile	In top quintile	Ave. hh size	Ave. children	Ave. rooms
Rented (LA/HA)	3,075	17.14	50.4%	1.4%	2.19	0.55	4.24
Rented (private)	2,472	15.02	25.4%	17.8%	2.41	0.53	4.56
Owned w. mortgage	6,467	34.76	5.8%	33.9%	2.82	0.69	5.60
Owned outright	6,278	31.82	16.3%	16.1%	1.91	0.10	5.63
Rent free	215	1.25	27.1%	13.8%	1.99	0.28	5.10
All cases	**18,507**	**100.00**	**20.0%**	**20.0%**	**2.35**	**0.45**	**5.21**

Table 6.20 Characteristics of English households by tenure, LCF data (2009 – 2012)

6.6.8.5.2 Central heating fuel

Considering households by central heating fuel type, one would expect those heated by oil to be worse off under all allocation methods, due to high emissions of oil per kWh of heating delivered (domestic heating oil has approximately 45 per cent greater emissions). From the household characteristics (Table 6.21), this group has larger than average dwellings (more rooms), slightly larger household size, and a lower proportion of this group are in the lowest income quintile. By contrast, the households with heating provided by solid fuel have more of their group in the lowest income quintile (23.6 per cent) and fewer in the highest quintile (just 8.8 per cent). Households heated by electricity are notably smaller, both in terms of occupants and number of rooms and have the largest proportion of any group in the lowest income quintile. Again, these results indicate that the dHCA method produces distributional effects in line with the other allocation methods according to groups of households defined by central heating fuel (Figure 6.27).

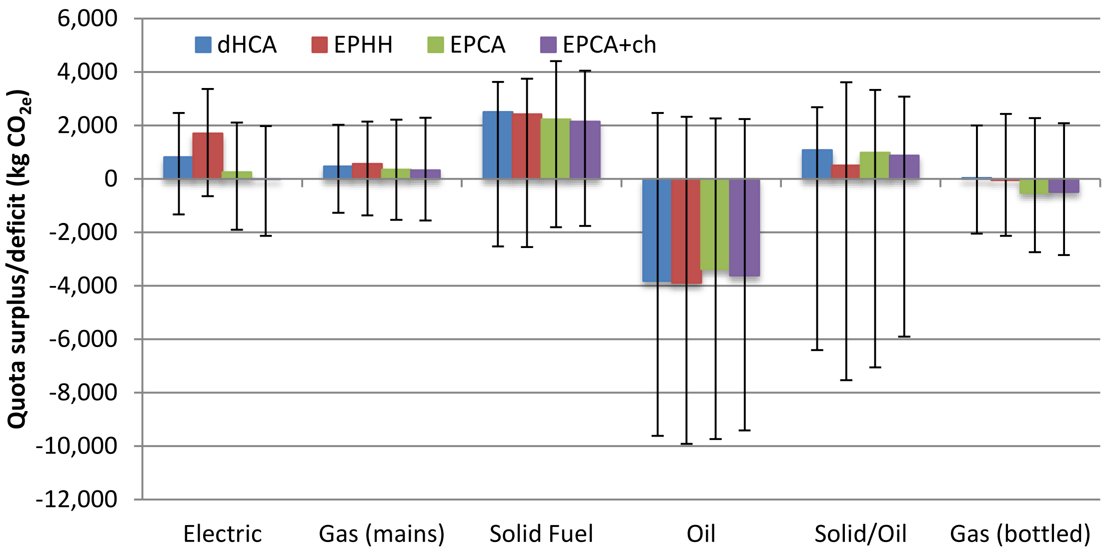

Figure 6.27 Median household quota surplus/deficit by heating fuel, modelled using LCF data (2009 – 2012)

Fuel	N	Proportion of households	In btm quintile	In top quintile	Ave. hh size	Ave. children	Ave. rooms
Electricity	1,246	7.17	31.0%	13.9%	1.74	0.20	4.17
Mains gas	15,241	82.18	19.1%	20.5%	2.42	0.48	5.29
Solid Fuel	117	0.60	23.6%	8.8%	2.40	0.28	5.41
Oil	894	4.42	10.7%	31.4%	2.48	0.43	6.05

Solid fuel and oil	58	0.31	11.4%	19.7%	2.27	0.25	6.38
Bottled (tanked) gas	122	0.59	18.1%	22.7%	2.07	0.26	5.45
Other/missing	829	4.73					
All cases	**18,507**	**100.00**	**20.0%**	**20.0%**	**2.35**	**0.45**	**5.21**

Table 6.21 Characteristics of English households by central heating fuel, LCF data (2009 – 2012)

6.6.8.5.3 Output area classification (super groups)

Looking at the characteristics of the output area classification groups, these results are what we would expect to see.

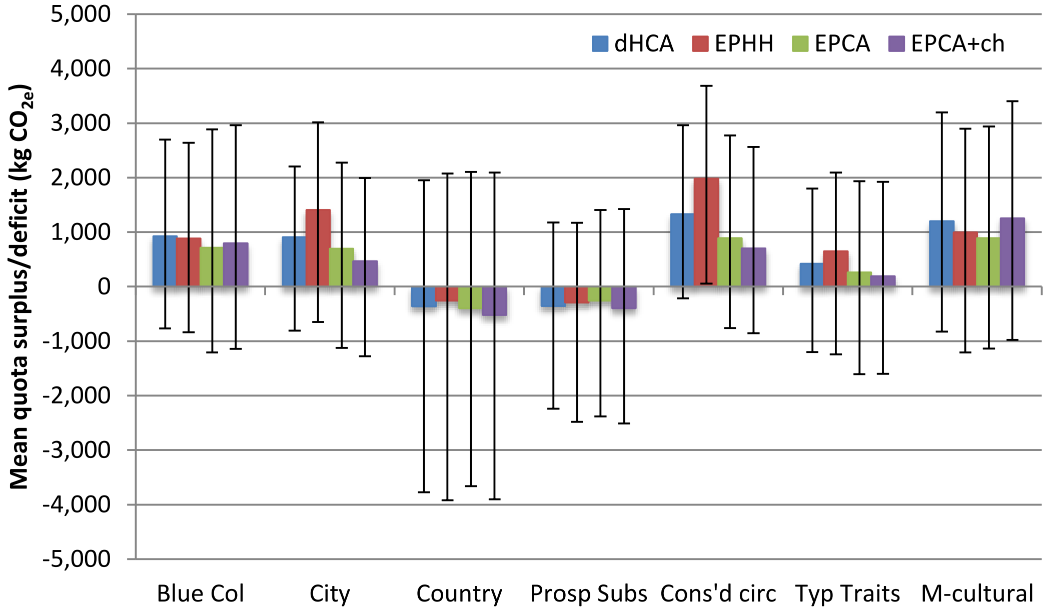

Figure 6.28 Mean household quota surplus/deficit by output area classification, modelled using LCF data, England (2009 – 2012)

Fuel	N	% of house-holds	In btm quintile	In top quintile	Ave. hh size	Ave. children	Ave. rooms
blue collar communities	2,867	15.10	27.2%	8.5%	2.51	0.59	5.13
city living	904	5.52	15.9%	35.3%	2.06	0.28	4.47
countryside	2,213	11.17	13.5%	26.4%	2.35	0.38	5.72
prospering suburbs	3,328	17.10	9.3%	28.5%	2.43	0.41	5.82
constrained by circumstances	1,815	9.89	36.2%	7.8%	1.96	0.34	4.43
typical traits	3,556	18.94	15.1%	21.4%	2.29	0.43	5.26
multicultural	1,530	9.72	32.0%	16.1%	2.72	0.66	4.78
missing	2,294	12.57					
All cases	**18,507**	**100.00**	**20.0%**	**20.0%**	**2.35**	**0.45**	**5.21**

Table 6.22 Characteristics of English households by output area classification, LCF data (2009 – 2012)

6.6.9 Summary

The analysis of the household emissions estimated from expenditure data contained in the LCF survey (2009-2012) and resulting residual quota levels is summarised below. While the median values provide a useful measure to compare the allocation methods and the *likelihood* of a household receiving a surplus or deficit, the large variation in household emissions (and residual quotas) within groups should be borne in mind while reading the following results. Examination of the three basic household characteristic variables reveals the following findings:

With respect to household income dHCA, in common with all four allocation methods, redistributes from higher income households to lower income households. The dHCA method allocates a distribution of quotas that provides the second largest differential of surplus to deficit across household income deciles, larger than both variants of EPCA but smaller than EPHH.

In terms of household size, dHCA is the most neutral of all the allocation methods for one-person households (measured at the mean and median). This method is also the most neutral for two-person households when using the median residual quota value. While providing a smaller surplus than EPCA+ch for larger households, the dHCA method is not consistently the most neutral. Examining median values for quota surplus and deficit across the distribution of household size, the dHCA method provides results that fall between the most redistributive method, EPHH, and the least, the two variants of EPCA.

Finally, looking at the effect on the six common household types, pensioner households are generally worse off under any allocation method than a working-age household of equivalent size due to their higher household emissions. For single-person households, the median surplus under the dHCA method for those of working-age reduces to a small deficit for single pensioners. As noted above, single-person households (including pensioners) are better off under dHCA than either variant of EPCA. For single parents with more than one child the dHCA method produces the largest median quota surplus values of all methods. For two-person households, dHCA results in lower median residual quotas than all other methods. For two-parent households with children the dHCA quota moves from worst to a close second place behind EPCA+ch.

7. Discussion

7.1 Overview

The content of this chapter will be presented in three parts. The first begins by presenting the realities of household energy use within which DCAT is positioned: in the context of pre-existing inequality and poverty. It will describe how energy poverty frames both climate change mitigation and domestic energy policy in the UK (7.2.2), and has played a significant role both in the evaluation of PCT in the UK and subsequent development (7.2.3).

This section will begin by outlining the impact of this issue on the response to distributional impacts of EPCA and attempts to develop an alternative allocation regime. Previous work on modifying household quotas has prioritised mitigating the impact of EPCA upon vulnerable households over consistency with the environmental aims of the policy (7.2.4). Two main limitations will be identified with this work: the choice of factors qualifying for additional emissions rights, and the method with which the modified quotas are calculated. Both limitations provide useful insights into the evaluation of differentiated allocation regimes. Linking to the theoretical foundation of the needs approach, I will argue that calculating modified quotas using measured energy demand is problematic due to the distinction between measured energy demand and household energy requirements.

The needs-approach of the dHCA method responds to the tensions that exist between emissions reduction and responding to fuel poverty, providing an integrated approach to these two policy drivers. In order to evaluate this approach to allocating emissions-rights an extended theoretical framework is required. In section 7.2.7 this extended framework is presented. First, the limitations of using measured energy demand are set out before an expanded conceptual view of the delivery of household energy services is described. The following section illustrates how this expanded conceptual view of energy service delivery, and within it the notion of needs for energy services, translates to Sen's capability approach to wellbeing. The final sub-sections describe examples that highlight the analytical distinctions provided for in the framework, thereby demonstrating its relevance in evaluating the treatment of household and dwelling characteristics that are considered for additional quotas.

The discussions will then return to fuel poverty (section 7.2.8) with an examination of how the fuel poverty indicator statistics provide an example of the application of a needs-based approach in UK energy policy. The relevance of the indicator, and its limitations, will be related back to the needs-capabilities framework for assessing of energy service needs. To conclude the first part of the chapter, the dHCA model will be presented as the previously missing normative measure that allows existing household energy modelling tools to respond to the task of measuring the energy needs in a methodologically consistent way.

The second part of the chapter, section 7.3, contextualises the results of the microsimulation. The dHCA model is presented relative to the existing distribution of households within dwellings in England over the period 2009 – 2012. Using the English Housing Survey (EHS) dataset, the dHCA is positioned with respect to existing dwelling sizes, revealing that the model reflects a reduction in overall living space for households, and that the size of the reduction varies according to household size. From this comparison, aggregate statistics are used generate high-level figures showing the extent to which the dHCA model represents a reduced consumption scenario. Further, implications are drawn for dwelling energy efficiency targets.

The chapter concludes by examining the implications of adopting the dHCA methodology for the feasibility of PCT in the UK (7.4). This section returns to the themes identified in Chapter 3 in order to draw some general implications of adopting dHCA on the design, operation, impact and feasibility of a DCAT scheme to control emissions from residential energy use.

7.2 Reconciling environmental and social policy aims

7.2.1 Overview

Two policy aims are particularly relevant in considering DCAT policies: environmental, i.e. climate change mitigation through emissions reduction; and social, i.e. the protection of human wellbeing through affordability of energy services (Walker and Day, 2012; Schaffrin, 2014). These aims are often seen to be in tension but commonalities can also be identified in responding to both (Ürge-Vorsatz and Tirado Herrero, 2012). This first part of the discussion will focus on this tension and how energy poverty has framed the evaluation of distributive impact of PCT in the UK. It will examine the trade-offs evidenced in a study responding to social concerns at the expense of consistency in treatment of environmental goals. The dHCA, and the needs-based approach, will be presented as a response to the challenge of an integrated response to the two policy imperatives. Furthermore, an extended theoretical framework will be described that provides for an evaluation of DCAT policy aimed at integrating the two policy aims.

7.2.2 Climate mitigation in the context of energy poverty

The problem of energy poverty has been a major driver in domestic energy policy. Energy poverty, more commonly referred to as 'fuel poverty' in the UK, is connected to the interaction of three components: the ability to pay (i.e. income or wealth), the price of energy and the efficiency of energy service delivery systems (Walker and Day, 2012).

The problem in the context of climate change is that policies attempting to mitigate fuel poverty by targeting the affordability of energy, for example, through increasing ability to pay (e.g. winter fuel payments) or lowering energy costs (e.g. social energy tariffs), also have the effect of increasing energy demand and emissions. Conversely, market-based instruments aimed at incentivising emissions mitigation are likely to exacerbate the problems of inequality and worsen fuel poverty in the UK (Ürge-Vorsatz and Tirado Herrero, 2012). The problem is described concisely by Walker and Day:

> Whilst fuel poverty is a problem of energy underconsumption, it is occurring within an overall climate of energy overconsumption and the

> two issues must be addressed in an interconnected way. Without this, the justice of reducing fuel poverty may be overshadowed by consequent exacerbation of global social and climate justice. (Walker and Day, 2012, p.75)

The two policy drivers, of large scale decarbonisation and reducing energy poverty, can therefore often be seen to be in tension and the trade-offs between policies and impact on vulnerable groups are often forefront in any analysis (Ürge-Vorsatz and Tirado Herrero, 2012). Despite this tension, synergies between the goals also exist: improving the energy efficiency of dwellings reduces the energy requirements of households, both reducing fuel poverty and emissions of greenhouse gas emissions. The policy impact on vulnerable groups is generally measured through evaluation of the redistributive effect, which must be weighed against the original environmental aims of the policy as Jacobs (1991) notes:

> These distributional effects make it extremely important that environmental policies are assessed on more than simply their environmental consequences. Environmental protection needs to go hand in hand with social protection, so that the costs of meeting sustainability targets fall equitably (Jacobs, 1991, p.175).

In other words, the social and environmental aims must be reconciled. Jacobs suggests that there are two ways in which to tackle the distributional impacts of environmental policies:

> One is to design environmental policies without any consideration of distributional issues, and then compensate those who lose out through reductions in (other) taxes or increases in welfare benefits (Jacobs, 1991, p.175).

Gough (2013) calls these compensatory measures ‘countervailing policies’ (for examples of this approach see Dresner and Ekins, 2004; White and Thumim, 2009; Gough, 2013). The other way, Jacobs suggests, “...is to integrate the social and environmental targets in the original design of the policies, ensuring from the start that the distributional effects are equitable.” (1991, pp.175)

Gough claims that integration is a more desirable option and that “...the future will lie with novel forms of policy integration. Alongside ‘traditional’ social policies, new pro-active, investment focussed 'eco-social policies' will need to be developed" (2013, pp.192). Schaffrin (2014) describes the orientation of such policies should be "to provide comfort and a minimum standard of living for the energy poor while at the same time stimulating energy conservation by both lower and higher income groups" (Schaffrin, 2014, p.23).

Energy poverty is of interest when thinking about fair shares of energy emissions as it brings the concerns of affordability and the inequalities of access and consumption to the foreground. While fuel poverty is concerned with energy affordability in terms of monetary budgets, PCT is concerned with affordability in terms of emissions budgets. The fuel poverty problem has played a significant role in the evaluation of PCT and is examined in the next section.

7.2.3 Redistribution and fuel poverty under EPCA

Fuel poverty is one issue that has framed the UK Government's analysis of PCT and has provided a narrow lens within which the policy has been evaluated. Individuals are considered to be at risk of fuel poverty when low household income is combined with high energy costs (the definition is discussed in more detail in a following section). Through the lens of fuel poverty, PCT has been viewed in terms of its negative impact on vulnerable groups, i.e. those in fuel poverty or at risk of being pushed into fuel poverty. In their study into the distributional impact of PCT, Thumim and White paid special attention to identifying 'vulnerable losers': households with low incomes and high emissions, and therefore insufficient quotas to meet their emissions. Characteristics of the vulnerable households included those in rural areas (where hard to heat homes are often heated using high emissions intensity oil) and under-occupying households (where large dwellings are occupied by small households). Despite modelling a scheme including emissions from private transport, the authors note that household deficits were related to central heating fuel rather than transport fuel. They draw parallels between the characteristics of these households losing under PCT and those in fuel poverty suggesting that:

> …interventions might be necessary in order to limit or remove this negative impact. These interventions might include specific initiatives

> to tackle under-occupancy, the thermal performance of rural homes, and the carbon-intensity of their heating fuels. (Thumim and White, 2008, p.6).

These 'vulnerable' households were identified in the pre-feasibility policy evaluation work commissioned by Defra as cause for concern from two perspectives. The first, that PCT would have a detrimental impact, and second, that concerns over vulnerable households by the public affected attitudes toward a scheme, and were linked to the notion of fairness. Mechanisms were offered as methods that might be used to tackle the concerns over distributional impact, such as "…scheme design, allocation methodology or through other measures, such as the existing benefits system" (Defra, 2008b, p.2). The same research highlighted that if concerns over vulnerable groups were addressed, public perception of PCT would likely improve (Defra, 2008b, p.15).

Responding to Defra's analysis of redistributive impact and drawing from their own research into public attitudes towards PCT, Bird and Lockwood (2009) also identify the links between considerations of protecting vulnerable households; circumstantial factors for high emissions; and the perceived fairness of PCT by the public (some households need larger quotas than others). However, despite claiming that a follow-up study would "carry out further analysis looking at how far some of these brute luck factors could be addressed" (Bird and Lockwood, 2009, p.37), their linking of these issues did not lead to a systematic treatment of circumstantial factors or an understanding of how these issues might be successfully integrated. Instead, a limited exercise in mitigating the negative impact of PCT on low income households was commissioned (White and Thumim, 2009). The following section examines the limitations of the mitigation study.

7.2.4 Mitigating the negative impact of EPCA

Following their own initial investigation of the distributional effect of PCT, White and Thumim investigated methods "for moderating the negative impacts of a personal carbon allowance system on low income households" (2009, p.2). The study examined two methods for mitigating against the impact of PCT on low income households. The first used modified allocation rules to provide households with additional quotas in two scenarios: to low income households only (identified by receipt of state benefits)[19], and to all households regardless of income. These two modified allocations were used in addition to EPCA to form three scenarios for the second mitigation method. The rules compensated only specific characteristics of losing households and resulted in increased allowances for the households shown in Table 7.1 below.

Allocation rules variables		Additional allowances
Households living in detached houses		494 kg
Households not living in cities	- Town and fringe - Village - Isolated	330 kg 738 kg 994 kg
Households with children	- One - Two - Three	651kg 949 kg 1,450 kg
Households living in houses heated by oil		7,648 kg
Pensioner households		458 kg

Table 7.1 Modified carbon allowance rules (Table reproduced from Bird and Lockwood, 2009)

The second method provided financial compensation to low income households under each of the three quota allocation scenarios and using a variety of compensation regimes. Low income households were again identified by receipt of benefits and two compensation regimes were tested. The first compensated only those households receiving a deficit of allowances and awarded the financial value of the exact deficit for each qualifying household. The second awarded all households the financial value of the mean (or median) deficit experienced across the identified low income groups. Varying values were applied for the price of carbon (£15 - £50/tonne CO_2).

Under the modified allocation rules, those households exhibiting all of the traits targeted for compensation received the most benefit; however, allocating more permits to certain groups also reduced the quota received by those that

[19] Two 'low income' groups were identified: the first included those in receipt of housing benefit, council tax benefit, income support, job-seekers allowance (income based) or pension credit (56 per cent of households in the lowest three income deciles); the second included in addition those households receiving state pension (80 per cent of households in the lowest three income deciles).

did not qualify, thereby exacerbating the position of other vulnerable households:

> … if a household does not qualify for any (or very little) additional allowances under the modified rules they will be subject to an equal per adult allowance at a lower rate than without the modified rules. (White and Thumim, 2009, p.35)

Here the authors acknowledge the problem that in compensating some households, others are made worse-off: quotas allocated using EPCA to adults only would fall from 4423 kgCO_2 per capita to 4321 kg and 3837 kg when modified allocation rules were applied to low income and all households respectively. In fact, the overall proportion of losers increases under both modified allocation scenarios. When low income households receive modified quotas the proportion of households in deficit increases slightly (0.4%) and low income households are less likely to be in deficit (down 1.9% compared to EPCA). When all households receive modified allowances the increase in losers is higher at 3%, and low income households are also more likely to be in deficit (up 1.2% compared to EPCA) (White and Thumim, 2009).

While the modified allocation rules only result in a small change in the proportion of winners and losers, the authors claim the success of the modified allocation rules, in that "…groups of low income households have been made better off as a result of the modified allocation" (White and Thumim, 2009, p.19). In terms of winning and losing clusters, modified allocation rules applied to the low income group have limited effect on households clustered by traits, however, when applied to all households a more even cluster distribution results with fewer extreme winners and losers (p.19).

7.2.5 Mitigating what?

The mitigation methods outlined by White and Thumim have two limitations when viewed in the context of integrating environmental and social policy aims. The first relates to the household and dwelling characteristics chosen for mitigation, the second relates to the method of calculating additional emissions allowances.

In calculating the modified allocation for their study, White and Thumim identify the traits of households associated with a quota deficit and "based on factors beyond the short-term control of individuals" (p.10, Table 2). When the factors selected for compensation are compared to the larger list of characteristics identified to be associated with household emissions, the selection of characteristics to mitigate appears inconsistent. Some factors associated with high emissions are compensated for, while other factors are not. Additional quotas were given to single pensioners and households with children but not to single-adult households or households with additional adult members. Additional quotas were also given to households residing in detached houses and with oil central heating but not to households with electric central heating or with greater numbers of rooms. The approach used mitigates against some factors related to the efficiency of energy service delivery (both in terms of energy and emissions) i.e. indirectly associated with energy needs, while not for factors more directly related to energy needs such as the number of adult members of a household. The factor chosen by White and Thumim to qualify for additional quotas raises questions about the grounds for mitigation.

The number of adult and child occupants and the size of dwelling are key variables explaining emissions quota surplus and deficit but, in their method of modifying household quotas, only children qualify for additional allowances (White and Thumim, 2009). Why give additional quotas to pensioner households but not people living alone, when number of adult members of a household is the top-rated factor for per-capita emissions and age of household representative person is ninth?

In addition, White and Thumim's strategy supplies additional allowances to households with oil-fired central heating while single-person households receive fewer allowances. Noting that while "single, potentially vulnerable pensioners … living in large houses" do not qualify for additional allowances and are therefore a cause for concern, such households "highlight the inefficiencies (in terms of household energy consumption) of under-occupation" (White and Thumim, 2009, p.35). While households and dwelling size is noted with regard to inefficiency, the authors do not acknowledge the high emissions intensity of oil and the perverse subsidy produced by giving additional quotas to households using it as a heating fuel.

Why compensate some high-intensity fuels and not others? Why mitigate for households with children and not people living alone? Or more generally, why mitigate against some traits associated with high emissions and not others? Although stating that the allocation levels were modified using rules designed to address 'structural' factors and avoiding 'choice-based carbon-intensive behaviour' or 'lifestyle' factors , the selection of factors awarded additional quotas reveals that mitigating the risk of fuel poverty was a higher priority than providing a comprehensive and integrated treatment of factors.

The inconsistency may in part be explained by the additional criteria for inclusion: that information on selected factors should be "practically obtainable and verifiable by the operator of a UK PCT system" and that the effect of each factor could be analysed using the fuel expenditure dataset used by CSE (White and Thumim, 2009, p.2). Holding information requirements and verification aside, compensating for some factors related to high emissions without due consideration of the need for energy services not only reduces the primary incentive of DCAT - to incentivise emissions mitigation - but does so without adequate treatment of existing inequalities.

The concern over fuel poverty and protecting vulnerable households provides the context within which White and Thumim's study is situated. It is of note then that while the concern over this group drives their mitigation strategy, the methodology used to allocate additional quotas is not well-aligned with that used to quantify the problem of fuel poverty in the UK. Before returning to the link between DCAT and fuel poverty, the second limitation of White and Thumim's mitigation study will be discussed briefly before setting out a framework from within which to understand these interlinked problems.

7.2.6 Energy demand and energy need

The second limitation of White and Thumim's study is due to the method used to calculate the additional emissions quotas. From a needs perspective, using measured household energy demand (estimated from fuel expenditure) to develop a mitigation strategy is problematic. It does not provide a methodologically sound basis for analysing household energy need, or for setting quota levels because it does not give adequate consideration to household energy service requirements.

To calculate additional quotas, White and Thumim use regression analysis of the household emissions estimated from fuel expenditure data to determine the effect of each factor and therefore quota deficit. The resulting value is used as the quantity of additional emissions rights to be allocated to each household recording the related characteristic. As discussed in Chapter 4, measured energy demand should not be confused with the need for energy services. Households typically exhibit 'under-consumption' of energy due to constraints such as low income or high energy needs i.e. mean household demand is typically less than the requirements estimated using household *and* dwelling characteristics (Hirsch *et al.*, 2011).

By combining physical attributes of dwellings from the English Housing Condition Survey (EHCS) and Expenditure and Food Survey (EFS) to model both household energy 'need' *and* estimate demand from fuels purchased, Hirsch et al. estimate the gap between modelled energy need and actual demand. They demonstrate that the 'consumption ratio', i.e. actual energy consumption divided by energy need[20], varies across many of the structural factors identified by White and Thumim. For example, households occupying older dwellings are shown to have a lower consumption ratio (larger gap between need and actual demand) than newer, better insulated dwellings (Hirsch *et al.*, 2011). The consumption ratio has implications for evaluating distributional impact; using actual household demand only represents the additional impact, without considering the effect of existing constraints to energy demand. Households already mitigate energy demand, as Boardman (2007) notes:

> Every household on a tight budget makes its own decisions about the extent to which it will spend money on fuel to be warm, adequate hot water and other energy services, and the extent to which it will give priority to other items (Boardman, 2007, p.15)

In failing to account for the consumption ratio, the studies evaluating and moderating distributional impact mentioned in this section (Thumim and White, 2008; White and Thumim, 2009) neglect the distinction between

[20] The modelled demand based on household *and* dwelling characteristics.

household energy requirements and actual (measured) demand, and therefore fail to adequately address the question of energy needs. In reality, the overall impact on household demand would be a combination of the pre-existing consumption ratio plus any additional impact from PCT, and is therefore likely to be understated by White and Thumim. The varying levels of consumption ratio across households also creates a problem when attempting to calculate differentiated emissions quotas. If differentiated quotas are calculated using measured household demand, then the structural factors associated with demand will be embedded within the allocation. The same holds true for the end-uses underpinning household energy demand and emissions.

To summarise, the two problems with the White and Thumim mitigation study are: the problem with discriminating the position of factors in relation to energy service needs and the energy service delivery; and the determination of energy needs with the use of demand data (the consumption ratio problem). In the analysis by White and Thumim, as with other studies, the factors associated with household emissions – be they related to household or dwelling characteristics - are lumped together, obscuring their position as constituting either ‘need’ i.e. household requirements for energy services, or ‘delivery’ i.e. the provision of energy services. This lack of clarity clouds the decision making process on whether each factor should be mitigated in the modified quota regime.

I have argued that if environmental and social policy aims are to be integrated, then compensating ‘structural’ factors associated with household quota deficit is not enough: further distinctions are required to determine whether factors reflect a greater need for energy services or the high emissions intensity of systems delivering energy services. A framework within which to differentiate household needs is central in making these distinctions. I have also argued that the choice of factors for mitigation by White and Thumim reflects a priority to reduce policy impact on households vulnerable to fuel poverty. In doing so, the authors do not integrate the environmental and social aims identified by Bird and Lockwood as important aspects of perceived fairness and public support for PCT.

The dHCA method responds to both problems encountered by White and Thumim described above. The needs-based dHCA model approaches the differentiation of emissions quotas by creating an end-use demand model for the energy services that underpins them. In doing so, the approach avoids the problems of producing perverse incentives linked to using expenditure data, and the embedded factors related to the efficiency of delivery of energy services (and the associated inequalities). Note the dHCA model presented in Chapter 5 does include elements of measured demand data, for example, for estimating 'unregulated' energy demand. This is an important limitation of the first generation model and reveals a methodological inconsistency (see Section 8.3 for further discussion).

The concept of needs provides the framework from within which to consider household energy requirements, and the inter-household comparison of (relative) needs for energy services that is required in order to differentiate emissions quotas. However, the distinction between these needs and measured household energy demand requires us to consider the delivery of energy services in the evaluation of which factors to differentiate for. This distinction should also be present in any subsequent analysis of policy impact. It is Sen's capabilities approach that provides the required analytical distinctions for this task. The following section will describe this part of the framework and the relevance to DCAT, household energy and fuel poverty.

7.2.7 Needs, capabilities and household energy

7.2.7.1 Overview

The theoretical contribution made by this thesis is the application and integration of two theories within the wellbeing literature to understanding the problem of reducing household energy demand while protecting wellbeing. More specifically the application to allocating emissions rights to participants in a downstream cap-and-trade type policy instrument covering emissions from the demand for household energy services. The two concepts, 'basic human needs' and 'capabilities' have been used in studies to define poverty thresholds and evaluate the levels of household income required to enable an acceptable standard of living (Deeming, 2005).

I described in Chapter 4 how a needs-based understanding of household energy demand provides a compelling account of the distributive principle for emissions quotas and that Gough and Doyal's Theory of Human Need (1991) provides a readily applicable framework for evaluating relative needs when used in the context of existing regulation and assessment methodology for household energy. This framework underpins the needs-based energy service demand model described in Chapter 5. Analysis of the distribution of residual emissions quotas has been presented in Chapter 6 and compared to existing methods of allocating emissions quotas. The work presented so far meets the research objectives set out in Chapter 1; however, it also represents only part of the framework required to adequately evaluate a differentiated allocation. What remains to be presented is how these energy service needs are met by the physical systems of service provision embedded within the fabric of the dwellings that households occupy. Further, the framework is required to address the question of which factors might qualify for mitigation through a differentiated allocation, and the capacity of householders to respond to a constrained emissions budget. This section of the discussion will present the application of Sen's capability approach to wellbeing as the remaining part of the analytical framework required to tackle these questions.

I propose that this application of Sen's capability approach provides a complementary framework with which to understand the ability of a household to meet demand for energy services. It also provides a useful analytical framework within which to evaluate household responses to energy use constraints, be they motivated by excessive cost or by a system of emissions quotas.

In Chapter 4, it was argued that if we are to adhere to a wellbeing understanding of household energy, then (in the problem of distributing emissions rights) demand should be considered in terms of energy services, or end-uses not energy itself. In this section I will begin by describing why a commodities-based allocation is not sufficient when thinking about energy demand and wellbeing, and how by expanding the analytical framework to include components of energy service delivery, important distinctions can be made between energy demand reduction through efficiency and through service levels. This allows a more precise consideration of the constituent elements making up the demand and provision of energy services within the household. The energy service delivery framework will then be translated to Sen's capability approach. In doing so, the framework allows for the considerations of households ability to respond to a DCAT type system.

7.2.7.1.1 The limitations of measuring energy demand

Realising a differentiated household allocation method based on energy needs might result in better outcomes when compared to EPCA, however, such an approach would not provide a sufficient analytical framework if energy itself is treated as the resource, or commodity, of interest. The limitation of measuring the standard of living in terms of energy demand itself is described in the example below.

Consider two households both living in identical, poorly performing dwellings and with space heating demand at a reference minimum level. Due to the inefficiency of the systems delivering and maintaining heat, both households have high fuel consumption and high greenhouse gas emissions. If the price of fuel rises, the first household has enough income to absorb the cost and can maintain the minimum level of space heating. The second household is unable to meet any additional costs; the dwelling is rented from a private landlord who has no interest in improving the efficiency of the envelope or heating system and so the energy performance cannot be improved in order to reduce energy costs. This household therefore has no choice but to reduce the amount of heating used, leading to lower internal temperatures in the dwelling. If the additional fuel costs were the result of an economic policy instrument, for example a downstream emissions trading scheme, and the outcome is measured in terms of energy demand or emissions, we would see that the second household had reduced demand, perhaps indicating a policy success. However, if we measure in terms of wellbeing (for example as thermal comfort) we come to a different conclusion. The second household has reduced internal temperature resulting in a reduced standard of living. We can go further if we accept Gough's view that meaningful thresholds for 'adequate housing' can be established and conclude that where temperature is reduced below a given point, the basic needs of a household are no longer met. A policy to incentivise emissions reductions has been 'successful' at the expense of the wellbeing, or needs, of one of the two example households.

This is a simplified example, but highlights the limitations of using a commodities-based approach as a framework for household energy demand. As already noted, Sen argues that the standard of living should be measured not in the consumption of resources, but by analysis of the contribution these resources make to people's lives. If we are to measure this contribution we require a framework with which to situate energy needs as services not commodities. Energy should be considered as the means contributing to a standard of living not the end in itself. It follows that evaluating PCT or other variants of a DCAT scheme using only energy demand or emissions data is limited.

7.2.7.1.2 From means to ends: the energy service delivery chain

To provide an adequate conceptual space within which to understand the need for, and provision of, household energy services we first need to expand the energy 'service' delivery chain. Energy provides household services (end-uses) by powering appliances and systems (Baker *et al.*, 1989). Each appliance or system has its own conversion factor representing the efficiency with which these services are delivered (Cullen and Allwood, 2010). Starting with the end-use, the delivery chain can be described below using the example of space heating:

(1) The end-use service demand is for a comfortable temperature inside the dwelling, expressed in degrees Celsius. In building physics, the demand for heat is expressed as a gradient between the desired internal temperature and the ambient (outside) temperature, multiplied by the number of hours that the temperature is to be maintained. This measure is expressed in degree hours (or degree days) (The Carbon Trust, 2007).

(2) The internal temperature of the dwelling is maintained by the heating system (using energy to provide heat) in combination with the thermal characteristics of the dwelling envelope, each with measures of performance (or efficiency). In this example the heating system and building envelope are treated as one system with its efficiency measured by the amount of energy required to maintain one degree of temperature gradient for the period of one hour.

The fuel required by the heating system (3), in kilo-watt hours (kWh) causes the release of greenhouse gases during generation or combustion (5), measured in grams of carbon dioxide equivalent (gCO_{2e}). The rate of emissions for each fuel is measured as emissions intensity in gCO_{2e} per kWh (4). Table 7.2 summarises the energy service delivery chain.

Stage	Element	Metric
(1)	End-use service demand: temperature for a period of time	degree hours
(2)	Energy efficiency of system: energy to deliver a degree hour	kWh/degree hour
(3)	Energy demand: energy used to meet desired temperature	kWh
(4)	Emissions intensity: emissions released for each fuel unit	CO_{2e}/kWh
(5)	Emissions: emissions released to meet energy demand	CO_{2e}

Table 7.2 Energy service delivery chain

A reduction in the energy and emissions from space heating can be achieved through one or more of the 'links' in the chain. Examples include:

- Reducing the desired internal temperature, or central heating 'set point', thus reducing service demand (1)
- Replacement of central heating boiler with a more efficient model, improving heating system efficiency (2)
- Making improvements to the thermal envelope of dwellings by the installation of improved insulation measures to increase the performance of the thermal envelope (2)
- Switching to fuels with lower emissions intensity to reduce the quantity of emissions for a given energy demand (4)

By separating the end-use, system efficiency and energy demand this delivery chain allows us to make a distinction between desired demand reduction and that which might cause concern for a householder's well-being. Using the example presented in the previous section, if the energy demand reduction for the poor household was shown as a drop in internal temperature below the minimum threshold, so occurring at position (1) in the chain, we might be concerned. Alternatively, if the demand reduction occurred due to efficiency improvements, position (2), we would not be concerned as the minimum internal temperature could be maintained while reducing energy consumption.

7.2.7.1.3 Translating household energy services to capabilities

The capability approach (Sen, 1984) provides useful analytical distinctions that can accommodate the delivery chain described above. This section will describe how the energy service delivery chain can be translated onto Sen's capabilities and how doing so allows the components to be related to the ability of households to meet their energy needs. The key terms in Sen's framework are *means*, *functionings*, and *capabilities* (Sen, 1984):

Means: the means to achieve, or capability inputs, for example, goods and services. The focus of the capability approach is on characteristics of goods or services. It is these characteristics, not the goods themselves that allow individuals to achieve certain functionings (Robeyns, 2005). In the context of household energy, means can be understood as the service that energy delivers in combination with other inputs. An example would be the means of a washing machine, water, detergent and electricity together providing the characteristics of performing laundry services to achieve clean clothes. Parallels can be drawn between Sen's notion of the characteristics of goods and Gough's universal characteristics of needs satisfiers.

Capability, Capability set, or opportunity set: a combination of an individual's potential functionings (Robeyns, 2005). Capabilities are the ability (or opportunity) for a person to realise certain practices that they have the desire to achieve. In the context of household energy, the capability set refers to household practices that commonly[21] require energy as one of the means to achieve.

Functionings: can be either potential or achieved. Achieved functionings are the achievements actually realised from the range of what is possible; the capability set, or opportunity set of achievable functionings (Robeyns, 2005). Continuing the laundry example, the achieved functioning would be the amount of laundry washed.

Having the capability to achieve is not the same as realising that capability as functioning. The approach recognises that while the capability set might define the potential level of energy services (functioning) for an individual, that individual retains the ability to make choices and trade-offs that determine their achieved level of functioning.

[21] Of course many household activities that *commonly* require energy can be achieved without. Indeed part of an individual's or household's response to energy demand reduction may be to carry out commonly performed tasks manually rather than using energy. The point here is that the majority of people would use energy-using appliances to perform these activities. This does not disregard the possibility of social norms reconstituting these practices.

Conversion factors and efficiency

Robeyns develops the concept of capabilities by including '*conversion factors'.* Figure 7.1 below illustrates how these personal, social and environmental factors are contextual and act at multiple levels to influence the ability of persons to convert means into functioning (Robeyns, 2005).

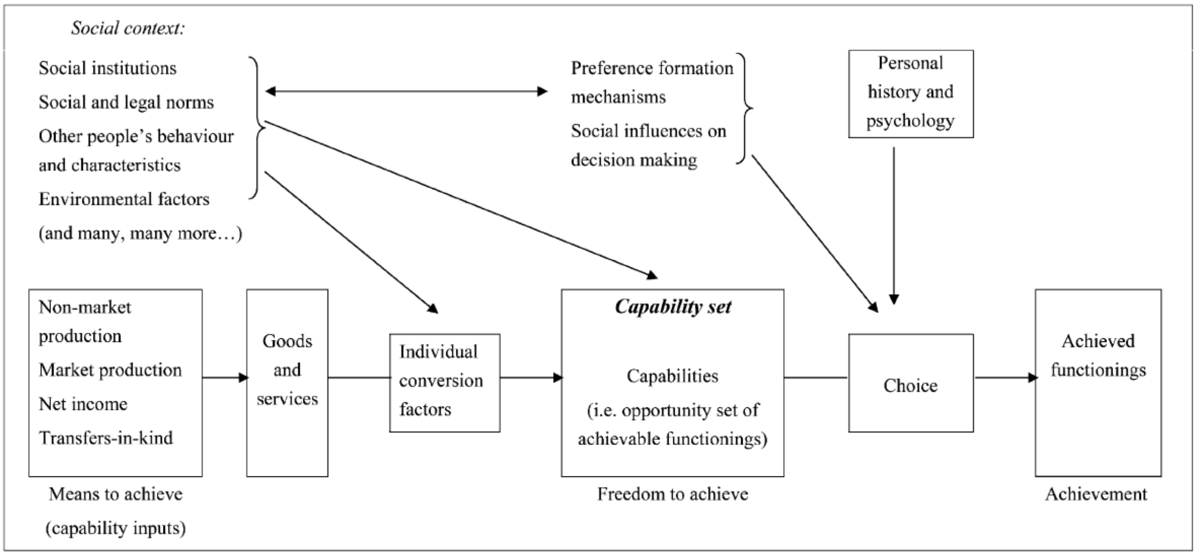

Figure 7.1 The capability set and personal and social context (Robeyns, 2005)

When focussing on the role of the dwelling in converting energy goods into capabilities, the conversion factors can be translated as the efficiency with which energy services are provided by each system. So conversion factors can also be thought of as the efficiency with which the systems and appliances within a dwelling, along with other inputs, provide services: Stage (2) in the energy service delivery chain. Continuing the example of laundry, we might measure the efficiency in terms of the electrical energy (measured in kWh), water use (in litres) and washing powder (in grams of detergent) used in a typical laundry cycle. Of course, the metrics needed to measure efficiency vary according to each household activity. In this context we might consider just three measurements: cost, energy and emissions, however others might also be relevant (e.g. water and time). The final conversion factor to consider in the delivery chain is the emissions intensity of fuels, Stage (4), which determine the amount of emissions associated with each unit of energy supplied.

Energy goods and characteristics

Discussion

The following section expands upon the space heating and laundry examples to describe household energy services. It is not intended as a definitive list but provides examples that demonstrate the distinctions between efficiency and emissions intensity, and between regulated and unregulated energy demand (see Chapter 4 for description). In the residential context, the energy goods and services available to a person or household can be grouped into three categories: infrastructure (utilities), housing and appliances. We are concerned with the characteristics related to the standard of living and the efficiency with which capabilities are delivered. The table below summarises these characteristics and the measurement metric for each:

Category	Characteristics (units)	Conversion factor/efficiency (units)
Utilities	Water (litres) Energy - gas, electricity and other fuels - (kWh).	Cost (£/unit) Intensity (CO_{2e}/unit)
Dwelling (regulated)	Living space (m^2) Fabric efficiency standard*: Comfort (˚C x time) Hot water (litres) Fixed lighting (lumens/m^2)	* Combined performance of dwelling (kWh/m^2) Cost (£/m^2)
Appliances (unregulated)	Laundry (washes) Cold storage (m^3) Additional lighting (lumens) Power (miscellaneous)	Individual performance of each appliance (kWh/unit) Cost (£/unit)

Table 7.3 Characteristics and measurement metrics of energy goods

A combination of the goods described in Table 7.3 above are fixed as an arrangement of physical systems within a dwelling by the occupying household and provide an *energy service* capability set. The choice and arrangement of these *energy goods* are in part determined by social factors (the cultural and social context of Gough's universal satisfier characteristics) and restricted by the personal and socio-economic characteristics of a household.

<u>Individual conversion factors</u>

Personal factors such as physical condition, health or technical competence affect the ability of a person to convert means into functioning. These factors will also affect the level of service required to give different individuals the same capability. For example, the level of heating required by an elderly person might be higher than that required by a younger, healthier or more active adult. In terms of converting capabilities into functionings, personal factors will also affect an individual's choices or preferences and the way in which a person reacts to constraints. For example, one individual may decide to wear more clothing to save energy and heating costs, while another might not.

Social institutions, social norms and public policies along with environmental factors such as climatic conditions also combine to influence the characteristics and availability of goods and services. These social-environmental circumstances act to expand or restrict a person's capabilities. To illustrate, changing social practices around watching television have implications for the energy services required for a household to fulfil leisure activities. Where it was once normal for a family to sit together in one room to watch television, it is now more normal for individual members of a family to occupy different rooms in their home using separate devices for entertainment. Conversion factors should therefore be thought of as a range of personal, social and material circumstances that enable or constrain the conversion of goods to capabilities and capabilities to functioning. Figure 7.2 below illustrates the application of capabilities to household energy. The boxes shown with grey, dashed outlines indicate elements of the energy service delivery chain with the numbers in parenthesis indicating the position of the element (refer to Table 7.2, p.173).

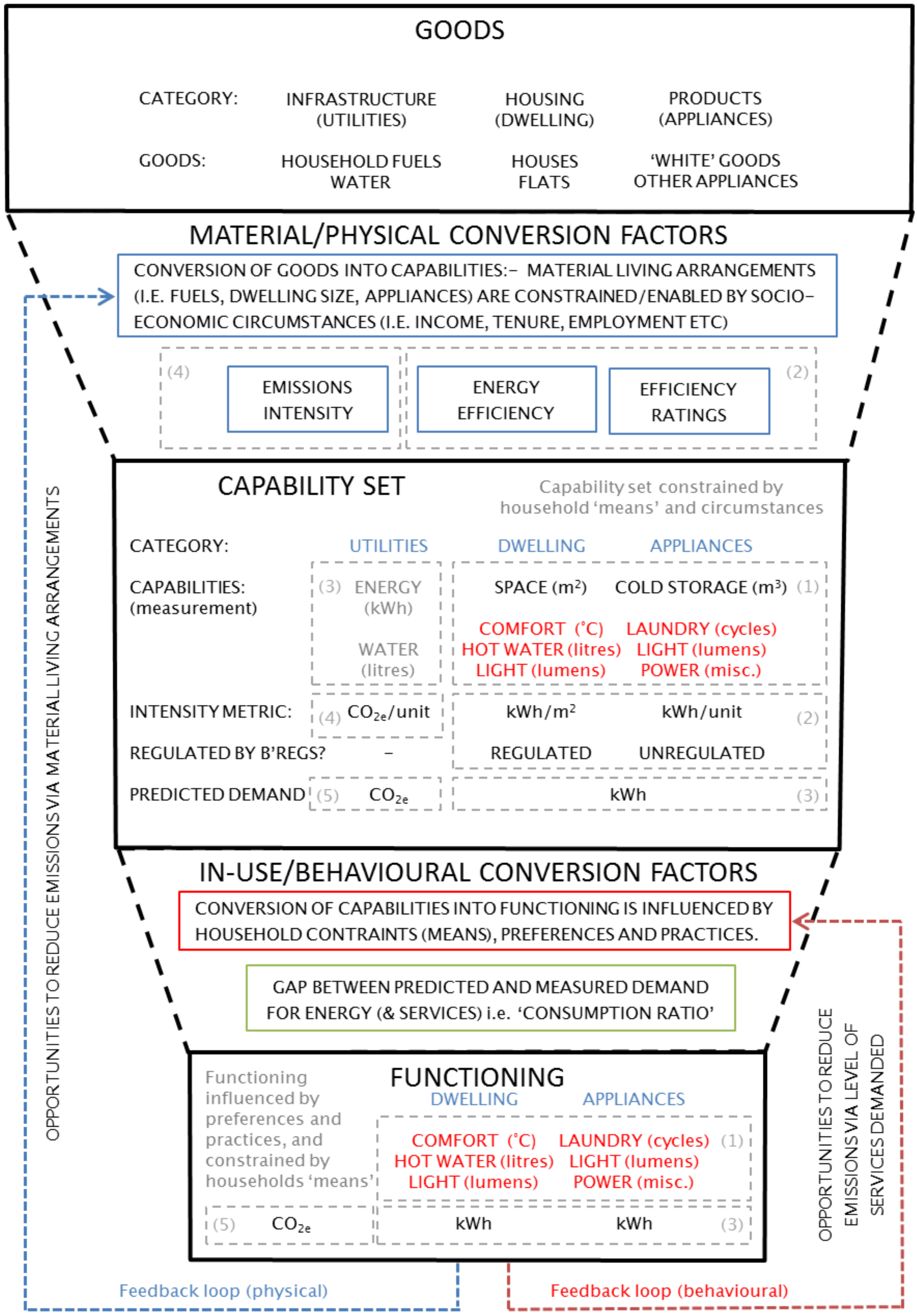

Figure 7.2 **Mapping capabilities to household energy demand**

As described in the energy services delivery chain above, it is end-uses - or the need for energy services – that underpin demand (1). These end-uses are represented in both the *capability set* and *functioning* but provide two different measures of energy services. In the capability set, the measure is of a household's need for energy services and is stated as estimated demand based on household size. The measure therefore provides the inputs to calculate energy requirements given the efficiency of the systems delivering these energy services. For functioning, the measure is of the quantity of services that have been achieved, or delivered. The distinction between the two is the difference between energy need and measured demand, or the 'consumption ratio' identified by Hirsch et al. (2011). See Section 7.2.6 above.

In this section, I have described how the capability approach is relevant and can be translated to the household energy domain. I have also demonstrated that the approach provides appropriate analytical distinctions with which to represent the energy service delivery chain. As described in the example earlier in this section, it is not only the quantity of energy and emissions that we are concerned with, but the level of functioning that is enabled by the use of energy. Ensuring a fixed minimum level of energy services, especially for vulnerable households, for a constrained, and reducing, quantity of emissions requires increasing efficiency (2) or reducing emissions intensity of fuels (4). So, the efficiency with which energy services are delivered (the conversion factors) are of great interest, especially where data on actual functioning is poor. It is the efficiency of the arranged systems and appliances that give a household the potential to achieve a set of energy capabilities given a constrained energy or emissions budget.

The remaining sections will discuss how this framework provides distinctions that are not only useful in assessing the impact of energy demand reduction on wellbeing, but also in evaluating how households are able to respond to constraints. Furthermore, I will describe how the needs-capabilities framework clarifies the decision-making process for which factors to include in a differentiated method of allocating emissions allowances.

Discussion

As outlined in Table 7.3 above, the three categories of goods providing the means to achieve energy services in the home are utilities, dwellings and appliances. As far as an individual household is concerned, the utilities servicing a property are generally fixed in terms of emissions intensity. The household's freedom to alter the energy delivery in this regard is a limited choice between the type of fuel used (largely for central heating) and the energy company that provides it (providing some variation in cost). The potential of a household to change its capabilities is therefore largely restricted to the dwelling and appliance categories and by switching fuels.

7.2.7.1.4 Two contrasting starting points

As already described in this chapter, put simply, the energy used to provide each service in support of the standard of living within a dwelling can be described as follows:

Emissions = *level of use* x *system efficiency*

Where the level of use reaches a minimum threshold, it is considered meeting a certain capability. It follows that the scenario of reducing household emissions can be thought of in two contrasting ways: increasing efficiency while maintaining (fixed) capability levels or, reducing capability levels while efficiencies remain fixed. In reality there would of course be a mixture of the two. On the one hand, regulation of dwellings and appliances aims to reduce energy demand by increasing efficiency. On the other, as we have seen, policies aimed at incentivising emissions reduction by affecting energy prices do not automatically result in efficiency improvements but can result in a reduction in energy capabilities. An approach more consistent with a concern for well-being is to fix service levels, or more explicitly to fix a minimum threshold for service levels – a minimum living standard. This would, in theory at least, protect energy capabilities under a drive to reduce emissions. The dHCA model will therefore assume that service levels are fixed, using those described in SAP as the minimum threshold and sufficient to provide functioning for occupants of the dwelling in normal circumstances.

7.2.7.2 Household response to emissions constraints

The capability of a household to achieve a given minimum level of energy services while staying within a defined emissions budget will be determined by a combination of circumstantial factors. These factors also serve to constrain or enable how individuals and households can respond to the incentive from DCAT. Households with high emissions, and resulting quota deficit, can respond in four ways:

i. alter energy using practices in order to reduce energy service demand (1) as illustrated by the behavioural feedback loop (red) in Figure 7.2 above
ii. increase the efficiency of energy service provision i.e. more efficient systems and appliances (2) as illustrated by the physical feedback loop (blue) in Figure 7.2
iii. switch to household fuels with lower emissions intensity (4) also illustrated by the physical feedback loop
iv. absorb additional costs: no change in energy demand or emissions

High emissions households with adequate means (e.g. income) will have access to a range of responses (ii) to (iv) and are less likely to resort to decreasing demand through a reduction in energy services (i). High emitting households with lower incomes are often restricted by their circumstances and lack the means to purchase newer, more efficient appliances, install insulation upgrades (ii), or switch to fuels with lower emissions (iii). They have little choice but to absorb the costs of additional emissions permits (iv) or reduce energy service demand.

Reducing energy service demand is likely to have a more negative effect on wellbeing in low income households as they are more likely to be under-consuming energy already (Hirsch *et al.*, 2011; Teli *et al.*, 2015). Such households are therefore vulnerable under any policies raising the cost of household energy services through price rises, taxes or DCAT. As discussed in section 7.2 above, it has been identified in the literature that creating additional energy costs through DCAT is therefore likely to carry risks to the wellbeing of constrained, high emissions households unless they receive higher quotas or are targeted with supporting policies to deliver mitigation measures.

7.2.7.3 To differentiate or not to differentiate

To demonstrate how the needs-capabilities framework assists decision-making, this section will examine a number of the structural factors. The purpose of this part of the discussion is not to re-examine the factors that should be mitigated for within the dHCA method, instead it provides a discussion of how the framework can be used to make those decisions. The discussion is illustrated using examples from the literature on PCT where factors have been proposed for mitigation with additional quotas.

Examining the structural factors associated with high household emissions in light of the needs-capability framework for energy services, makes the considerations around differentiation and mitigation of emissions quotas explicit. To illustrate, a number of the factors identified in White and Thumim's (2009) study on modified allocations will be used. The examples were chosen as they illustrate a range of different justifications that can be invoked for providing households with additional quotas. They are as follows:

a. Pensioner household/households with children
b. Geographical location
c. Inefficient heating system/ inefficient dwelling
d. Use of oil as a central heating fuel

Looking at each example in turn:

(a) The analysis presented in Chapter 6 shows that pensioner households have, on average, higher emissions compared to households with working-age occupants and therefore lower residual emissions quotas. The presence of elderly persons in households is associated with higher internal temperatures (Guerra-Santin and Itard, 2010) and an increased likelihood of heating dwellings during weekday periods (Palmer and Cooper, 2013). Pensioners therefore have a greater need for energy services; inactivity and age are considered to be significant factors in requirement for heating in order to remain healthy. In other words, pensioners have higher energy requirements for maintaining the same level of well-being as others. If all other things remain equal, we would expect higher emissions from this group due to the increased energy service demand (higher temperature and longer heating periods). The justification for a higher emissions quota therefore relates to position (1) in the energy service delivery chain: end-use service demand.

(b) Geographical location is a structural factor as local climatic conditions such as ambient temperature, solar irradiance, wind speed and direction all affect the space heating energy demand. A house in a colder location will require more energy to maintain a set internal temperature than an identical house in a warmer location. The increased energy demand is due to the increased temperature gradient between internal and external conditions and a resulting increase in degree-hours to maintain the desired internal temperature. A dwelling in a colder climate will therefore have a higher energy service demand than an identical one in a warmer climate. The justification for a larger quota also relates to position (1) in the energy service delivery chain: end-use service demand.

(c) For households occupying inefficient dwellings (high fabric thermal losses) or dwellings with inefficient energy service delivery systems (e.g. low efficiency central heating boiler), the energy demand and emissions will be higher than households where services are delivered more efficiently, all other things remaining equal. A poorly performing dwelling would therefore require additional emissions permits to maintain the same standard of service compared to a higher performing one. The increased quota requirement in this example is due to *inefficiency* not increased energy service demand and therefore relates to position (2) in the energy service delivery chain.

(d) The final example is the use of oil as a heating fuel for dwellings. In comparison to an identical dwelling heated by gas, a household using oil as a heating fuel will require additional permits due to the higher emissions intensity of oil (Office for National Statistics, 2009). Justification for a higher emissions quota in this example relates to position (4) in the energy service delivery chain: emissions intensity.

These examples help to reveal criteria by which factors might be considered for further differentiating household quotas. Upon initial consideration, all four examples above appear to warrant additional quotas or qualify for some other kind of mitigation measures on the grounds of wellbeing. After all, if living in a colder location or poorly insulated dwelling “is the result of unchosen circumstance rather than a deliberate choice,” (Hyams, 2009, p.249) then shouldn't such a household also be entitled to a larger emissions quota? The more detailed examination below reveals factors, which at first appear to carry equal weight for mitigation, actually have different justifications when considered within the stages of energy service delivery and therefore require different treatment.

To begin, consider pensioner households. The justification for allowing pensioners an increased allocation can be made on the grounds of wellbeing. We might allow pensioners an increased allocation of rights – or some form of compensation – due to the increased periods of heating and higher heating set-point temperature required to achieve the same level of comfort as a younger household. This justification would also apply to other households with occupants requiring warmer temperatures and longer occupancy profiles, for example households with young children or including persons with disabilities. Oldfield (2008) takes just such an approach and differentiates by household type for heating regimes when modelling the energy demand of households in the Minimum Income Standard work.

Just as getting old leads to an increased demand for emissions quotas, so does living in a colder climate, poor energy performance, and the high emissions intensity of some fuels. All of these factors could also be described as circumstantial and beyond deliberate choice for many households. However, by considering these examples from an energy service perspective, clear differences in justification are revealed. Asking whether the deficit in emissions-rights is related to an increased need for energy services separates factors related to the *needs of the household* from those related to the *delivery of needs* made by the dwelling and household fuels, i.e. a household's capabilities related to the physical arrangement and properties of energy delivery services.

Responding to this distinction, the four examples are now separated into two groups. Household size qualifies for increased need for services as larger households require increased energy service provision (heated living space, hot water, and power for lighting and appliances). Household size has therefore been included for comparison:

Increased need for services	Need for services not increased
a. Pensioners (& others) b. Cold location *(Household size)*	c. Poor energy efficiency d. High emissions content

Should mitigation be provided only where structural factors are associated with increased need for energy services? Such an approach would appear to be wholly compatible with the needs approach, after all, separating the human aspects of energy demand (needs) from the physical systems of provision (a household's capability set) would leave incentives in place to both improve the efficiency of energy service provision and reduce 'overconsumption'. At the same time, quotas would be differentiated for those circumstantial factors related to energy service need that are beyond the control of households. In this case minimum provision of energy services would only be protected if supporting policies provided for enforcement of the minimum energy performance and emissions rate of dwellings, thereby ensuring that a household had the *capability* to meet their demand while staying within their emissions quota. Such standards would need to be improved in line with the decreasing national emissions budget and also any growth in household numbers or change in composition. Fleming (1997) accepted that TEQs would provide a framework but would not exist in a policy vacuum.

Any PCT policy would require a range of supporting policies, particularly in the early stages, and instead of justifying the different treatment of factors by separating along the lines of needs versus delivery of needs as above, Hyams (2009) offers another argument, suggesting that rather than distributing additional quotas to mitigate the impact on all households with circumstances leading to high emissions, governments should address some structural inequalities directly. This, he suggests, would be for two reasons: for the sake of simplicity and that, where possible, a government would wish to align the environmental goal of emissions mitigation with the social goal of reducing structural inequalities. He uses two examples to illustrate the point: the energy efficiency of a dwelling and the geographical location. Hyams argues that households living in colder locations should receive larger quotas whereas poorly performing homes should be tackled directly using supporting policies aimed at improving energy efficiency of dwellings. Hyams claims additional quotas due to geographical location are justified because "an agent living in a part of the country with a particularly cold climate may need extra emission dependent energy to keep her house warm, however well insulated the house is" (Hyams, 2009, p.249). Here, the justification is that cold locations lead to additional *heating* demand that cannot be mitigated by energy efficiency alone.

Hyams argues that mechanisms with which Governments could address the source of unfairness would not always be available and that an increased allocation is therefore justified in lieu of alternatives, such as subsidies for energy efficiency improvements for poorly performing dwellings. Hyams infers that sources of unfairness should be taken into account when there is no other viable means with which to address the cause. He seems to suggest, that as energy efficiency improvements could be subsidised or provided through some other mechanism, it should not be used as factor in the allocation of emissions rights. Starkey (2012b) also suggests that egalitarian liberal philosophers would agree that those who live in colder regions would be entitled to more energy. But if Hyams' condition, as set out above, holds this should only be taken into account if there is no mechanism with which to address the cause.

Following the argument above, that there are practical limits to the extent to which additional insulation can cost-effectively offset colder climatic conditions, Hyams suggests that geographical location should be considered a factor qualifying for additional emissions quota. While this argument might hold in countries where there exist great differences in climate between locations, in the UK this argument does not carry much weight. This is demonstrated by the existence of provision within the updated rating procedure for energy efficiency of dwellings (SAP2012) to take into account the geographical location of a dwelling: the dwelling emissions rate for compliance with building regulations is calculated using local climate data BRE (2014). In England, therefore, two identical homes built with building regulations approval are required to meet the same energy demand target regardless of their location. These dwellings would be required to meet the same emissions target taking into account regional temperature variation during assessment. The result is that dwellings built in colder regions are required to have a higher thermal performance and thus would not require additional emissions quotas. This is an existing mechanism controlling the energy efficiency of new dwellings, and which could be extended to include existing dwellings, that addresses the source of the injustice.

When evaluated using the needs-capabilities framework (and expanding the energy service delivery chain), it becomes clear that the increase in demand for emissions in a cold location is due to higher end-use demand (degree hours) and is therefore easily distinguished from increased energy demand due to lower system efficiencies. Accordingly, the framework suggests that we should mitigate households in colder locations with additional quotas. Hyams suggests that if an existing mechanism exists with which to tackle the cause of inequality, it would be preferable than allocating additional quotas to mitigate for that cause. Therefore, despite Hyams not being aware of an existing mechanisms with which to tackle this particular inequality, geographical location can be ruled out as an additional factor for differentiation.

While Hyams (2009) states the requirements for additional quotas in terms of 'emissions dependent energy' rather than need for energy services explicitly, he highlights how policy-makers might make the choice between integration or mitigation of factors associated with high emissions. Further, he intuits that there is a balance to be struck between simplicity and justice, as he notes:

> From a policy perspective, it is tempting to say that, in order to keep the system simple, we should allocate PCAs equally despite the injustices that will arise if we do so. But I doubt that we need to go so far in prioritizing simplicity over justice. Simplicity is only of value here insofar as it helps the system to run smoothly and transparently, so that administrative costs are kept down and so that the public understand the system and regard it as fair. (Hyams, 2009, pp.251-252)

Hyams recommends that for the sake of public acceptability and administrative costs, the allocation of quotas under a DCAT scheme should be simple and transparent, but not so simple as to forsake the demands of justice completely. He suggests, to this end existing mechanisms can be used to tackle the structural causes of inequalities in emissions (Hyams, 2009). Gough (2013) also notes that "Too many exceptions to the standard allowance could undermine the scheme, but too few would result in rough justice, which could undermine public support (in addition to the political risks of such an overtly redistributive project)" (Gough, 2013, p.208). Gough also argues for balance between environmental and social goals. In other words: too many exceptions to the EPCA method, by mitigating for factors associated with high emissions, would risk undermining the environmental goals of PCT (see 7.2.5). There is, however, also the risk that without mitigation, PCT would exacerbate energy related social problems such as fuel poverty and lead to lower levels of public support (see 3.6.5).

As the example of geographical location highlights, existing regulatory instruments are well-placed to control for some structural factors. It also demonstrates that in order to decide on the appropriate treatment, evaluation of these factors must be made in light of relevant existing policy instruments. Using the needs-capabilities framework also reveals synergies where initial consideration found policies in tension. An example of this is fuel poverty.

7.2.7.4 Challenges to a 'needs-capabilities' framework

Hyams uses the term 'grandmothering' to describe a method that would provide additional emissions rights to those who, "[...] as a result of circumstances beyond their control, would require more PCAs than other agents in order to function at some normal level" (Hyams, 2009, p.248). The approach is based on a luck egalitarian interpretation[22] of 'normal-functioning' in contrast to Gough's needs or Sen's capabilities. Hyams' claims that his approach is superior to the needs and capability approaches based on two critical observations. The first, that neither approach provides an account of how luxury emissions should be distributed, was addressed earlier in the thesis (see 4.2.5.3). In his second critique, he states that:

> The approach requires us only to ensure that agents can satisfy basic needs or develop their central capabilities, but not to ensure that they can do so at the same cost as other agents. (Hyams, 2009, p.250)

This statement is based on the assumption that an individual or household might be required to purchase additional emissions rights, over and above their allocated quota, through the trading element of the scheme in order to meet the standard of wellbeing set by these definitions. The implication is that in doing so they potentially bear significantly greater cost than others. It is not clear how Hyams arrives at this assumption or how it might be mitigated by his

[22] A view of distributive justice that wealth or resources be determined by the choices people make, not by their unchosen circumstances (Lamont and Favor, 2013).

proposals, as in both cases neither the operationalisation of the allocation principle into the initial allocation (before trading), nor the details of the scheme in operation have been described. Where Hyams approach does differ significantly is that "…it understands normal functioning not in terms of an objective list, but by comparison with the situation of other agents." (Hyams, 2009, p.250) His approach is subjective as opposed to the objective needs-approach of dHCA and Hyams recognises the difficulties in implementing such a principle, stating:

> In practice this would mean, roughly, that agents for whom activities important to their welfare are, as a result of unchosen circumstance, more carbon intensive, would need to receive more PCAs than agents for whom activities important to their welfare are less carbon intensive.[…] Clearly there are difficulties in determining when an agent's situation is the result of choice and when it is the result of unchosen circumstance." (Hyams, 2009, pp. 250-251)

Hyams gives the example of an individual living in a colder location requiring additional energy (and thus emissions rights) to keep their house warm. While an individual could obtain additional rights to cover this extra energy through the market under a trading scheme (although not a strict rationing scheme) the grandmothering principle suggests that the cost of doing so would be significant. Hyams considers this to be unfair and so proposes that the individual would qualify for a larger allocation if 'living in this location is the result of unchosen circumstance rather than a deliberate choice' (p.249). As described in the previous section, the needs-capabilities framework makes it explicit that this would be considered a legitimate claim for additional quotas as (regardless of choice) the justification falls into the category of 'increased need for energy services'. However, as there is potentially provision to mitigate this factor through another mechanism (i.e. the extended regulation of energy efficiency in dwellings), the decision might be not to mitigate this factor through additional quotas.

7.2.8 Fuel poverty indicator methodology

Fuel poverty is concerned not with the affordability or 'distribution of access' to energy itself but with the ability of a household to meet its need for energy *services* (Ürge-Vorsatz and Tirado Herrero, 2012; Walker and Day, 2012). The methodology used to measure fuel poverty in the UK also has a focus on energy services (Department of Energy and Climate Change, 2015b) and therefore aligns with the capabilities approach. The fuel poverty indicator (FPI) provides an example of how household needs and capabilities are currently used within the domestic energy policy landscape. The primary focus of fuel poverty indicators (FPIs) in the UK has been the affordability of energy for households and individuals, and is measured using modelled household fuel costs and household income (Moore, 2012). The FPI estimates the energy requirements of a household in its current circumstances by combining household characteristics and the physical characteristics of the currently occupied dwelling (Department of Energy and Climate Change, 2015b). The 'Hills review', *Getting the measure of fuel poverty* (Hills, 2012), makes clear that the methodology behind the fuel poverty indicator was intended to recognise the importance of differentiating energy requirements across households:

> …we want to be able to understand what it is 'reasonable' or 'unreasonable' for each household to spend on energy given their household composition…(Hills, 2012, p.51)

The role of needs in comparing energy requirements is acknowledged along with the role of living space and occupancy:

> …it is also clear that energy needs do not rise directly in proportion to household size: a couple will, for instance, share living space, and so their space heating requirements will not be twice those of a single person (Hills, 2012)

The definition of fuel poverty has changed since originally adopted for use in the UK, beginning as describing a household that cannot achieve "adequate energy services for 10 per cent of income" (Boardman, 1991 in Boardman, 2010). Following the 'Hills review' , the description of fuel poverty was updated to: a household with Low Income and High Costs (LIHC), i.e. where a household has fuel costs above the national median and residual income after fuel costs below the poverty line (Department of Energy and Climate Change, 2015b).

Energy poverty is however a contested concept that can be measured both objectively and subjectively (Healy, 2004; Waddams Price *et al.*, 2012) and the number and distribution of energy-poor households varies markedly depending on how income and expenditure are measured; for example, including housing costs within the measure of income, biases those household deemed to be in energy poverty towards households owning their own home, while not equivalising incomes biases energy poverty towards single-person households (Moore, 2012).

The fuel poverty indicator uses the BREDEM methodology to model household energy requirements (Department of Energy and Climate Change, 2015b). The BREDEM calculation uses the same methodology as SAP, although small differences between the methods are present, for example, it allows the input of household characteristics and other parameters such as number of persons, heating demand (temperature and duration) and others, and also predicts energy demand for lights and appliances (BRE, 2010). Despite these inclusions, making the method more suitable for calculating the energy requirement of a household than SAP, the fuel poverty indicator is not a normative tool; it provides no measure of the suitability of a particular dwelling for a household. This is highlighted by the treatment of living space: while the FPI uses the Parker Morris Standard as a measure of under-occupancy, the assessment of living space is not made systematically with reference to a minimum level, nor does it consider over-occupancy, or overcrowding.

7.2.8.1 Energy poverty and capabilities

A household in fuel poverty can be defined as one where meeting its needs for energy services in current circumstances is prohibitively expensive. The efficiency of the dwelling, the means (income) of a household and costs are all important in measuring the ability of a household to meet its needs for energy services (Roberts, 2008). This measure of poverty lacks meaning without contextual knowledge such as the relative size of the dwelling occupied, as illustrated by the following example: if a dwelling is considered to be under-occupied, the amount of heated living space is considered to be higher than necessary. The higher energy requirement of an oversized dwelling, and the poverty caused for such a household could arguably be considered qualitatively different to that of a smaller, but poorly performing dwelling. The first being caused by higher energy service demand (heated space), the latter being caused by poor efficiency of energy service delivery.

In a similar way, considering household energy from within a DCAT capability framework, a household can be considered as incapable of meeting its needs for energy services in current circumstances from a finite emissions budget. This framework considers the emissions intensity of energy services delivery as the primary concern. In both cases, without the pre-defined level of energy services required as a minimum threshold, the reason for a household being incapable of meeting its needs cannot be determined: it could be from either demanding a high level of energy services, *or* high emissions (or costs) intensity, or a combination of these factors.

Dwelling size standards therefore provide one measure of the 'over-consumption' of energy services. Of course, households occupying dwellings larger than the minimum size would still be capable of keeping within their emissions quota by occupying a dwelling of increased efficiency or by adjusting their demand for energy services.

7.2.8.2 FPI consideration of floor space

Consideration of a household's requirement for living space is made in the FPI methodology but it is not used in a systematic way to inform energy requirements: a household's current home is assessed against the Parker-Morris Standard for living space to determine whether the dwelling is under-occupied[23]. If a household is not considered to be under-occupying, the whole dwelling is assumed to be heated. For these households therefore, the energy demand (and costs) are calculated according to the size of the actual dwelling occupied by households. Where a household is deemed to be under-occupying a dwelling, it is assumed that only half is heated when calculating the household energy requirement[24] (Department of Energy and Climate Change, 2015b). This treatment of floor space in regard to heating demand is

[23] Under-occupancy is defined, in part, as a household with Surplus floor area, i.e. double that set out in the Parker Morris Standard (PM). Surplus floor space is not the only qualification for under-occupancy: the definition also requires a household to have surplus bedrooms: "A dwelling is considered to have surplus bedrooms if there are one or more extra bedrooms than required for homes without dependent children (children under 18 years); or there are two or more extra bedrooms than required for homes with dependent children" (DECC, 2015a, p.38).

[24] In Scotland energy requirements are not modified for under-occupancy (ref).

recognition that households under-occupying large dwellings do not need to heat the whole of their home.

As shown previously in this section, using survey data from the EHS, the efficiency of floor space utilisation relative to the minimum adopted in the dHCA model varies by household size: larger households occupy dwellings closer to the minimum size. Similarly, the EHS data is compared to the under-occupancy criteria of the FPI indicator in Figure 7.3 below. The chart shows the Parker Morris Standard floor space (PM) and under-occupancy threshold (2xPM) presented as a proportion of the median dwelling size from EHS data according to household size. Upper and lower quartiles are also shown to show the interquartile spread.

It is clear from Figure 7.3 below that the threshold set for 'surplus floor area' (double the Parker Morris Standard) is more likely to be exceeded by smaller households than larger ones. According to data from the EHS 2009 to 2012, for single-person households the median floor area is equal to twice that of the PM standard i.e. half of these households have surplus space. For larger households, this threshold lies an increasing distance above the 75th percentile of dwelling floor space.

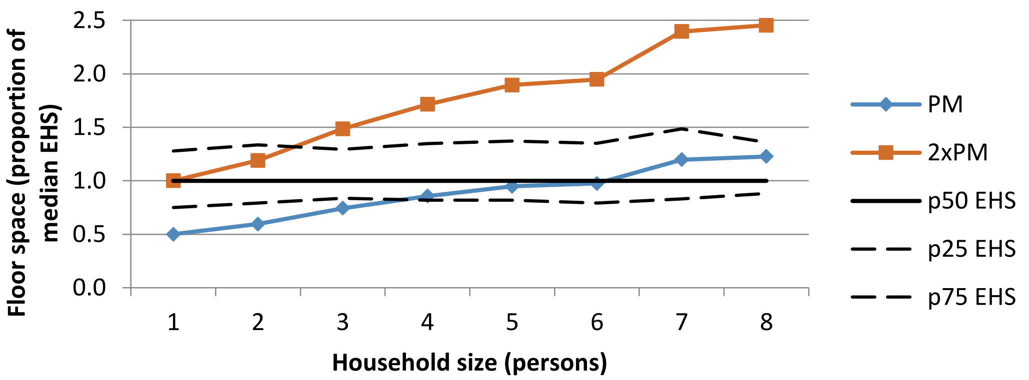

Figure 7.3 Under-occupancy threshold using the Parker Morris Standard and dwelling size of English households, EHS data (2009-2012)

This measure of under-occupancy results in an increased likelihood that smaller households be classified as under-occupying homes. The FPI methodology assumes under-occupied dwellings to be 'partially heated', with the implication being that energy requirements are more likely to be underestimated for smaller (one and two-person) households and fewer deemed fuel poor as a result. This partial treatment of under-occupancy biases the measure of under-occupancy toward smaller households and falls short of a consistent measure of how the dwelling occupied relates to the minimum space requirements of a household or more generally how the physical dwelling, and the provision of energy services within it, relates to the normative standards of 'decent homes' that already exist in the regulatory landscape. Examples are: Building Regulations (Department for Communities and Local Government, 2010b), Lifetime Homes (Lifetime Homes, n.d.) and Secured by Design (Police Crime Prevention Initiatives Limited, 2016).

Within the FPI the notion of household energy requirement is based on the current distribution of living space across households and the energy performance of the existing housing stock. The focus of the fuel poverty indicator as currently conceived is unable to describe the gap between a household's current housing situation (within the existing distribution) and a more desirable housing situation (a more equitable, and more energy efficient distribution). It is able to measure a household's current ability to afford the energy services required – given its current living arrangements (dwelling) - but unable to measure the gap between current living arrangements and those deemed to be sufficient. What is required for that measurement is an explicit normative measure of an appropriate (or minimum acceptable) dwelling size. This is exactly the contribution made by the dHCA model. In adopting a more explicit definition of the threshold for the minimum living space that a household requires, the dHCA model provides a threshold with which to measure the minimum energy services required by households of differing size (and by extension composition). This information allows for the calculation of the proportional household requirements for the allocation of differentiated emissions quotas. It also moves a step further than the FPI in the treatment of living space. As noted previously, the FPI measures household energy requirements using actual floor space (unless classified as under-occupying). The dHCA methodology, however, considers all household energy requirements to be based on a notional dwelling of only sufficient size to meet the minimum floor area. It therefore provides a method for measuring existing household circumstances, and specifically the provision of living space, against a defined minimum standard providing an essential measure of under- or over-consumption of living space. This measure – together with measurements of a household's energy services delivery systems – is required to assess the capability of a household to meet its need for energy services within both financial and emissions budgets, and further, a more accurate description of why a household might fall into energy or 'emissions poverty'. Before moving to a description of how the dHCA model is positioned relative to the existing distribution, the discussion will expand a little on the positioning of the dHCA model in terms of methodology.

7.2.9 Modelling perspectives

The dHCA method conceptualised and tested in this thesis provides an alternative approach for comparing household energy requirements. It provides the relative proportions of the minimum energy service requirements (living space and energy demand) for households of different sizes, thereby providing an allocation of emissions-rights on the basis of generalised need for energy services. The model is combined with statistics on the number of households of each size in the population, and the size of the sectoral emissions budget to produce emissions quotas differentiated by household size (as described in Chapters 5 and 6). The purpose of the dHCA model is to distribute the national carbon budget among households based upon need for energy services. It therefore approaches the task of estimating household energy requirements and emissions from a different perspective to existing dwelling-focussed approaches used to calculate household energy requirements and evaluate dwelling performance.

The dHCA was proposed as a response to the methodological problems and unjust outcomes of the EPCA and EPHH emissions quota allocation methods, and concern over the inequalities arising from the non-linear relationship between household size and energy related emissions. It aims to explicitly connect normative ideas about fair distribution of emissions from household energy with those of adequate minimum living space within the constraints of a shrinking national emissions budget. The approach used to allocate quotas in the dHCA is substantively different to the modified rules tested by White and Thumim, which were based on the estimation of actual demand using statistical analysis. In contrast to their method, the dHCA model uses a simple bottom-up energy service demand model to differentiate household emissions quotas.

Discussion

In using needs, and excluding the energy efficiency or emissions intensity of energy service delivery from the dHCA model, the resulting quotas are intended to be independent of the factors relating to the energy performance of dwellings. This provides mechanism with which to incentivise efficiency improvements without any embedded inequalities (or subsidies) related to fuels, materials, built form or other factors related to the building envelope and systems, unlike the modified allocation regime proposed by White and Thumim (White and Thumim, 2009). The resulting incentive is therefore much simpler to understand and fits within existing assessment procedures such as SAP i.e. reducing energy demand (kWh/m^2/year) or emissions (kgCO_{2e}/m^2/year). It should be noted that there are limitations to the first generation dHCA model related to excluding these factors altogether, see limitations chapter for further details.

As noted in Chapter 5, the dHCA method can be seen as moving further toward measuring household energy service needs (in isolation from the dwelling) than other studies. The 'dwelling-focussed' methods such as BREDEM and SAP describe only part of a household's capability set and provide a measurement of the cost, energy efficiency and emissions intensity of delivered energy services. In contrast the household-focussed approach of the dHCA represents the level of energy services required to meet a defined minimum level of *functioning* (or definitive list of *intermediate needs*). The dHCA model, as with the *Bare Necessities* study, provides the minimum standard with which an evaluation of the level at which households are occupying living space can be performed. Definitions of minimum acceptable dwelling sizes provide an absolute measure of Gough's notion of intermediate housing needs and the benchmark against which to measure the provision of living space. This provides essential information with which to assess the notion of poverty and position a household's measured consumption against its needs. This measurement of floor space, along with the definitions of minimum energy service levels, provides the link between the two perspectives, occupant and building. Further, they can provide benchmarks against which the energy service 'consumption ratio' of measured demand to needs, can be measured. The principle behind such a measure is already in use within UK energy and social policy: the Fuel Poverty Indicator (Department of Energy and Climate Change, 2015b).

7.2.10 Summary

The first part of this chapter has presented fuel poverty as a policy driver which has played a significant role in the evaluation and development of PCT in the UK. It has been argued that the response by White and Thumim (2009) to mitigate the impact of EPCA does not align with an integrated response to the twin social and environmental policy drivers: responding to fuel poverty by reducing the impact of PCT on vulnerable households has been given the priority over producing an integrated eco-social policy response. An evaluation of their study into differentiated household quotas highlighted their methodological limitations.

Further, it has been argued that the fuel poverty indicator provides an example of a needs-based approach adopted for use in energy policy in the UK. However, while the indicator differentiates household fuel requirements by household composition, the treatment of living space is not systematic and appears to bias the indicator against smaller households. Both approaches also focus on the existing circumstances (living arrangements) of households without distinguishing demand and need, and with little reference to the question of a minimum acceptable standard, specifically in terms of dwelling size.

This section has reviewed dHCA in regard to the question of integration of environmental and social policy goals and the alternative strategy of providing countervailing or supporting measures. The needs-capabilities approach, together with the expansion of the energy service delivery chain, has been shown to provide a comprehensive theoretical framework to consider the factors to be included or excluded from a differentiated quota allocation. The dHCA method adheres to the approach promoted by Hyams (2009), and assumed by Fleming (2007): keeping the differentiated allocation as simple as possible, while appeasing concerns over fairness, and allowing supporting policies to tackle other structural causes of inequalities.

The dHCA approach takes the first step toward a needs-based emissions allocation in taking account of household size. The next logical step would be to take account of households with small children, pensioners, unemployed members or occupants with disabilities. These households would justify increased emissions quotas due to increased occupancy rates (and associated increased duration of space heating/cooling demand), higher internal temperatures and other additional energy service demands such as hot water, cooking and washing. Taking account of these factors would add additional layers of complexity to the dHCA model in two aspects: first, the household matrix would requiring the age of household members and disability status to be identified in order to create additional household types; second, the quota calculation for these households would need to take into account increases in regulated and unregulated energy demand caused by changes to the standardised assumptions of energy service demands noted above.

7.3 The dHCA model results in context

7.3.1 Overview

This part of the discussion will provide a comparison of the floor space allocated by the model for households with that gained from analysis of the English Housing Survey (EHS). The dHCA model describes a 'minimum standard' scenario in terms of living space provision. This section will position the floor space allocated to households by the model within the current distribution across the housing stock. The existing dwelling stock is described by the English Housing Survey (EHS) dataset. Data for the period 2009 to 2012 is used in order to match the period covered by the household expenditure dataset (Department for Communities and Local Government, 2016a, 2016b, 2016c, 2016d). Of primary relevance to the dHCA scenario is the distribution of floor area across households.

7.3.2 Household size

Chapter 4 described how the existing approaches to allocating emissions quotas to households, EPCA nor EPHH, do not adequately deal with the relationship between household size and emissions from energy demand. The fuel poverty methodology uses actual living space in calculating energy 'requirements' but provides an unsystematic assessment of adequate living space. In contrast, the dHCA model adopts a more comprehensive approach, using a notional minimum floor area as the basis for calculating household energy and emissions needs.

The results from the comparative analysis of residual household quotas provide evidence that dHCA creates a more equitable distribution according to household size despite using a needs-based demand model as opposed to one based upon existing demand. The dHCA therefore achieves a more equitable distribution across household size without creating the perverse incentives that were generated by White and Thumim (2009). The results from this study presented in the preceding chapter demonstrate that the negative redistributive impact on single-person households under EPCA can be mitigated relatively successfully using an allocation of quotas differentiated by household size. For the dHCA allocation, the quota deficit present under both variants of EPCA is transformed into a surplus at the median. In addition, comparing the dHCA allocation to EPHH shows that the surplus for single-person households under EPHH is reduced and the increasing deficit for larger households is replaced with a surplus. In terms of impact across household size, dHCA is the most neutral when compared to EPCA and EPHH methods, with residual quotas sitting between the two. The modified EPCA allocation resulted in a lower mean deficit among single-person households and a small reduction in mean deficit among two-adult households. Three and four adult households saw the mean quota surplus reduced.

7.3.3 Positioning the dHCA model

In Figure 7.4 below, the floor area of dwellings in England (obtained from the EHS) are plotted against the floor area used in the dHCA model. Also included for comparison are the floor areas of the Parker Morris Standard. The figure shows that the dHCA model generally adopts a dwelling size smaller than the median for households of six persons and smaller. Floor areas adopted by the dHCA model are shown to be closer to both the median and mean dwelling size for households in England than the Parker Morris Standard, with the exception of four and five-person households. For seven-person households the dHCA model provides floor area closer to the median EHS value, while the Parker Morris provides floor area closer to the mean.

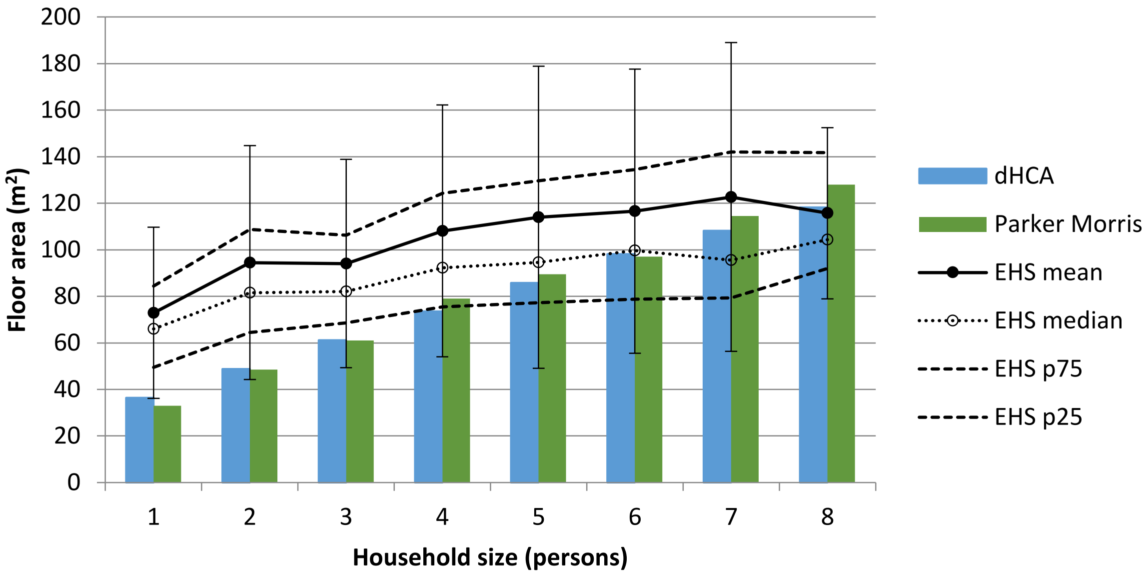

Figure 7.4 Mean floor area by household size compared to dHCA model input (EHS 2009-12)

The dHCA scenario does not represent a consistent point in the distribution of floor space across household sizes. This is revealed by examining the percentile at which the dHCA scenario dwelling size is equal to dwellings in the existing population. Analysis of the EHS shows that for English dwellings, as the number of household occupants increases, the proportion of households with floor area above that assumed by the dHCA model generally decreases. This is indicated by the final column (Percentile) in Table 7.4 below. For example, for households containing one or two occupants, the dHCA adopts a dwelling of equal size to one in the 7th percentile. Put another way, 93 per cent of one or two person households in England had a floor area larger than that allocated by the dHCA model. This decreases to 61, 51 and 41 per cent for five, six and seven person households.

		Total floor area (square metres, m^2)						
Household size	N	dHCA TFA	Mean	sd	Median	P25	P75	Percentile
1	16682	36.5	72.9	36.8	66.0	49.5	84.4	7th
2	20367	48.8	94.5	50.3	81.5	64.4	108.8	7th
3	9211	61.2	94.1	44.8	82.1	68.6	106.3	14th
4	7668	73.5	108.1	54.1	92.2	75.5	124.3	22nd
5	2851	85.8	114.0	64.9	94.5	77.2	129.6	39th
6	964	98.2	116.6	61.0	99.6	78.7	134.5	49th
7	291	108.2	122.7	66.2	95.6	79.4	142.0	59th
8	115	118.2	115.7	36.6	104.3	92.0	141.8	56th

Table 7.4 Summary statistics of dwelling sizes by number of occupants, EHS 2009 - 2012

These figures reveal that smaller households are living less efficiently than larger households when compared to the dHCA minimum dwelling sizes (i.e. a greater proportion of households occupy dwellings larger than the dHCA scenario). Therefore, when compared to existing dwelling sizes, the dHCA scenario represents a greater reduction of living space for smaller households than larger households. With dwelling size positively associated with emissions (Thumim and White, 2008), the resulting pattern of quota surplus and deficit across household size modelled with current household emissions is in line with expectations: larger households are better-off relative to smaller households even when quotas are differentiated for household size using the dHCA method.

A more neutral distribution of quota surplus/deficit would be expected across household size if dwelling sizes within the dHCA model were based on median values from the EHS. This reveals a significant feature of the dHCA model and the needs-based methodology: it does not aim to produce a neutral distribution with respect to household size. As noted above, the difference in the size of dwellings from EHS data compared to the minimum standards such as Parker Morris or London Housing Design Guide varies across household size, and therefore the residual quotas would be expected to produce an outcome reflecting this. This is in fact what the results by household size show: larger households with median dwelling size closer to the dHCA model are more likely to receive a quota surplus than one or two person households.

Discussion

While it is outside of the scope of this project to compare the residual quotas obtained using different minimum space standards the choice of dwelling size standard adopted by the dHCA model will clearly alter distributive effect across household size.

7.3.4 Dwelling size

In terms of dwelling size, the residual quotas were compared using number of rooms as a proxy for dwelling size. This study provides evidence that all four allocation regimes result in a redistributive affect from larger to smaller dwellings and that the dHCA method produces a greater redistributive effect across dwelling size than both variants of EPCA. This is in contrast to the modified allocation rules by White and Thumim (hereafter the ‘modified EPCA’) which, when applied to all households, resulted in a smaller redistributive effect than EPCA (White and Thumim, 2009). The quota surplus and deficit levels for dHCA also lie between the values for EPCA and EPHH when considering dwelling size and income.

7.3.5 dHCA as a reduced consumption scenario

The dHCA reflects a reduced ‘consumption’ scenario with all households occupying dwellings that are sized to provide the minimum floor space required by household size. Table 7.5 presents the aggregate floor area statistics for England, calculated using the EHS and the dHCA model (aggregate floor space is shown in 000s m^2) in order to compare the dHCA model with the amount of floor space currently occupied by households.

	2009	2010	2011	2012
EHS (000s m^2)	2,034,334	2,051,531	2,075,582	2,079,767
EHS mean dwelling size (m^2)	94.5	95.0	94.7	94.8
dHCA (000s m^2)	1,147,564	1,165,942	1,160,982	1,237,179
dHCA mean dwelling size (m^2)	53.1	53.0	53.3	53.2
dHCA % of agg. floor area	56.4%	56.8%	55.9%	59.5%
dHCA % of mean dwelling size	56.2%	55.8%	56.3%	56.1%

Table 7.5 Aggregate floor area comparison (England only), comparison between dHCA model and English Housing Survey 2009 - 2012

The mean floor area of all dwellings calculated from the EHS survey, for the period 2009 to 2012, is approximately 95 square metres. This compares to an average dwelling size of approximately 53 square metres for the dHCA scenario. The dHCA scenario represents approximately 56 per cent of the occupied floor space for England. The 'minimum standard' dHCA scenario therefore represents an aggregate 44 per cent reduction in living space based on the data for England only. Comparing the existing distribution of dwelling sizes across households with the dHCA model sizes reveals that significant changes to the housing stock would be required to reflect this reduced consumption scenario. While smaller households are constrained by the availability of dwellings of a suitable size, if such changes were to occur, the implication for dHCA would be that smaller households would fare better.

7.3.6 Other factors

The dHCA method is aimed only at differentiating quota levels by household size, therefore, other factors associated with high emissions, for example the use of oil as central heating fuel, remain largely unaffected by a change in allocation method from EPCA to dHCA. The differential impact of the method by central heating fuel type is due to the different within-group characteristics of heating fuel across household size. The bottom-up approach of the dHCA method contrasts with the study by White and Thumim (2009) into mitigating the impact of a PCT scheme. When compared to the EPCA and EPHH methods, the analysis results indicate that dHCA provides a successful attempt to introduce living-space utilisation into the quota allocation system.

7.3.7 Energy efficiency

If all households in England conform to the minimum need scenario used in the dHCA model, the dwelling emissions rate required to stay within a sectoral budget for residential energy can be calculated. In Table 7.6 below, the 'regulated' emissions budget is shown together with the aggregated floor space. Chapter 5 details how the dHCA model defines the regulated and unregulated components of household energy demand, and how they are used to calculate household emissions quotas. Regulated energy, generally speaking, relates to the provision of space heating and cooling, hot water and fixed lighting and is controlled in the building regulations as emissions per unit area of floor space. It relates directly to the measured energy performance of homes – the dwelling emission rate (HM Government, 2014).

Using the regulated budget and aggregate floor space, the efficiency that dwellings would be required to meet to stay within the sectoral carbon budget can be calculated. This average efficiency can be expressed as a target dwelling emissions rate, in line with the metric used by building regulations in England (HM Government, 2014). For the period 2009 to 2012 the target rate generally reduces from 92 $kgCO_{2e}$ per square metre of floor area, to 84 $kgCO_{2e}$. If the emissions rate is calculated using the aggregate floor area calculated from the EHS the target is much lower, at 52 $kgCO_{2e}$ per square metre in 2009, reducing to 50 $kgCO_{2e}$ in 2012.

	2009	2010	2011	2012
Regulated emissions budget MtCO2e	106.1	110.7	99.2	103.9
Aggregated floor area (EHS) thousands of square metres (000s m2)	2,034,334	2,051,531	2,075,582	2,079,767
Target dwelling emissions rate (EHS) kgCO2e/m2/year	52.1	53.9	47.8	49.9
Aggregated floor area (dHCA) thousands of square metres (000s m2)	1,147,564	1,165,942	1,160,982	1,237,179
Target dwelling emissions rate (dHCA) kgCO2e/m2/year	92.4	94.9	85.4	84.0

Table 7.6 Comparison of dwelling efficiency targets based on aggregate floor area (England only), dHCA model output (LCF data) and English Housing Survey 2009 - 2012

This simple calculation demonstrates that there is a balance between floor space utilisation and energy performance targets if the residential sector is to keep within a sectoral budget. The results of the dHCA model presented here, like Druckman and Jackson's *Bare Necessities*, demonstrate that in providing housing that meets only the minimum space requirements of households, dwellings would be required to meet less onerous performance standards to keep household energy emissions within the sectoral budget.

The dHCA model uses two components to determine household emissions quotas, the regulated and unregulated energy requirements. The regulated requirements are determined by (and proportional to) floor space and the unregulated energy requirements are determined by household size. As the provision of the regulated services becomes more efficient, through improvements such as the installation of insulation measures and less emissions-intensive heating technologies, the ratio of regulated to unregulated energy requirements will change. This change will alter the relative size of emissions quotas between households of different sizes – thus changing the equivalence values of households of different sizes.

7.3.8 Equivalence scales

Equivalence scales can be used to make inter-household comparisons and provide indexing of goods in the measurement of the standard of living (Lewbel and Pendakur, 2008). In Figure 7.5 below, the equivalence factors are presented for a number of household energy related measurements discussed in this chapter: the mean dHCA emissions quota (2009 to 2012); the Fuel Poverty Indicator (FPI); and the EHS, Parker Morris Standards and dHCA model floor space. Equivalence scales are only presented for households of up to five persons, as the FPI equivalence scale considers all households of five persons and above as having the same equivalence value. The values presented follow the FPI in using two-person households as the reference case (Department of Energy and Climate Change, 2015a).

Figure 7.5 shows that the FPI provides equivalence values for household energy requirements (costs) that are close to those obtained for the EHS median floor space values for dwellings, indicating a correlation between dwelling size and energy requirements measured in cost.

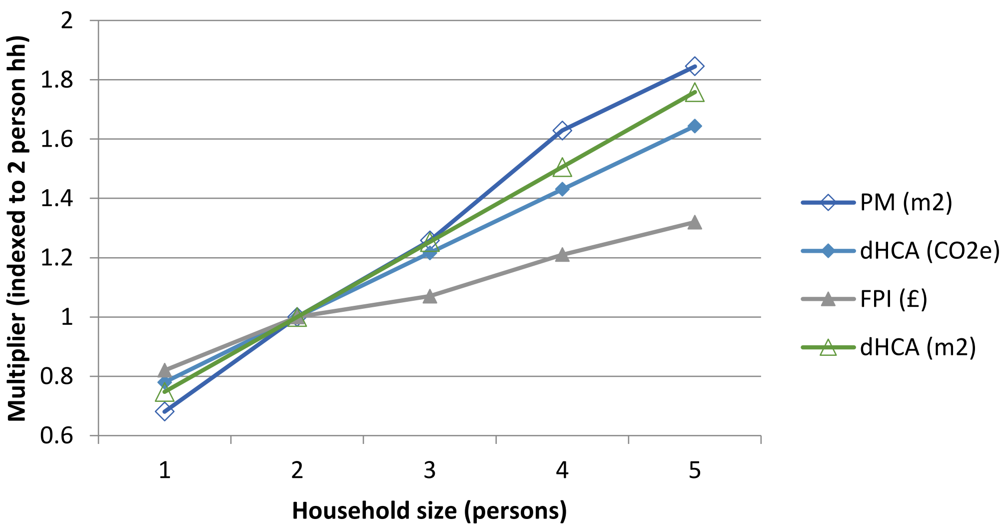

Figure 7.5 Equivalence scales for energy related goods by household size

In contrast the equivalence values for dHCA emissions quotas generally show larger differences between household sizes and are closer to those obtained for the floor areas of dHCA and Parker Morris Standard. This comparison shows that the equivalence scales are least varied across household size when calculated by dwelling floor area (existing), followed by calculated energy requirements. The most varied is the equivalence scale produced from the Parker Morris living space standard, followed by the dHCA living space and finally the equivalence values based on the dHCA emissions quotas. The dHCA methodology does not distinguish between child and adult household members and in this regard is in line with the Fuel Poverty Indicator methodology for fuel costs (Department of Energy and Climate Change, 2015a, p.101).

With the findings that dHCA is an allocation method with advantages in terms of redistributive outcomes, the analysis will now turn to the implications of adopting a household-based allocation method.

7.4 Policy Implications

7.4.1 Administrative arrangements and costs

The scope of this work ruled out a detailed examination of the implications of adopting dHCA, for example recalculating the costs of an alternative household-based scheme design. However, the review of the policy and academic literature, along with the microsimulation modelling and redistribution analysis, allows the drawing of some general policy implications for the design and implementation of DCAT in the UK. Furthermore, the application of the needs and capabilities framework to the residential energy context potentially provides new for policy-makers. In this discussion section, I will return to the themes identified in the review of the current literature (see Chapters 2 and 3)

It is outside the scope of this thesis to explore elements of the cost-effectiveness space for DCAT, such as potential additional emissions abatement or carbon price, however some implications can be identified of the impact a household-based approach would have on scheme costs. In Chapter 3 it was noted that evaluations of cost-effectiveness would rule out DCAT on the grounds of large transaction costs. Calculations typically assume PCT would include the participation of 50 million individuals. Adopting dHCA or other household-based scheme would alter the issue and surrender regime for all scheme variants as quotas of emissions-rights, or the revenue from sale, would be distributed to households rather than individuals. As only one account per household would need to be held, irrespective of the size, a household system would dramatically reduce the number of accounts required over an individual-based system from 48.2 million (61.3m if including accounts for children) to 26.2 million.

Adults	48.2 m
Children	13.1 m
Total	61.3 m
Households	26.2 m

Table 7.7 Population and households, 4 year average, LCF data (2009 – 2012)

The number of agents and transactions occurring within the system would be substantially reduced due to the reduction in participating agents, although the system of enforcement would determine the arrangement of accounts and how many transactions would take place over (Eyre, 2010; Starkey, 2012a, 2012b). In operation, it is unlikely that a dHCA scheme (with the scope restricted to household fuels) would be implemented in the way described for HHCT by Niemeier et al. (2008). In their proposal, accounts would be held and administered by utility service providers utilising existing systems but with account holders retaining full control of their allowances:

> Since each household already has an account with a utility provider the existing infrastructure can easily be used to facilitate the HHCT system. The utility account would then double as a carbon allowance account. The owner of the account would have complete control over these allowances even though the account is set up through the utility. (Niemeier *et al.*, 2008, pp.3438-3439)

It is common for households in the UK to use multiple fuels. Therefore, households would require an account at each utility provider and the issue and surrender regime described by Niemeier et al. (2008), reproduced in Figure 7.6 below, would be duplicated for each fuel supplied to a household. The system would require the transfer of emissions quotas between each utility account for a household to be able to surrender the required emissions permits for each fuel.

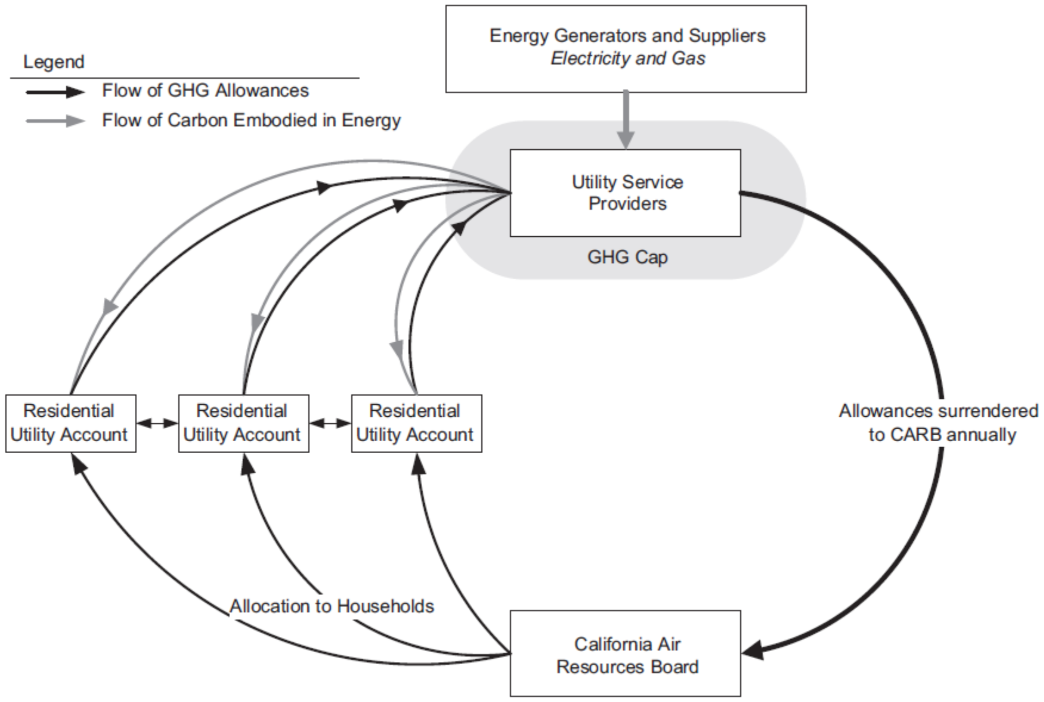

Figure 7.6 Household-based issue and surrender regime (Niemeier *et al*., 2008)

The HHCT accounting and enforcement arrangement is contrasted by the proposals of schemes with individuals holding carbon accounts. In an individual-based system it is likely that a hybrid arrangement would emerge using a variety of surrender mechanisms (Starkey, 2012a). Whatever the arrangement, moving from an individual to household-based system implies a significant reduction in the number of accounts and associated set-up and running costs for accounting and enforcement.

Administration and data requirements

Moving to a differentiated household system as opposed to an equal-per-household system would result in an increase in administrative burden (and costs). While individuals sharing accommodation would no longer be required to pool their individual quotas to settle a carbon account, additional administrative arrangements would be required to ensure that households were claiming to have the correct number of occupants. There would be an incentive for households to claim more members to increase their quota and systems to track the number of individuals residing in each household would be required to tackle fraudulent behaviour. White and Thumim's study set the condition that for any factor selected for mitigation, information "should be practically obtainable and verifiable by the operator of a UK PCT system" (White and Thumim, 2009, p.9).

The data requirements would increase along with the number of factors qualifying for additional quotas however, there would be the potential for the quota system to integrate with existing systems used to administer other state benefits such as child benefit and pensions. Such arrangements are likely to be sensitive with respect to public acceptability. Defra's pre-feasibility research found that key concerns over trust in Government related to the holding (and use) of personal data, although the timing of the study coincided with high-profile data security incidents (Defra, 2008b, p.14). Likewise public (dis)trust in energy utility companies is also likely to be a concern among the public, with similar levels of trust reported in Government and energy companies to "… focus on the best interests of consumers and wider society" (YouGov, 2014, p.13).

While this investigation has not examined the administrative arrangements of downstream cap-and-trade schemes in any detail, the reduction in the number of accounts held by citizens and the ability of utility companies to incorporate carbon accounting into existing accounting systems suggest that the costs of a household system would reduce initial set up costs, and be significantly less than an individual system. However, any decrease in system costs would only result in a more cost-effective scheme if the reduced administration costs outweigh the additional costs of determining the number of members in each household (and other qualifying criteria). There would seem to be some potential here for data linkage between administrative bodies to save costs, for example electoral registers, local authorities and welfare benefits systems. As noted above, such arrangements raise considerations of trust and data privacy which in turn affect public attitudes and political acceptability. While these aspects are outside the scope of this study, however, the public acceptability and political feasibility are affected by the initial distribution of emissions quotas, this will be examined in the next section.

7.4.2 Public attitudes and political feasibility

As detailed in Chapter 3, the existing literature on public attitudes to PCT clearly shows that people are sensitive to the issues of fairness and equity and view PCT schemes as fairer than alternatives such as a carbon tax. The literature also reveals the significance of the allocation method and that differing household circumstances should be considered when distributing emissions permits. The findings of Bird and Lockwood - that the public recognise the failings of EPCA in this regard – indicate that adopting dHCA might lead to a widening of the preference gap in favour of DCAT schemes over energy and carbon taxation, or at least further distinguish such policy options from carbon, or energy taxes and the preference for DCAT over taxes.

Any improvement in public support is likely to be strongest among the groups that fare better under dHCA than EPCA due to the self-serving bias reported by Jagers et al. (2010). Accordingly, groups of households found in this study to fare better under a dHCA regime, for example single-person households and single-parents, would be expected to display an above average increase in support. The reverse would be true for other household types that would be worse off under dHCA, i.e. couples without children. The attitudes to income redistribution, found by Jagers et al. not to adhere to the self-serving bias, would also point to greater support for dHCA than EPCA due to the stronger re-distribution across income deciles. The strength and persistence of these biases in view of the dHCA method require testing.

7.4.3 Supporting policies

The needs and capabilities framework presented in this thesis provides the analytical tools required to better understand mitigation strategies in response to the factors causing high household energy emissions. The framework makes explicit the causes of high emissions: whether from a high demand for energy services by occupants, or poor efficiency of dwelling fabric and service delivery systems. The framework, with its inclusion of the notions of wellbeing and capabilities, aligns well with recent reframing of energy efficient policies towards wellbeing among other benefits. For example, Rosenow and Sagar (2015) call for wellbeing to be integrated within the metric with which energy performance for homes is measured.

The needs-capabilities framework also has the potential to provide more clarity on the ethical judgements for which factors to provide compensatory measures (or mitigation against negative impacts). As identified in the first part of the discussion, differentiation and mitigation of DCAT are directly linked. If mechanisms already exist to tackle inequalities, for example geographical location, then these existing policies must work effectively in order to avoid inequalities arising or persisting with the introduction of DCAT. Existing policies may also need to be revised in order to act effectively. Such policies can be considered as directly supporting desired policy outcomes, but others would also be required indirectly. If DCAT policy proved to be effective in incentivising rapid energy efficiency improvements in the housing stock, the resulting increase in labour and materials would need to be predicted and supported. If this indirect support were to be unavailable then unforeseen inequalities might arise. For example, regional availability of materials and labour might result in regional bias to the energy performance of dwellings. Another example might be that a shortage in the supply of energy efficiency upgrades would result in increasing prices, which would introduce further bias in delivery by household income i.e. wealthier households find efficiency improvements more affordable.

8. Conclusion

8.1 Summary

The chapter is structured in two parts. First, the findings are presented in the next section with reference to the objectives stated in chapter 1. Second, the limitations of this study are described along with recommendations for further work.

As the culmination of an interdisciplinary project, this thesis applies a more nuanced understanding of energy justice to the context of domestic energy demand and downstream cap and trade schemes. The contribution of this work to the literature is twofold. First, a contribution is made by the application and integration of two theories of wellbeing to understanding the energy needs of households. More specifically, a needs-based energy demand model is applied to the problem of allocating emissions rights under a downstream cap and trade scheme, and a capabilities approach is applied to understanding the potential of households to respond to policy incentives. Second, an empirical contribution is made by performing a comparative redistribution analysis of four methods of allocating emissions-rights. This has provided evidence to support the conclusion that a needs-based household emissions allowance (accounting for the number of persons in a household) mitigates the differential impact of DCAT across households of different sizes, when compared to alternative allocation methods.

This thesis describes how the needs approach provides the foundation for a simple model of household energy or emissions requirements. While intentionally kept simple, the approach is robust for more complex models. Further, when evaluated using the capability framework, clearer distinctions can be made on the causes of high household emissions. This framework provides a tool for evaluating whether factors should be mitigated or not, and whether the factors should qualify for additional quotas, or be mitigated through other supporting measures. Drawing on a combination of the theoretical and empirical work, a further contribution is made in the analysis of the implications of adopting a household-based allocation on DCAT policy design. This thesis was conceived with the aim of understanding the opportunities and barriers to PCT as a policy idea. Fuel poverty was identified as an issue that has, so far, constrained the development of policies such as PCT in the UK. Bringing together an analytical and evaluative framework that can include notions such as 'prebound' and the 'need' effect on energy consumption, provides an integrative space within which to examine the tensions and trade-offs between environmental and social policy aims.

8.2 Findings

Objective 1: Determine what stage PCT has reached within the policy process and what opportunities and barriers exist for further development.

The first objective has been met by providing a review of the literature presented in Chapter 3. The review identified three main stages of policy development: the initial proposals and academic interest; the spike of activity related to the commissioning of the pre-feasibility study by Defra; and a subsequent period of more focussed academic inquiry. The policy interest from the UK Government and the increased academic interest resulted in a significant increase in the peer-reviewed literature and a more critical examination of PCT policy proposals and empirical evidence generated from a number of perspectives. This literature has provided policy relevant analysis of many aspects relevant to policy decisions.

Generally PCT is seen as a desirable policy option but one that does not fit within the wider climate change strategy and policy landscape. It is seen as a radical policy option lacking political support that is unlikely to be considered unless other policies have failed. Key questions remain and PCT is still considered by both the academic and policy community as a concept rather than a credible policy option. Significantly, the Government's own Environmental Audit Committee criticised the lack of leadership in continued research into PCT, suggesting that barriers to the policy could be overcome. The committee called for more debate around public and political acceptability, which was heeded by the research community. As a result, social acceptability became the most active area of research. In this recent body of research, the link between PCT and fairness is examined with a focus on public attitudes, generating some evidence that the public view PCT more favourably than carbon taxation. Further, public support is linked to the design of the scheme and the method with which quotas are allocated and identified that additional quotas should be given to those with additional needs. Finally, in assessing the potential distributional impact of PCT, existing inequalities were identified and concerns raised about the impact upon vulnerable households.

The issue of the design of PCT schemes, and specifically the use of the individual as allocation unit and the equal-per-capita method, was found to cut-across the themes found in the literature review. Alternative scheme designs were considered to be part of the policy development process, however, despite having the potential to address many of the barriers and opportunities, new proposals remain absent from the literature with one notable exception. Fuel poverty was identified as being a defining concept, both in terms of evaluating the impact of PCT in the UK and in constraining the development of alternative allocation regimes in response.

Objective 2: Review the theoretical underpinnings of the equal-per-capita allocation method and demonstrate ethical and methodological challenges to PCT as currently conceived.

In Chapter 4, I presented a problematisation of the equal-per-capita (EPCA) quotas adopted by most variations of DCAT scheme proposals. The objective has been fulfilled by offering a critique consisting of two challenges, one philosophical and one methodological. An argument on philosophical grounds was presented, challenging EPCA on the grounds that simply giving individuals equal rights to use the atmosphere as a sink for GHG emissions does not give effect to moral equality. In adopting EPCA, DCAT schemes create unequal outcomes for households based upon the structural inequalities that exist in energy consumption. Critiques from both the ethical and empirical literature support the counter argument that equality in the domain of household energy demand, whether viewed from an individual or household perspective, is only realised through an unequal distribution of emissions quotas.

A second challenge was directed toward the methodological individualism of EPCA. I presented a critique of considering the individual as the unit of allocation when, using a socio-cultural understanding of energy use, energy services are shared within households; both in terms of the energy using appliances and systems, and the services themselves. This section concluded that methodologically, it is the household, not the individual that provides the correct unit of allocation and analysis in the domain of residential energy demand.

Objective 3: Review alternative principles for allocating emissions that are compatible with the ethical challenges and determinants of household emissions. Operationalise into a model for distributing emissions quotas.

The second part of Chapter 4 provided a review of alternative principles for allocating emissions rights. Equal-per-household, historic (grandfathered), and quota allocations linked to dwelling performance were all considered, with the conclusion that none provided a satisfactory solution as none of the methods could adequately address the relationship between household size and emissions or the ethical demands that efficient use of resources be rewarded. In response, an approach to equality based on human wellbeing was examined. Sen's *capabilities*, and Doyal and Gough's *human needs* offer the theoretical framework required to make moral distinctions about the under- and over-consumption of energy in the home. The framework provides the analytical tools with which to understand energy as means to achieve (or *capabilities*) the ends of supporting human wellbeing (or *needs*). This framework provides the *sufficiency* principle of allocation.

Finally, the remaining part of Chapter 4 described how the needs-capabilities framework was operationalised simply by adapting the existing standards and procedures used in the regulation of dwelling energy performance. Chapter 5 presented a simple needs-based energy demand model used to operationalise the sufficiency principle into a differentiated household carbon allocation method (dHCA) along with the empirical evidence and literature underpinning it.

Objective 4: Provide analysis of the redistributive impact of dHCA and compare with existing methods for allocating emissions-rights such as equal-per-capita (EPCA) and equal-per-household (EPHH).

This research objective has been met by providing a comparative analysis of four quota allocation methods: differentiated household carbon allowance (dHCA), equal-per-household (EPHH), equal-per-capita (EPCA) and equal-per-capita with an allowance for children (EPCA+ch). To provide the empirical data for this analysis a microsimulation model was created to estimate household energy consumption and emissions and to calculate household emissions quotas. The LCF survey provided household level fuel expenditure data and was used to calculate household emissions and aggregate, residential sector emissions. The aggregate emissions provided the sector budget that the model allocated to households as quotas.

The microsimulation modelling and analysis of residual household quotas provided evidence to support the following conclusions on the redistribution potential:

1. The dHCA method results in a distribution of residual quotas that is different to the three other allocation methods modelled and is statistically significant.
2. With respect to household income, all of the allocation methods were generally progressive: with the potential to redistribute from higher to lower income groups[25].
3. The dHCA method has a greater redistribution potential than both variants of EPCA although not as great as EPHH. Similar findings were observed for households grouped by the number of rooms in a dwelling (a proxy for dwelling size).
4. In terms of household size (number of persons), the dHCA method reduces the negative impact on single-person households, including pensioners, when compared to both variants of EPCA. It is also provides more favourable quotas for single parents. The dHCA is the most neutral of the four allocation methods for one and two-person households. For larger household sizes, the dHCA results in residual quotas that fall between the least and most distributive.

Objective 5: Examine the implications of adopting dHCA in practice. Provide an analysis of the impact of dHCA for the feasibility of DCAT schemes in the UK.

Moving from an individual scheme to a household scheme would reduce the number of quota accounts required from 48.2 million (61.3m if including

[25] The distributive impact is potential as the simulation method does not model household response to the incentives produced, nor does it apply a price to emissions. See limitations for further detail.

accounts for children) to 26.2 million. While the associated set-up and running costs would also be reduced due to the reduced number of accounts, the development costs for the system would likely be similar as the accounting and enforcement regime would be the same for either scheme design. The administrative burden, particularly of keeping up-to-date records of the number of persons in each household, would however increase. Any decrease in system costs would only result in a more cost-effective scheme if the reduced administration costs outweigh the additional costs of determining the number of members in each household (and other qualifying criteria).

In terms of public support, the literature indicates that adopting dHCA could lead to an increase in the preference for DCAT schemes over energy and carbon taxation, or at least further separate it with respect to equity concerns. The literature also indicates that public support is likely to be strongest among the groups that fare better under dHCA than EPCA. Households found to benefit under dHCA would be expected to display an above average increase in support. The reported attitudes to income redistribution would also point to greater support for dHCA than EPCA due to the higher redistributive potential of the method by income decile. Public acceptability could however, be negatively impacted by additional administrative arrangements (over and above those required by an equal-per-capita system) required to administer a household system.

8.3 Limitations and future work

This section will outline the limitations of the work undertaken in this thesis and will identify potential future avenues of enquiry. It will be divided into three sections related to: the limitations of the dHCA model, the limitations of the microsimulation model, and future work on administrative arrangements for a household allocation approach to DCAT.

8.3.1 Limitations of the needs-based energy demand model

A significant limitation of the first generation needs-based energy demand model is the unregulated component of needs-based energy demand. In the work undertaken for this thesis it was necessary to simplify the modelling. This included the representation of both the regulated and unregulated elements.

The calculation representing unregulated demand (appliances and cooking) utilised survey data (see Section 5.4). In using this calculation (and measured energy consumption data), the unregulated demand component approximates actual energy consumption according to household size. This is not aligned to the needs-based methodology, which makes the distinction between needs and measured consumption. Further, the sample size, particularly for larger households, was small. Future work on integrating a bottom-up, end-use demand model for unregulated energy demands would better align this component with the needs-based energy demand methodology. Examples of this approach are Paatero and Lund (2006) and Richardson et al. (2010).

Another limitation of the needs-based model is the over-simplification of the regulated demand component. While Fahmy et al. (2011) found that the number of bedrooms was the variable with the single largest effect size, their analysis was conducted on the existing distribution of households within the dwelling stock. Further analysis is required of the relationship between dwelling size and energy demand, particularly in the context of a scenario with minimum dwelling sizes and normalised energy performance. Further work is needed to provide a more robust evidence base for describing the comparative 'regulated' energy needs for households of different sizes in the dHCA scenario.

Finally, adapting the SAP methodology for use in the dHCA reduced consumption scenario requires further consideration of potential methodological inconsistencies. The calculation algorithms are based on empirical data on energy demand and the implications of using them to model reduced consumption scenarios such as the dHCA requires further investigation to determine its suitability, and re-calibration for this use.

These limitations provide a modelling agenda for the next generation needs-based energy demand model (and dHCA emission allocation). Combining the two elements (regulated and unregulated) would provide the most robust approach from a building physics simulation perspective. McKenna and Thomson demonstrate an integrated approach using an integrated thermo-electrical household energy demand model (2016).

8.3.2 Limitations of the microsimulation model and data

As previous distribution impact analysis has revealed, the heterogeneity of some household groups (i.e. by income, household size or type) can hide significant changes in the distribution of residual quotas due to other factors (see White and Thumim, 2009). The general trends reported in this study should be further analysed using a dataset that includes more comprehensive information about physical (dwelling) variables in order to further examine the role of other structural factors in winning and losing groups.

The use of a static arithmetic microsimulation model has limitations in terms of inferences that can be drawn. The first is that while the change in quota surplus and deficit levels for households can be quantified for various methods of allocating emissions rights, the response of households to the change in incentive cannot. The second is that despite quantifying the median (or mean) change in quota levels for households grouped by characteristics, the differential response of households in differing circumstances (for example income) cannot be predicted and is assumed to be uniform. The simulation can provide no insight into the behavioural impact of adopting an alternative allocation regime.

The analysis is limited by the non-representative nature of the LCF survey dataset at the level of individual households. The use of expenditure data produces accurate mean group values but not at the household level due to the infrequency of purchase problem. This also leads to the overestimation of measures such as the standard deviation and variance (Büchs and Schnepf, 2013). Future analysis would ideally include energy consumption data at the household level to improve the analysis of distribution within groups. Measuring consumption directly, as opposed to via fuel expenditure data, would also improve estimation of variance.

The distributive impact study presented in chapter six is subject to the same data limitations as those raised in the sections above. This study attempts to provide the conception of an alternative, needs-based allocation method and comparative analysis of the distributive impact. The limitations of using actual household energy demand data without quantifying need with respect to current household living arrangements is acknowledged. What cannot be quantified by the data used in the analysis is the comparative impact of dHCA in terms of energy needs. Future work with respect to the distinction between three measures of energy requirements would be valuable. The three measures being: first, a needs-based (i.e. the dHCA scenario as set out in this thesis); second, household energy requirements in current circumstances (aligning with the method used by the fuel poverty indicator); and third; actual consumption. Analysis of these three measures would provide insights into the gaps between current consumption, standardised circumstantial energy 'requirement', and a needs-based (reduced consumption) scenario.

8.3.3 Administrative arrangements and cost-effectiveness

A key advantage for a household scheme over a personal scheme, is the reduction in the number of quota accounts required. The associated reduction in costs arising from the altered scheme design would, however, be offset by the costs incurred for the arrangements to track how many individuals live within each household. If additional factors were also to be included in the quota allocation regime (for example for young children, pensioners or disabled people), the administrative data requirements are increased further (as are the opportunities for fraudulent claims). In order to better understand these concerns, and the related costs, further work is required to understand how such systems would operate in practice, including a comparison of costs by scheme design.

Further work is also required to determine the extent to which agents would engage with a household system, and how the mitigation potential (or effectiveness) differs from a personal scheme design. Given the view, that in practice, energy retailers could be expected to favour a system of accounting and enforcement that would differ from that previously assumed (Eyre, 2010), further research into how the design and operation of accounting, enforcement and information systems influences participant engagement and behaviour is also required.

Finally, the potential for data linkage between administrative bodies to save costs should also be considered when evaluating whether a household or personal scheme design would be a more cost-effective policy option. The practical arrangements of doing so were not examined and should be investigated to enable an evaluation of the cost implications of moving to a household-based system.

Appendices

Household emissions and residual quota results tables

		Household GHG (kg CO2e)						Median household quota surplus/deficit (kg CO2e)							
								dHCA		EPHH		EPCA		EPCA+ch	
	N	Mean	S.D	S.E.	Median	P25	P75	Mean	Median	Mean	Median	Mean	Median	Mean	Median
All	18507	5646	4180	30.7	4987	3268	7127	0.80	481	0.61	648	1.28	332	0.98	277
Income decile															
1	1786	4052	3660	86.6	3631	1569	5581	1423	1685	1621	2046	514	709	907	866
2	1846	4551	3948	91.9	3915	2340	6066	812	1100	1093	1738	273	350	406	375
3	1868	4928	3720	86.1	4494	2760	6294	536	777	708	1097	250	391	304	387
4	1911	5153	3558	81.4	4637	3033	6568	475	728	469	966	390	531	443	524
5	1884	5551	3597	82.9	4958	3391	7070	92	491	77	642	65	365	90	300
6	1875	5824	3856	89.0	5260	3727	7202	17	404	-191	407	320	448	277	413
7	1861	6071	3821	88.6	5376	3900	7408	-226	271	-429	177	141	331	61	256
8	1841	6259	4214	98.2	5500	3920	7421	-447	191	-604	150	-28	417	-169	263
9	1812	6480	4471	105.0	5594	3928	7877	-759	62	-821	16	-289	278	-518	67
10	1823	7593	5438	127.4	6335	4297	9396	-1916	-700	-1916	-572	-1622	-591	-1792	-684

		Household GHG (kg CO2e)						Median household quota surplus/deficit (kg CO2e)							
								dHCA		EPHH		EPCA		EPCA+ch	
	N	Mean	S.D	S.E.	Median	P25	P75	Mean	Median	Mean	Median	Mean	Median	Mean	Median
All	18507	5646	4180	30.7	4987	3268	7127	0.80	481	0.61	648	1.28	332	0.98	277
Household size (persons)															
1	5066	4115	3172	44.6	3697	2322	5239	-10	397	1539	1943	-1047	-648	-1418	-1014
2	6992	5815	4343	51.9	5115	3564	7053	-561	136	-174	521	84	806	-532	175
3	2921	6320	4217	78.0	5592	3964	7922	78	725	-673	5	657	1138	787	1354
4	2421	6817	3939	80.1	6384	4528	8560	708	1163	-1170	-735	611	641	1834	2190
5	799	7165	4671	165.3	6550	4503	9207	1476	2072	-1522	-938	1126	1137	3208	3613
6	214	8377	7303	499.2	6976	5125	10271	1358	2612	-2748	-1390	1212	1375	3890	4498
7	66	7546	5294	651.6	7262	4008	10230	3136	2887	-1895	-1865	3129	3202	6578	6507
8	21	9652	4430	966.7	8770	7100	13204	1894	2916	-4018	-2792	1951	1351	6194	7008
9	7	9886	4511	1705.0	7343	7343	12168	3194	5926	-3990	-1366	11249	17240	12109	17040

		Household GHG (kg CO2e)						Median household quota surplus/deficit (kg CO2e)							
								dHCA		EPHH		EPCA		EPCA+ch	
	N	Mean	S.D	S.E.	Median	P25	P75	Mean	Median	Mean	Median	Mean	Median	Mean	Median
All	18507	5646	4180	30.7	4987	3268	7127	0.80	481	0.61	648	1.28	332	0.98	277
Number of rooms															
1	45	2478	3816	568.8	1667	0	3973	2384	3586	3229	3805	2070	2914	1729	2560
2	191	2794	2515	182.0	2352	1063	4096	1690	1975	2856	3357	1099	1416	710	912
3	1386	3062	2539	68.2	2805	1552	4162	1477	1723	2581	2869	902	959	542	607
4	3213	4143	2768	48.8	3879	2514	5339	985	1096	1507	1773	653	731	512	515
5	4525	5126	3307	49.2	4772	3313	6478	588	737	522	835	502	590	589	527
6	7758	6956	4682	53.2	6075	4371	8460	-879	-220	-1259	-415	-606	-119	-523	-105
7	623	6635	3846	154.1	5844	4573	7807	-894	-341	-1294	-503	-608	-117	-520	-3
8	385	7101	4311	219.7	6410	4589	8192	-1247	-627	-1760	-1069	-844	-517	-749	-245
9	213	8709	5792	396.9	7117	5490	10047	-2820	-1578	-3368	-1776	-2260	-1095	-2234	-1061
10	168	10314	7657	590.8	9289	5975	12463	-4251	-3367	-4973	-3948	-3670	-2575	-3535	-2933

		Household GHG (kg CO2e)						Median household quota surplus/deficit (kg CO2e)							
								dHCA		EPHH		EPCA		EPCA+ch	
	N	Mean	S.D	S.E.	Median	P25	P75	Mean	Median	Mean	Median	Mean	Median	Mean	Median
All	18507	5646	4180	30.7	4987	3268	7127	0.80	481	0.61	648	1.28	332	0.98	277
Housing tenure															
Rented L.A./Hsng	3075	3673	3071	55.4	3323	1401	5202	1799	1805	1980	2300	1169	1132	1414	1265
Rented Private	2472	4463	3492	70.2	4024	2361	5825	1232	1522	1166	1569	1146	1251	1237	1275
Owned with mortg	6467	6462	3939	49.0	5730	4123	7927	-277	326	-811	-111	-223	165	78	455
Owned outright	6278	6376	4642	58.6	5373	3870	7540	-1231	-380	-730	232	-904	-304	-1401	-781
Rent free	215	5656	6318	430.9	4438	2634	7397	-396	672	19	1260	-496	447	-700	11
Household Type															
Single, no children	2445	3673	2930	59.3	3312	2012	4851	432	760	1981	2303	-605	-273	-976	-654
Couple, no children	3088	5483	3952	71.1	4874	3334	6722	-228	362	159	748	639	1223	-101	485
Single, pensioner	2621	4524	3328	65.0	4079	2723	5617	-419	67	1130	1614	-1455	-968	-1827	-1353
Couple, pensioner	2312	6375	4645	96.6	5520	4054	7401	-1125	-301	-739	89	-260	569	-999	-167
Single, & children	1016	4648	3663	114.9	4428	2361	6415	1499	1663	999	1172	-1584	-1369	446	613
Couple, & children	3581	6391	3854	64.4	5864	4149	7942	934	1390	-748	-268	-268	208	1455	1870
3+ adults, no children	996	7002	4993	158.2	6323	4484	8521	-52	604	-1367	-705	3446	3889	2303	2730

		Household GHG (kg CO2e)						Median household quota surplus/deficit (kg CO2e)							
								dHCA		EPHH		EPCA		EPCA+ch	
	N	Mean	S.D	S.E.	Median	P25	P75	Mean	Median	Mean	Median	Mean	Median	Mean	Median
All	18507	5646	4180	30.7	4987	3268	7127	0.80	481	0.61	648	1.28	332	0.98	277
Output Area Classification															
blue collar communities	2867	4925	3510	65.5	4731	2997	6515	919	927	731	886	748	712	961	795
city living	904	4874	3465	115.2	4201	2583	6253	406	905	739	1404	429	696	210	469
countryside	2213	7749	6822	145.0	5867	3561	9512	-2101	-364	-2101	-253	-1908	-397	-2020	-522
prospering suburbs	3328	6637	3601	62.4	5897	4411	8122	-897	-355	-991	-289	-646	-257	-731	-394
constrained by circumstances	1815	4018	3363	78.9	3725	1942	5611	1193	1327	1635	1980	828	890	756	699
typical traits	3556	5509	3347	56.1	4997	3515	6916	66	417	131	646	30	261	9	192
multicultural	1530	4960	3537	90.4	4574	2663	6801	1022	1200	609	997	1019	887	1286	1251
Central Heating Fuel															
Electricity	1246	4760	4010	113.6	4072	2227	6293	192	806	891	1691	-119	249	-376	-7
mains gas	15241	5498	3414	27.7	5090	3467	7041	230	457	147	553	249	345	290	315
solid fuel	117	7420	11255	1040.5	3130	1894	8410	-1694	2495	-1754	2412	-1021	2224	-1367	2135
Oil	894	10832	8776	293.5	9406	3469	15604	-5026	-3828	-5173	-3896	-4800	-3387	-4838	-3617
solid fuel and other	58	8718	9856	1294.2	4838	2135	12905	-3196	1073	-3117	503	-2943	974	-3137	867
Bottled (tanked) gas	122	6312	5415	490.2	5799	3055	8060	-923	36	-601	-49	-831	-526	-1089	-501

Group characteristics and allocation method test statistics

Two-sided Wilcoxen Signed rank sum tests were performed in Stata to compare the mean household quota surplus/deficit values from the EPHH, EPCA and EPCA+ch allocation methods with dHCA (e.g. Ho: median of dHCA - EPHH = 0 vs. Ha: median of dHCA - EPHH ~= 0). The p-values are shown in the final three columns.

	N in lowest income quintile	N in highest income quintile	Mean household size	Mean no. of children < 16	Mean no. of rooms in dwelling	dHCA vs. EPHH	dHCA vs. EPCA	dHCA vs. EPCA+ch
All	20.0%	20.0%	2.35	0.45	5.21	0.0000	0.0000	0.0000
Income decile								
1	100.0%	0.0%	2.18	0.61	4.60	0.0000	0.0000	0.0000
2	100.0%	0.0%	2.11	0.48	4.74	0.0000	0.0000	0.0056
3	0.0%	0.0%	2.20	0.45	4.99	0.0000	0.0000	0.0000
4	0.0%	0.0%	2.36	0.47	5.08	0.0000	0.0000	0.0000
5	0.0%	0.0%	2.36	0.46	5.22	0.0000	0.0014	0.0000
6	0.0%	0.0%	2.53	0.46	5.36	0.0000	0.1059	0.0000
7	0.0%	0.0%	2.52	0.44	5.41	0.0000	0.0180	0.0000
8	0.0%	0.0%	2.48	0.39	5.50	0.0000	0.0000	0.0000
9	0.0%	100.0%	2.40	0.34	5.50	0.0000	0.0000	0.0000
10	0.0%	100.0%	2.35	0.36	5.71	0.0000	0.0000	0.0000
Household size								
1	31.8%	13.7%	1.00	0.00	4.55	0.0000	0.0000	0.0000
2	14.0%	25.1%	2.00	0.06	5.30	0.0000	0.0000	0.0000
3	14.7%	22.9%	3.00	0.63	5.47	0.0000	0.0000	0.0000
4	13.4%	19.7%	4.00	1.40	5.77	0.0000	0.0000	0.0000
5	25.5%	14.6%	5.00	2.05	5.88	0.0000	0.0000	0.0000
6	33.3%	9.0%	6.00	2.49	5.93	0.0000	0.0000	0.0000
7	35.3%	2.8%	7.00	3.10	5.82	0.0000	0.0356	0.0000
8	58.7%	6.9%	8.00	3.54	6.38	0.0000	0.3833	0.0000
9	12.1%	0.0%	9.00	2.21	6.24	0.0156	1.0000	0.0156

Tenure								
Rented L.A./Hsng	50.4%	1.4%	2.19	0.55	4.24	0.0000	0.0000	0.0000
Rented Private	25.4%	17.8%	2.41	0.53	4.56	0.0000	0.0000	0.0000
Owned with mortg	5.8%	33.9%	2.82	0.69	5.60	0.0000	0.0000	0.0000
Owned outright	16.3%	16.1%	1.91	0.10	5.63	0.0000	0.0000	0.0000
Rent free	27.1%	13.8%	1.99	0.28	5.10	0.0000	0.0405	0.0202
Household type								
Single, no children	29.8%	23.5%	1.00	0.00	4.33	0.0000	0.0000	0.0000
Couple, no children	8.7%	39.7%	2.00	0.00	5.12	0.0000	0.0000	0.0000
Single, pensioner	33.6%	4.7%	1.00	0.00	4.76	0.0000	0.0000	0.0000
Couple, pensioner	14.3%	9.5%	2.00	0.00	5.58	0.0000	0.0000	0.0000
Single, & children	51.6%	2.9%	2.78	1.65	4.98	0.0002	0.0000	0.0000
Couple, & children	14.9%	20.9%	3.83	1.73	5.57	0.0000	0.0000	0.0000
3+ adults, no children	10.0%	28.1%	3.51	0.08	5.79	0.0000	0.0000	0.0000
Output area classification								
blue collar communities	27.2%	8.5%	2.51	0.59	5.13	0.0000	0.0000	0.0000
city living	15.9%	35.3%	2.06	0.28	4.47	0.0000	0.0000	0.0001
countryside	13.5%	26.4%	2.35	0.38	5.72	0.0000	0.0000	0.0000
prospering suburbs	9.3%	28.5%	2.43	0.41	5.82	0.0000	0.0000	0.0000
constrained by circumstances	36.2%	7.8%	1.96	0.34	4.43	0.0000	0.0000	0.0542
typical traits	15.1%	21.4%	2.29	0.43	5.26	0.0000	0.0000	0.0000
multicultural	32.0%	16.1%	2.72	0.66	4.78	0.0007	0.0000	0.0000
Central heating fuel								
electricity	31.0%	13.9%	1.74	0.20	4.17	0.0000	0.0000	0.0000
mains gas	19.1%	20.5%	2.42	0.48	5.29	0.0000	0.0000	0.0000
solid fuel	23.6%	8.8%	2.40	0.28	5.41	0.0029	0.0053	0.0000
Oil	10.7%	31.4%	2.48	0.43	6.05	0.0000	0.0001	0.0000
solid fuel and other	11.4%	19.7%	2.27	0.25	6.38	0.0003	0.5118	0.0054
bottled (tanked)	18.1%	22.7%	2.07	0.26	5.45	0.0000	0.0850	0.0000
Number of rooms in dwelling (a111p)								
1	29.0%	16.4%	1.61	0.14	1.00	0.0002	0.0008	0.0725
2	37.1%	9.2%	1.33	0.06	2.00	0.0000	0.0000	0.0000
3	38.9%	11.3%	1.38	0.08	3.00	0.0000	0.0000	0.0000
4	27.5%	14.2%	1.89	0.31	4.00	0.0000	0.0000	1.0000
5	22.9%	14.1%	2.41	0.50	5.00	0.0000	0.0000	0.0000
6	12.4%	27.1%	2.68	0.54	6.00	0.0000	0.0000	0.0000
7	10.1%	19.9%	2.73	0.56	7.00	0.0162	0.0778	0.0000
8	10.5%	23.8%	2.83	0.57	8.00	0.1535	0.0031	0.0000
9	2.4%	39.5%	2.86	0.51	9.00	0.5837	0.0016	0.0000
10	5.5%	45.1%	3.03	0.61	10.00	0.4876	0.0000	0.0000

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