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Distributional Impacts of Personal Carbon Trading

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Distributional Impacts of Personal Carbon Trading

Final Report to the Department for Environment Food and Rural Affairs

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1 Executive Summary

1.1 Defra commissioned CSE to undertake an analysis of the equity and distributional impacts that might arise from the introduction of a Personal Carbon Trading (PCT) system. This Executive Summary sets out the approach we have taken, and the headline findings.

1.2 This research forms part of Defra's pre-feasibility study to explore some of the high-level issues surrounding PCT: effectiveness and strategic fit; equity and distributional impacts (this report); public acceptability; and technical feasibility and cost. To ensure the four workstreams are consistent, the analysis is undertaken in the context of a set of common assumptions regarding the type of PCT system (Annex A).

Approach, scope, limitations

1.3 There is currently no representative survey of personal carbon emissions in the UK. For this work we created a partial dataset based on the ONS Expenditure and Food Survey (EFS), using price information and emissions factors to convert EFS expenditure records into energy consumption and carbon emissions for household and private road transport fuels (i.e. 'personal' emissions). This derived dataset, which contains extensive socio-demographic data, has two key limitations:

(1) The emissions covered exclude those from aviation, public transport, and shipping;

(2) The EFS is non-representative at the individual case level. This precludes certain detailed analyses of the distribution of emissions at the level of individual households.

1.4 We used our derived dataset to model a PCT system based on allocating equal allowances among the UK adult population, with the overall cap set at current total personal emissions (excluding aviation and public transport). We then assessed the distributional impacts of the PCT system using information on household characteristics recorded in the EFS. **Sections 2 - 4** of this report set out the detail of the methodologies used to achieve this. **Section 5** sets out the results, and **Section 6** our conclusions.

Headline Findings - Income

1.5 Because lower-income households tend to have lower carbon emissions, the PCT system modelled here is progressive. The table below shows that 71% of households in the lowest three income deciles would have surplus allowances to sell (defining them as 'winners'), while 55% of households in the highest three income deciles would either have to buy allowances or reduce their emissions (making them 'losers').

1.6 The table also shows that low income households would tend to have higher allowance surpluses (3,577 kgCO_2 per year on average), and lower deficits (-4,170 kgCO_2), than higher income households (3,398kg and -5,930kg respectively).

Table A: Distribution of gain and loss by equivalised income decile

	Income deciles (equivalised)	% of group winning/losing	% of all HH's	Mean credit/deficit	% of all winners/losers
WINNERS	1 to 3	71%	21%	3,577	36%
	4 to 7	60%	24%	3,530	41%
	8 to 10	45%	13%	3,398	23%
LOSERS	1 to 3	29%	9%	-4,170	21%
	4 to 7	40%	16%	-4,532	39%
	8 to 10	55%	17%	-5,930	40%

1.7 Despite this progressiveness, 8-9% of all households would be low-income losers. However, over half of these would be likely to have an allowance deficit of less than 3tCO_2, which, taking the current Shadow Price of Carbon (£29/tCO_2) would equate to a financial loss of less than £90 per year.

Headline Findings - Geography

1.8 The results show a distinct tendency towards urban/fringe households having allowance surpluses, and village/isolated households having allowance deficits. Interestingly, this appears primarily to be related to heating rather than transport energy use. Emissions from heating fuels tend to be higher in rural areas, due to older and less efficient housing and heating systems, and lower ambient temperatures in the absence of the urban heat islands effect (although the latter is not observable directly from our dataset), both of which drive a higher kWh demand for space heating (which is observable).

1.9 With less access to gas, there is also far more use of oil as a heating fuel in rural areas compared to urban, which has almost 30% higher emissions per kWh than gas.

1.10 Emissions from petrol and diesel consumption are also higher in rural areas. However the difference is far less marked than for heating fuels, and road transport accounts for a smaller proportion of total personal emissions in rural areas than in cities.

1.11 These findings suggest that the distributional impacts of PCT on rural households could be mitigated through a systematic approach both to improving the thermal efficiency of rural houses, and to replacing oil with lower carbon heating fuels in rural areas.

1.12 There are also differences between Government Office Regions (and Devolved Administrations), although much of this is driven by variations in income and rurality. In particular, high per-capita emissions drive a tendency for households in Northern Ireland to experience allowance deficits. This results both from a large rural population, and a lack of access to gas, with a consequent reliance on oil for heating.

Headline Findings – Household Composition

1.13 Larger households (in terms of number of adult occupants) are more likely to have surplus allowances. This is because household demand for shared energy services such as heating and lighting does not increase linearly with the number of occupants, while the allowance allocation (as modelled here) follows exactly such a pattern. Hence higher adult occupancy adds additional allowances in excess of the resulting increase in emissions.

1.14 The question of whether to allocate allowances to children is a subject of debate. Allocating a full allowance to every child appears consistent with PCT as a system based on the right of every citizen to emit an equal amount of carbon. However, our data suggests that children have a smaller marginal effect on household emissions than adults. Allocating full allowances to children would therefore disproportionately benefit large families at the expense of childless households.

1.15 Our analysis shows that allocating children 1/3 of an allowance would minimise the disproportionate effects, and represent a reasonable compromise between allocating children a full allowance, and allocating them no allowances at all.

Identifying the vulnerable losers

1.16 To gain a more detailed picture of the characteristics of low income households likely to receive fewer allowances than their current emissions, we used a classification tree technique to create clusters of households with similar characteristics and allowance surplus/deficits **(Section 5)**.

1.17 This showed that of the 2.1 million low income ‘loser’ households that would receive insufficient allowances to meet their current emissions:

- a high proportion live in rural areas (where their often solid-walled homes are typically harder to heat and a lack of access to gas has led to the use of more carbon-intensive fuels);
- many are living in (or ‘under-occupying’) larger-than-average homes (characterised as ‘empty-nesters’ and single pensioners still living in family

houses);

- the allowance 'deficit' is driven by their heating rather than their transport emissions.

1.18 This characterisation of the low income 'losers' indicates where 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. It is likely that such initiatives would also have the benefit of addressing fuel poverty, which is also prevalent in lower income rural 'hard-to-treat' homes and in 'under-occupied' homes in both rural and urban areas.

Next Steps

1.19 It is essential to note that the work presented here can only present a partial picture of the distributional impacts of a PCT system. To gain a full understanding, further analysis is required to build upon the analysis undertaken for this study. This includes:

- Integration of aviation and public transport emissions;
- An assessment of the distributional impacts of different ways of recovering the likely costs of operating the PCT scheme. For example, recovering costs as a % levy on allowance transactions would have a different impact than a single annual charge (though both would change the net financial impact of PCTs on each household).
- Developing an understanding of the distribution of 'opportunities to act' to cut emissions and the costs of such action. This can depend on housing type, current thermal performance, cost of improvements, access to public transport, potential impact of behavioural change on meeting basic needs (e.g. for warmth), etc.
- Modelling the distribution of household carbon emissions over time as the cap in a PCT scheme starts to tighten. Since different households will have different opportunities at different costs to curb their emissions, it is likely that the distributional pattern of 'winners' and 'losers' would change over time.

1.20 In addition, there would be merit in including additional questions in future national surveys, such as the English House Condition Survey (and its devolved administration equivalents), to gather actual fuel bill and road fuel consumption data alongside its existing detailed housing and income data. This would significantly improve the dataset for analysis of the distributional impacts of carbon emission reduction policies including PCT.

1.21 In the mean time, it should be noted that the dataset and analytical framework developed for and used in this study could now be used to assess the distributional impacts of other existing or potential carbon reduction policies, such as the CERT, carbon taxes, upstream cap-and-trade (with different approaches to revenue recycling), the Renewables Obligation (and other renewables support mechanisms).

2 Introduction

Defra introduction to Personal Carbon Trading (PCT)

2.1 The UK is committed to reducing its greenhouse gas emissions and the Climate Change Bill[1] proposes a target of a reduction in carbon dioxide emissions of at least 60% by 2050 (against a 1990 baseline). Individuals are responsible for around 40% of the UK's carbon dioxide emissions (largely from heating homes and water, and leisure travel), and in order to meet our longer-term emissions targets, emissions from individuals must be reduced as well as those from business and industry.

2.2 One potential measure is personal carbon trading. This is an emissions trading scheme where equal rights to emit are allocated to individuals in the economy as emission allowances (or 'carbon credits'), which must be surrendered when purchasing goods or services that cause emissions (e.g. paying their gas bill, or refuelling their car). Anyone with surplus carbon credits could sell these to individuals who require extra (where it is cheaper to buy extra, than to reduce their emissions).

2.3 In 2006, Defra commissioned the Centre for Sustainable Energy to assess the ideas and issues involved in the concept of individual carbon trading, and a report was produced: "A Rough Guide to Individual Carbon Trading"[2]. The Government has since conducted a pre-feasibility study to explore key high-level issues highlighted by the CSE report: effectiveness and strategic fit; equity and distributional impacts; public acceptability; and technical feasibility and cost.

2.4 There are different types of personal carbon trading that vary depending on the emissions covered, who participates and how it might be implemented. For the purposes of this study, a Domestic Tradable Quota model has been assumed:

- A mandatory scheme involving individuals and organisations, where 40%

[1] At the time of publication the Climate Change Bill is continuing its progress through Parliament. These details are therefore subject to the outcome of the Parliamentary process: http://www.defra.gov.uk/environment/climatechange/uk/legislation/index.htm
[2] http://www.defra.gov.uk/Environment/climatechange/uk/individual/pca/pdf/pca-scopingstudy.pdf

of carbon credits are allocated free to each adult, and the remaining 60% are auctioned – traders and large organisations would make up the majority of buyers.

- ‘Credits’ would be surrendered to cover the carbon content of electricity and gas use in the home and for personal transport fuel purchases, with airlines covered and treated just as other fuel consumers.
- All individuals and organisations would have access to the market to trade their carbon credits.
- A ‘pay as you go’ option would allow individuals to pay the price of the carbon credits at the point of purchase, leaving the vendor to buy and surrender sufficient allowances for that sale.

2.5 A start date range of 2013 – 2020 has been assumed, with 2013 representing the earliest possible introduction date (a detailed list of assumptions is included in Annex A).

Introduction to this study

2.6 This document is a report on the findings of research undertaken by CSE for the equity and distributional impacts workstream of the Government’s pre-feasibility study into PCT.

2.7 The overall aim of the equity/distributional impacts workstream is to analyse how PCT might affect different groups in society, teasing out the impact on different individuals of changing different factors (e.g. inclusion/ exclusion of children), and whether or not PCT would represent a fiscally progressive policy instrument.

2.8 To achieve the above aim, this study has the following objectives:

- Build a representative dataset incorporating carbon emissions from household and private road transport fuel use
- Analyse the dataset to identify the main household characteristics driving these emissions
- With a PCT cap set at current total household emissions, identify the

relevant characteristics of households emitting above and below their total allowance level.

- Use this information to identify the likely segments of 'winners' and 'losers' created by such a system. Here the winners are households whose allowances exceed their current emissions, and who therefore have surplus allowances that could be sold. Conversely the losers are households whose emissions exceed their allowances, and who would therefore need either to (1) reduce their emissions, or (2) purchase additional allowances.

2.9 For the purposes of this research we have identified winners and losers based only on the net annual balance of carbon allowances per household – that is, without consideration of how the running costs of a PCT system might be distributed in the population. The way in which these costs were recovered could affect the findings presented here.

2.10 Note that the dataset created for this project could be applied to more general analysis of the social distribution of personal emissions, which would be relevant to a distributional impact assessment of any policy instrument used to constrain those emissions.

3 Methodology

Summary of approach

3.1 There is currently no nationally representative survey that captures all the information required to undertake an analysis of the social and geographic distribution of the full range of direct (as opposed to embodied) personal carbon emissions in the UK.

3.2 Although the English House Condition Survey, managed by the Department for Communities and Local Government, captures very useful information on housing condition and heating systems, it does not record actual expenditure on or consumption of household or transport fuels or energy services. Similarly, the Expenditure and Food Survey (EFS) undertaken by the Office for National Statistics, upon which we have based our analysis, records expenditure on a wide range of items, including household and private road transport fuels, public transport, and aviation, but does not record their consumption.

3.3 Within the constraints of the current project we have derived consumption and emissions data from the expenditure recorded in the EFS, for household and private road transport fuels only – and although we have proposed a methodology for creating a synthetic dataset comprising emissions from public transport and aviation, this would still represent a compromise in comparison with a single representative survey capturing the full range of information.

3.4 However, as such a survey does not currently exist, the starting point for this research is the annual UK Expenditure and Food Survey (EFS), undertaken by the Office for National Statistics. The EFS is a representative survey of around 7,000 households, whose main purposes are to gather representative information on (1) household expenditure for use in calculating the retail price index (RPI), and (2) national patterns of food consumption and nutrition.

3.5 The EFS dataset comprises descriptive information on households, along with detailed weekly expenditure on a huge range of items. These items include the full range of household fuels, as well as petrol and diesel used in private road transport. We first combined three years' worth of survey data (for financial years 2003/4, 2004/5 and 2005/6), increasing the sample size to over 20,000 cases. Then, using time- and location-specific fuel price information, we converted survey expenditure on these fuels into consumption. Standard factors were then applied to this consumption data to derive carbon emissions from the various fuels (see Annex B). Finally, for each household a per-adult emissions value was calculated by dividing total household emissions by the number of adults in the household.

3.6 For each individual survey case the resulting dataset comprises the full set of socioeconomic, demographic, housing and location information collected in the EFS, along with per-adult emissions from each fuel.

3.7 Using this dataset, the analytical steps were as follows:

- Step 1: Identify and investigate variables influencing overall per-adult emissions, and degree of allowance credit/deficit, by using multiple linear regression (Section 3 and Annex C)
- Step 2: Segment the survey households into groups based on combinations of values of the influential variables identified in step (1), and the resulting degree of allowance credit/deficit. This was done using exhaustive CHAID, a method used to study the relationships between a dependent variable and a set of predictor variables which may interact with one another (Section 4).
- Step 3: Investigate the characteristics of the groups created in step (2), identifying trends and exceptions relevant to the assessment of the likely social distributional impacts of PCT (Section 5).

Limitations and assumptions

3.8 The analysis undertaken in this study is based on data provided by the Expenditure and Food Survey. The factors identified as drivers of household carbon emissions are therefore limited to variables included in the survey. While the available variables are extensive, there are numerous factors of interest and relevance that are not covered in the survey, for example, dwelling age, SAP rating[3], types of vehicle (engine size etc).

3.9 The Expenditure and Food Survey is designed to be representative of household expenditure at the dataset level, but not at the individual case level. Much of the data is derived from an expenditure diary, whereby respondents record all expenditure on particular items, including some household and vehicle fuels, over a short (typically 2-week) period of the year. This results in some apparently very high annual expenditure figures (for example if a household happened to drive a long distance during the diary period) and some artificially low or zero figures (e.g. if the household happened not to buy any vehicle fuel during the diary period).

3.10 Although the survey is designed so that the total annual expenditure from this diary data is representative of all UK households, the results for an individual household cannot be relied upon. A further implication of this is that the distribution of household expenditure (and consumption derived from it) cannot be taken as accurate.

3.11 This non-representativity at the case level leads to the requirement for creating groups of cases, from which the mean (but not the internal distribution about that mean) can be taken as accurate. While the CHAID process used to achieve this does not eliminate the issue of the high and low expenditure values, it enables these groups to be formed based on combinations of factors that result in a significant difference in the dependent variable (which in this case is the difference between household emissions and the allowance given).

3.12 Income is an important factor in analysing the distribution of household energy consumption and emissions. The EFS records both disposable (i.e. net) and OECD equivalised household income. Income equivalisation is a process whereby a household's income is corrected based on the household composition. The logic behind this is that the effective income of a household depends on the characteristics and number of people that income has to support. Put very simply, if two households receive the same net income, equivalised income will be lower for the household with the greater number of occupants. In practice the OECD equivalisation scale is more complex than

[3] SAP is the Government's Standard Assessment Procedure for Energy Rating of Dwellings. The SAP index is based on the modelled cost per unit floor area to maintain certain indoor temperatures

this, and more details are given in Annex C.

3.13 In the regression analysis we found that the choice of income scale made little difference to the strength of the models. However, since the objective of this research is to identify the social distributional impacts of PCT, we have elected to base our analysis on the OECD equivalised income scale. Nevertheless, where appropriate we have also included analysis of the distributional effects using the disposable income measure.

3.14 A further assumption of this study is that, in terms of emissions allowances, households operate as a homogenous unit. That is, all allowances allocated to the occupants are pooled and shared by the household as a whole. In reality this will vary with the composition of the household, vehicle usage, etc. Nevertheless, the results shown here hold at the household level.

3.15 This research is centred on the relative differences in emissions and allowances between households. We have therefore calculated total household emissions from within the EFS dataset. This is a requirement for internal consistency in our analysis. For example, it means that the average allowance surplus/deficit across all households is zero, which flows logically from setting the PCT cap at total personal (within-scope) emissions.

3.16 The approach described in paragraph 3.15 results in overall total and average household emissions figures that are similar to other emissions estimates (NAEI, Defra, DBERR), but do not match them precisely. This is not important in the context of this project, which is focused on assessing the relative distributional impacts of PCT, rather than on estimating personal emissions.

3.17 Table 1 and Table 2 below show how the survey data for the three EFS years used here compare with national figures for the same period. (Note that the national data is for calendar years, while the EFS data covers financial years).

Table 1: Comparison of EFS data with national data

(Thousands)	2003/04		2004/05		2005/06		National data source
	EFS	National data	EFS	National data	EFS	National data	
Households	24,670	24,700	24,431	24,700	24,799	24,700	2001 Census
Adults	44,891	47,841	45,162	48,189	45,310	48,612	ONS
Children	13,259	11,712	13,151	11,646	13,163	11,598	ONS
Population	58,150	59,554	58,313	59,834	58,473	60,209	ONS
tCO_2 household fuel	149,802	163,737	146,936	153,666	134,001	147,993	Defra
tCO_2 petrol & diesel	59,024	-	59,236	-	49,738	-	-

Table 2: Comparison of EFS data for all three years with national averages

(Thousands)	All years combined EFS	Average of National data for 2003-2005
Households	24,633	24,700
Adults	45,121	48,214
Children	13,191	11,652
Population	58,312	59,866
tCO_2 domestic fuel	143,580	155,132
tCO_2 household road fuels	55,999	-

Number of adults, children and total population

3.18 The national data is taken from the mid-year estimates from the Office of National Statistics. In this data set children are defined as under-16s. In the EFS children are defined as under-18s, which may explain why there are fewer children and more adults in the ONS data than the EFS data. The total population figure from ONS is close to the EFS figure.

Carbon emissions from household fuel use

3.19 These data are taken from Defra local authority-level datasets. The Defra figures show higher emissions from household fuel use than the EFS data. Over recent years Defra has been refining the methodology for calculating this data, for which the gas values are weather corrected (unlike the EFS data, which reflect actual consumption).

Carbon emissions from household petrol and diesel use

3.20 The closest approximation available is the DBERR estimate of local and regional level road transport emissions. This dataset attempts to divide road transport fuel use into ‘personal’ and ‘freight’, rather than ‘business’ and ‘non-business’. The emissions estimate from this dataset is 78.9MtCO_2 (for 2003) which is unsurprisingly much higher than the figure derived from the EFS. The BERR data methodology is based on traffic survey data rather than fuel purchased. BERR uses this methodology in order to estimate the personal / freight split, which cannot be ascertained from fuel sales data. All vehicles which are not light or heavy goods vehicles are defined as personal transport, which will result in an overestimate of the level of non-business transport. As this national data on domestic road fuel consumption is likely to be an overestimate, it has not been included in Table 2.

4 Analysis: influential variables

Introduction

4.1 Two methods were used to explore the relationship between EFS variables of interest and two dependent variables:

1. CO_2 emissions per adult
2. Degree of allowance credit/deficit per household

4.2 These dependent variables were both calculated from EFS expenditure and household composition data, in conjunction with fuel price data and CO_2 emissions factors, as set out in Annex B.

4.3 We first used bivariate analysis to investigate the relationships between single independent variables and the two dependent variables, followed by multiple linear regression to investigate the multivariate relationships.

4.4 Note that the bivariate plots ignore the many relationships between independent variables (e.g. number of rooms increasing with income), and cannot be interpreted as demonstrating a direct and simple causal relationship between the independent and dependent variables. In addition, these plots do not account for interaction effects, where the influence of one independent variable is altered by the value of another (a hypothetical example of this might be the effect of number of appliances on total emissions changing with income, with wealthier households less concerned with switching appliances off).

4.5 The multiple linear regression technique used later controls for the direct correlations between independent variables, so that variables included in the linear models have all been found to have an effect on their own, after taking these into account. However the linear regression does not account for interaction effects. Although these can be analysed using CHAID, a detailed analysis of interaction effects is beyond the scope of this project.

Bivariate Analyses

4.6 Error bar plots are a simple method for illustrating the two-dimensional relationship between a single independent variable and a dependent variable. The graphs shown below cover all independent variables that were used in the final CHAID classification model, and show the relationship with both dependent variables of interest (per adult emissions and difference between allowance and emissions). The error bars on the graph points represent the 95% confidence interval for the means. This means that for each point, there is a 95% probability that the mean value falls between the bars.

Per adult emissions

4.7 Figure 1 below illustrates that, on average, per-adult emissions increase with income: the highest income decile has the highest average per-adult emissions and the lowest income decile the lowest emissions. Figure 2 shows the same information for disposable income deciles, and illustrates that the difference between deciles is less pronounced than is the case with the equivalised measure of household income. The income ranges and means for each decile are shown below in Table 3.

4.8 Figure 3 shows that mean per-adult emissions decrease as the number of adults per household increases. This is not surprising, since many household emissions result from the use of shared energy services such as heating and lighting, for which demand does not increase linearly as a function of the number of occupants.

Table 3: Income decile definitions

Income decile	Equivalised income (£ per week)		
	Mean	Minimum	Maximum
1	81	0	113
2	128	106	153
3	172	145	200
4	217	189	247
5	266	233	299
6	320	283	360
7	382	340	429
8	461	405	524
9	580	495	687
10	1,035	649	23,201

Income decile	Normal weekly disposable hhld income (£ per week)		
	Mean	Minimum	Maximum
1	91	-1710	131
2	161	124	197
3	221	187	258
4	285	245	329
5	358	311	407
6	435	385	491
7	524	464	589
8	630	556	716
9	789	677	930
10	1,351	879	23,255

Figure 1: Per adult CO_2 emissions and income (equivalised)

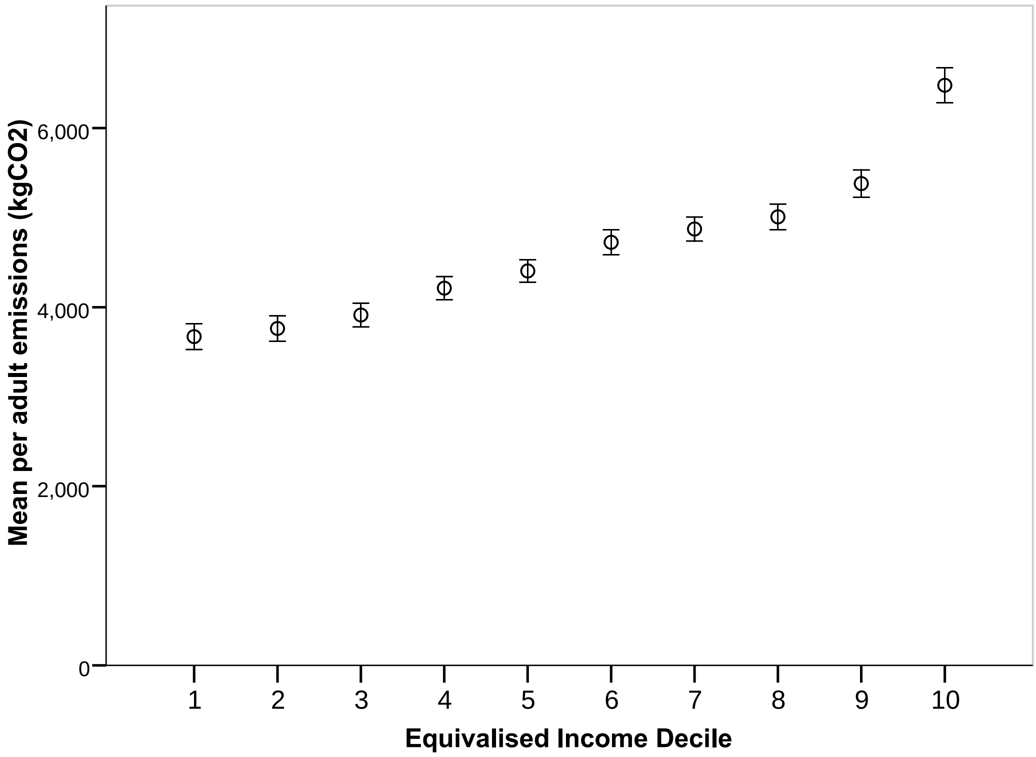


Figure 2: Per adult CO_2 emissions and income (disposable)

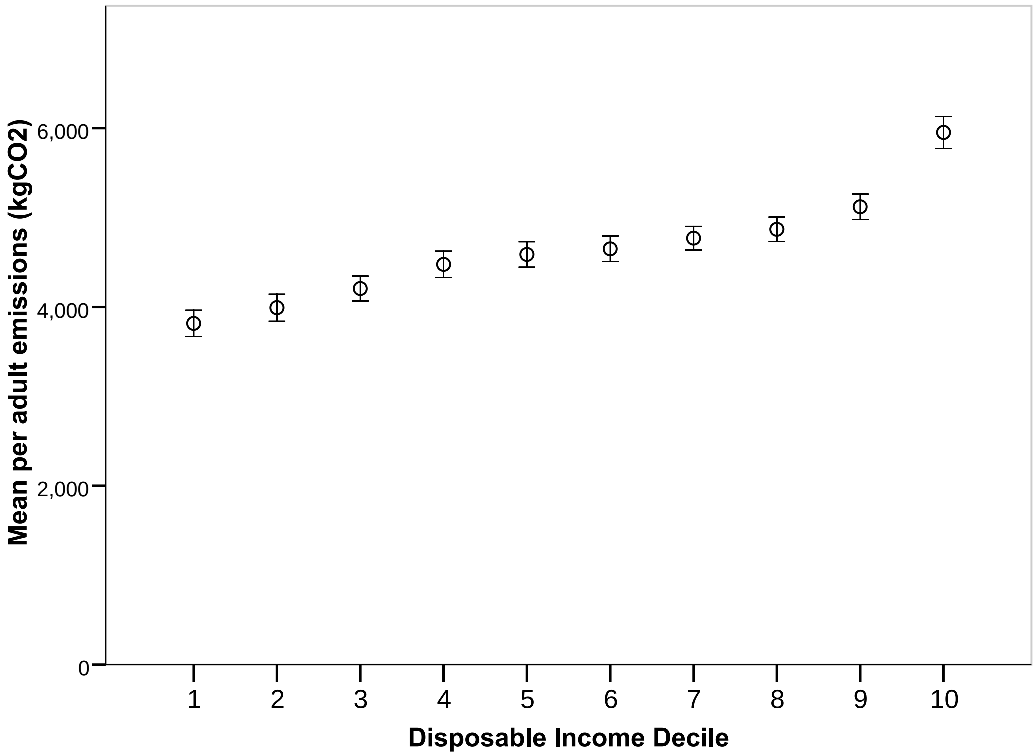
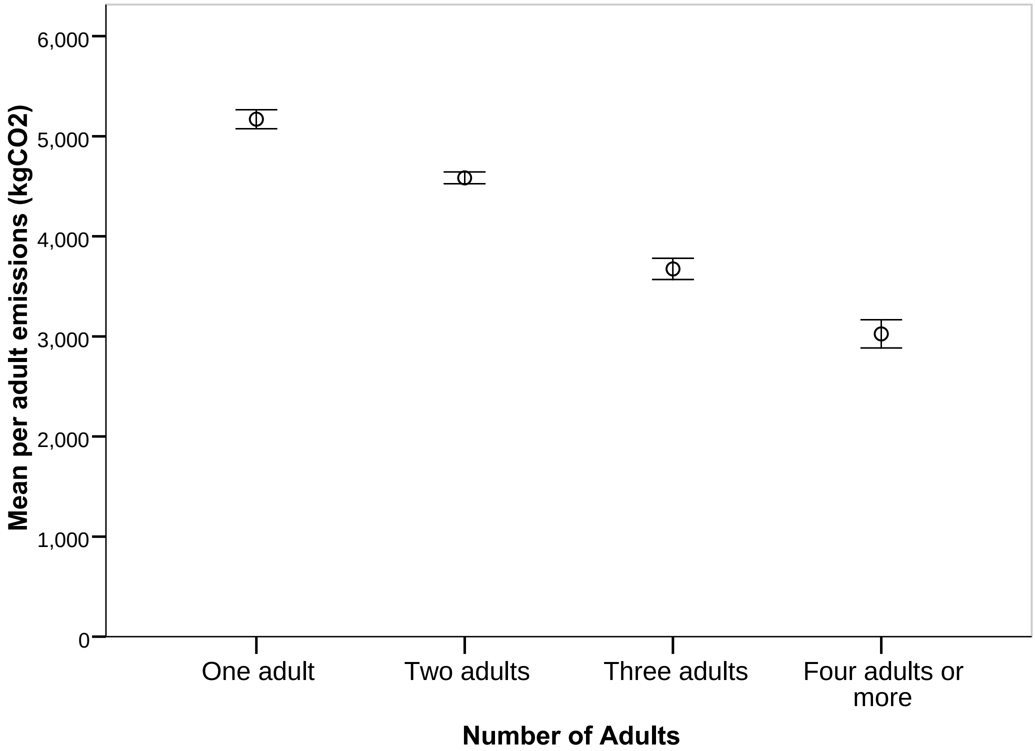
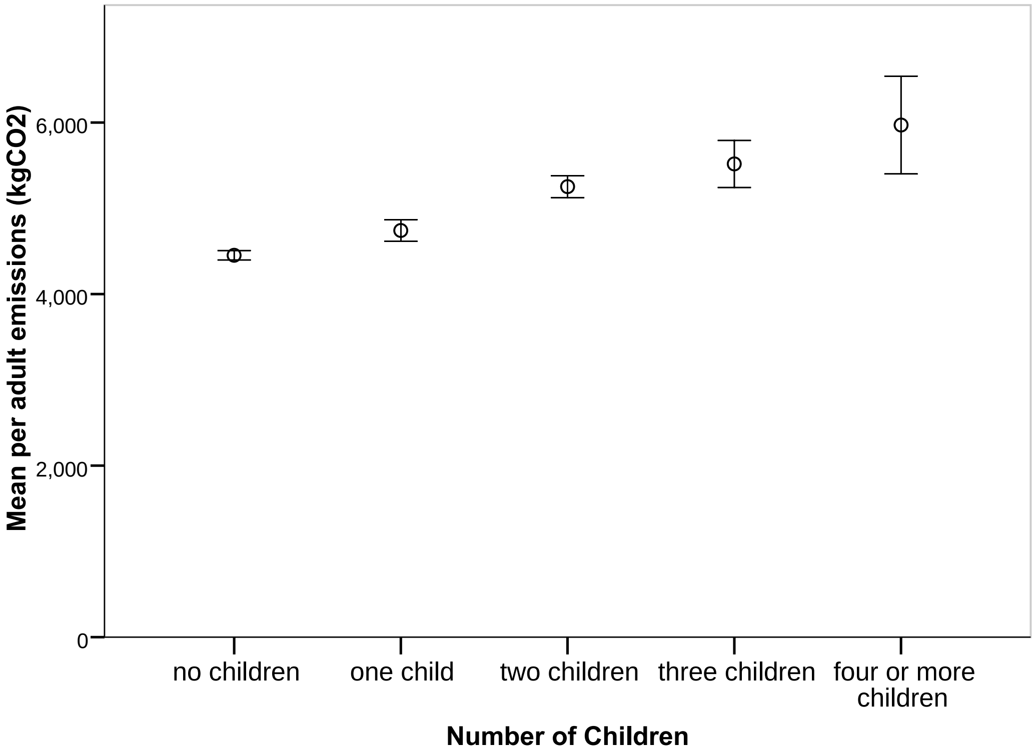


Figure 3: Per adult CO_2 and number of adults per household



4.9 Figure 4 shows the relationship between mean per adult emissions and the number of children in a household. While this shows that mean per adult emissions increase slightly with number of children, the error-bar ranges overlap for the last three categories, indicating that the means could in fact be the same for these categories. The implication of this graph is that *if* additional children do increase emissions, the effect is modest, and the effect of additional children is lower once there are already two children in the household.

Figure 4: Per adult CO_2 and number of children per household



4.10 Figure 5 and Figure 6 show that mean per adult emissions also vary with housing type (referred to as dwelling type here) and tenure. Detached houses have, on average, the highest per adult emissions of all dwelling types, with flats having the lowest. Similarly, local authority (LA) rented accommodation has the lowest per adult emissions and households owned with a mortgage have the highest.

4.11 Both tenure and housing type vary with income (Figure 7), which is likely to account for some of the differences in emissions observed here. However, there are also likely to be physical characteristics associated with the different household types and tenures which will affect the energy efficiency of the dwelling and therefore emissions.

4.12 Note that the very wide error bars associated with 'Other' result from the fact that there is a very small number of samples in this category. This reduces statistical confidence in the result for this category.

Figure 5: Per adult CO_2 and dwelling type

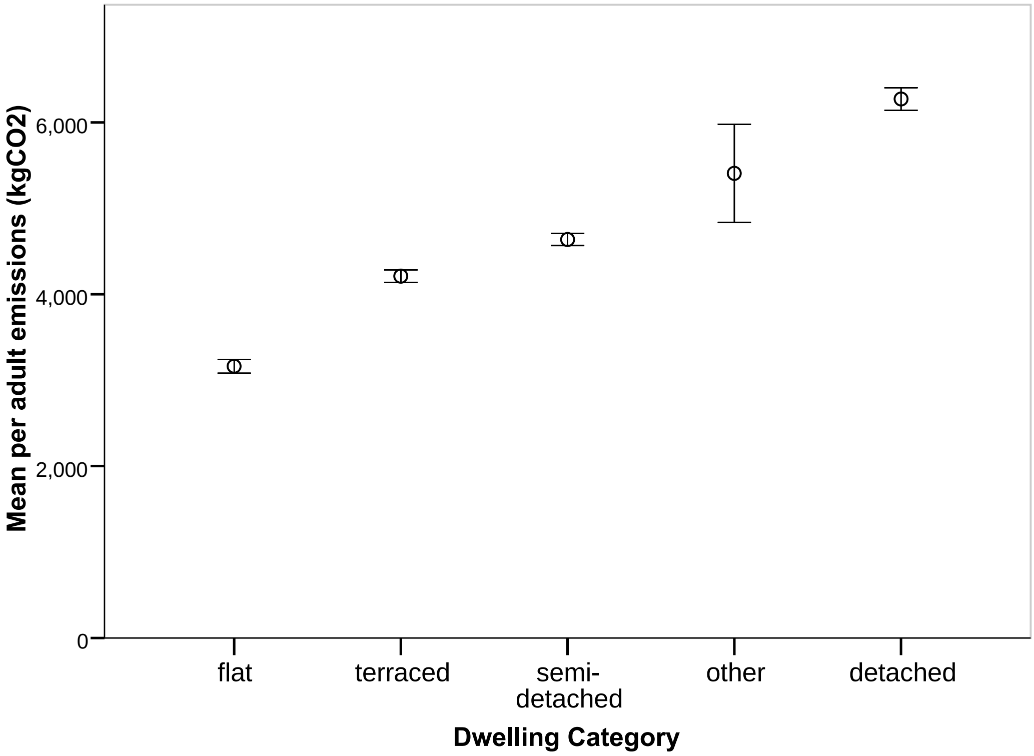


Figure 6: Per adult CO_2 and tenure

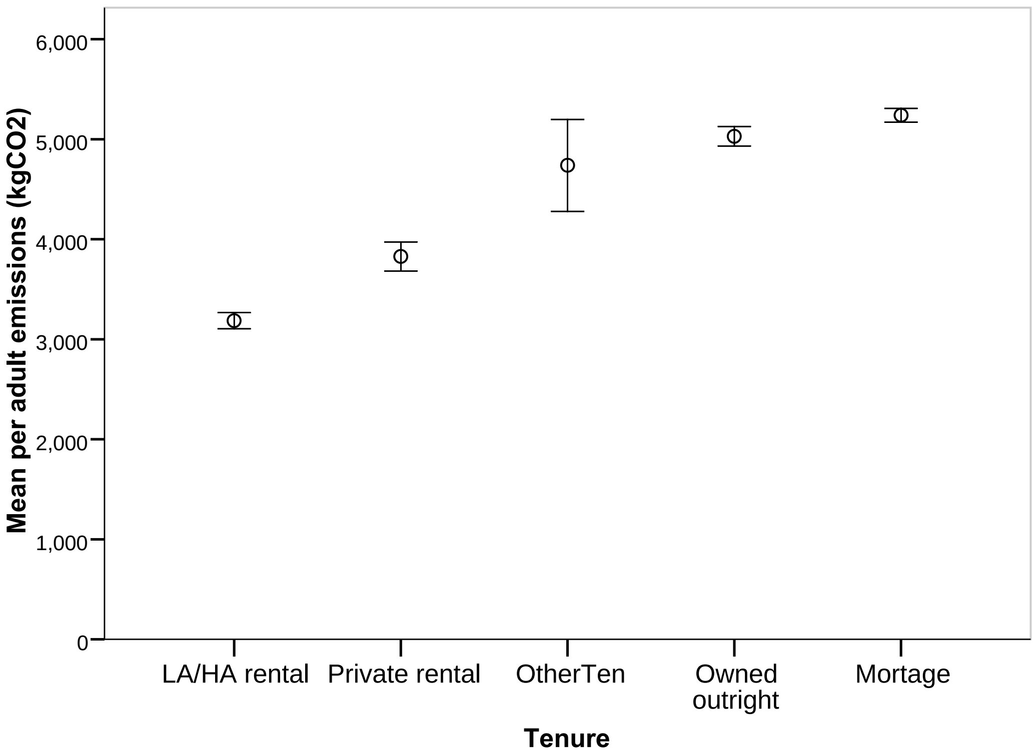
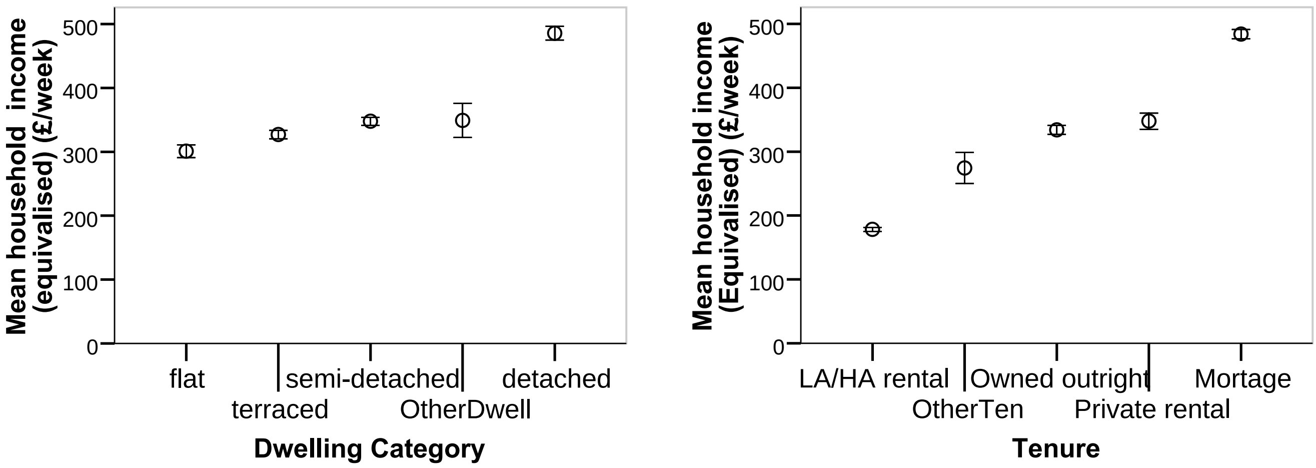
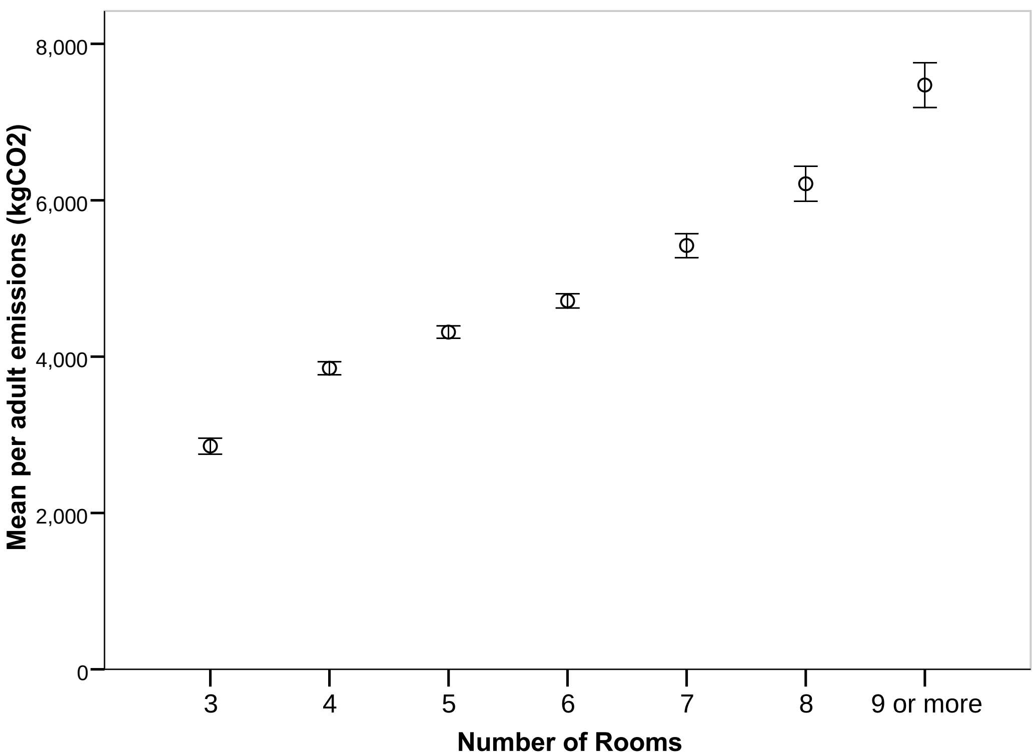


Figure 7: Income and dwelling category and Income and tenure



4.13 Figure 8 below shows that mean per-adult emissions increase with the number of rooms (which we can take as a proxy for house size). This is related to the trend shown in Figure 5.

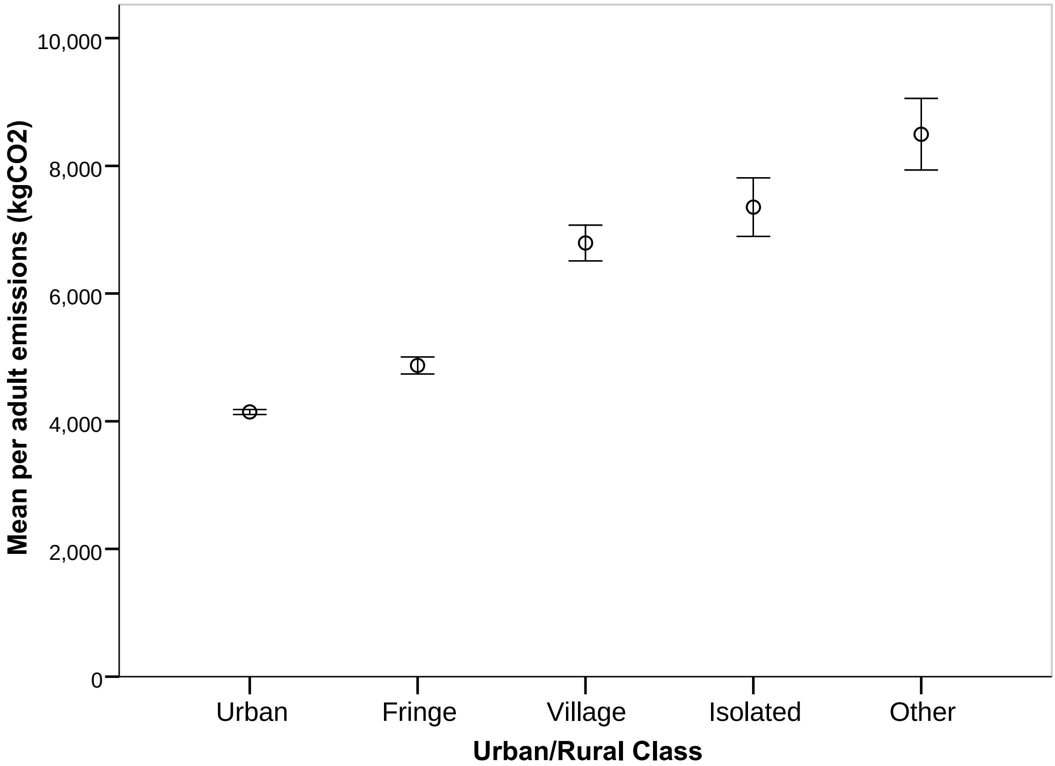
Figure 8: Per adult CO_2 and number of rooms



4.14 Households in rural areas have, on average, higher per adult emissions than households in urban areas (Figure 9). Here 'Other' represents Northern

Ireland which is not categorised under the urban/rural classification used in the EFS. The reasons for higher per-adult emissions in Northern Ireland and rural areas are discussed in Section 5.

Figure 9: Per adult CO_2 and urban/rural classification



Allowance surplus/deficit

4.15 Bivariate analysis was also undertaken looking at the average difference between total household carbon allowance allocation and household emissions. The same limitations apply to the following graphs as those discussed in paragraph 4.4.

4.16 Figure 10 shows that, on average, households in the highest income decile have a deficit in allowances of around -3.5tCO_2, while those in the lowest income decile have a surplus of nearly 1. 5tCO_2. This reflects the trend shown in Figure 1, and has important implications for the likely progressiveness of a PCT system, which are discussed in Section 5.

4.17 Figure 11 shows the same information for disposable income deciles, which again presents differences between deciles on a smaller scale to equivalised income.

Figure 10: Allowance surplus/deficit and income

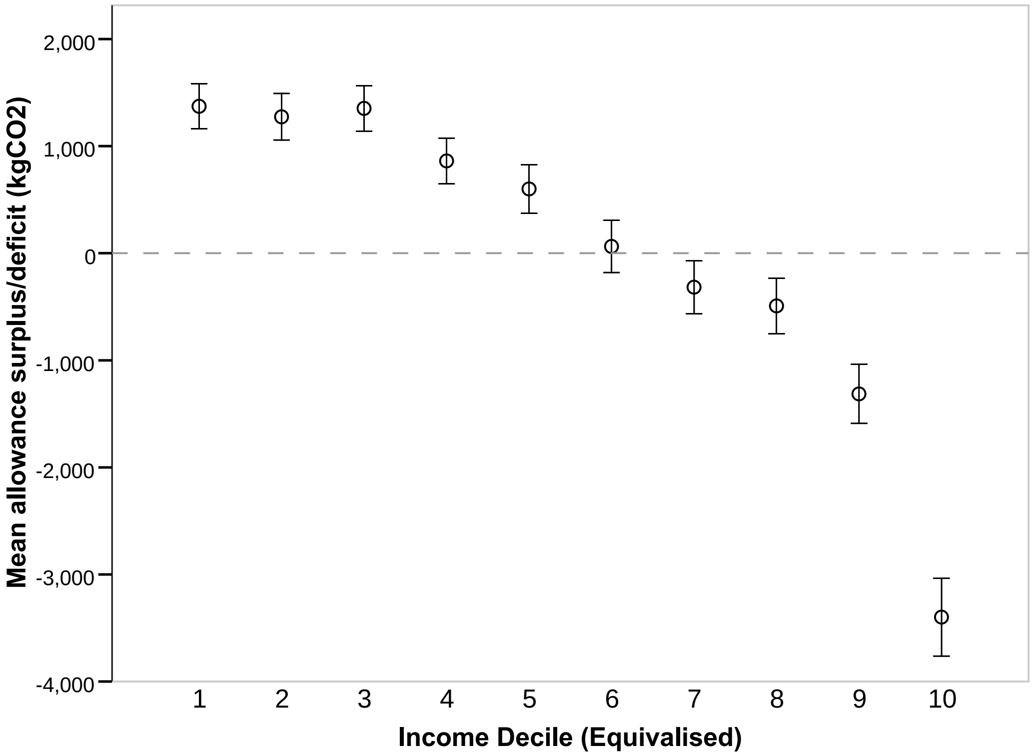


Figure 11: Allowance surplus/deficit and income (disposable)

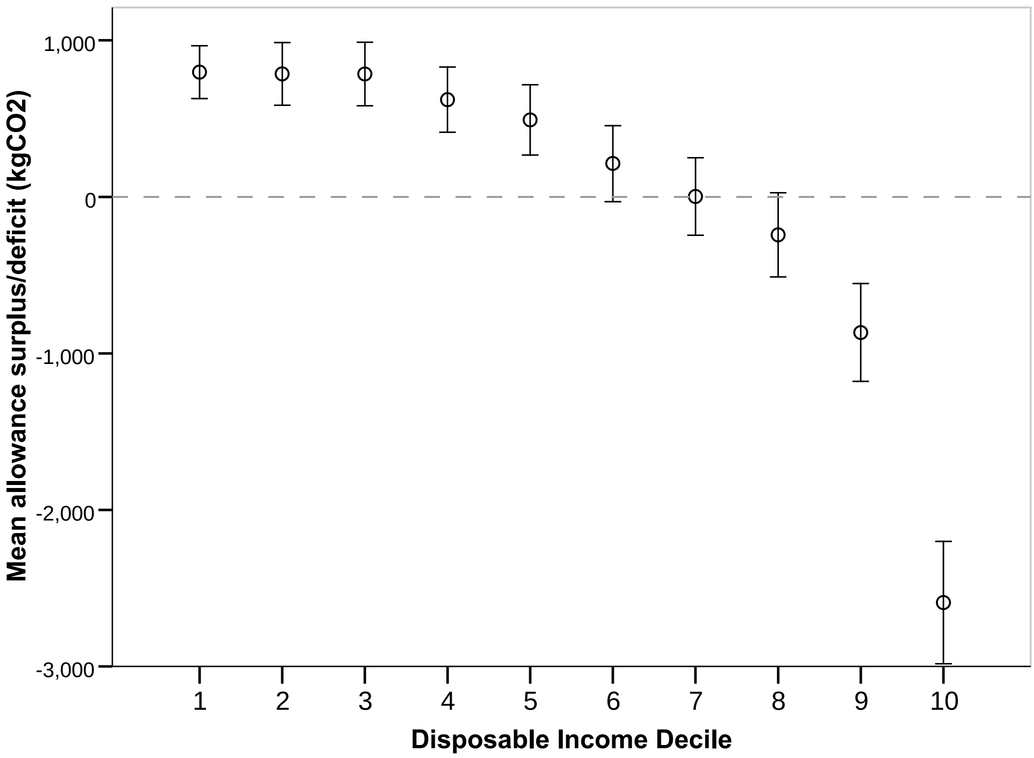
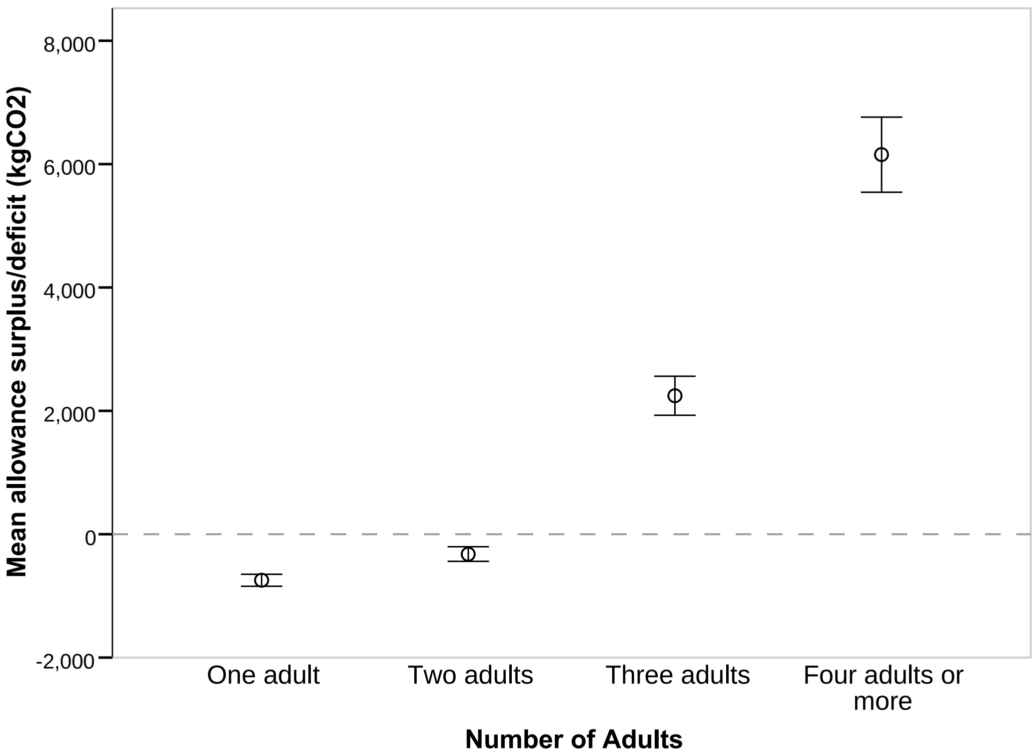


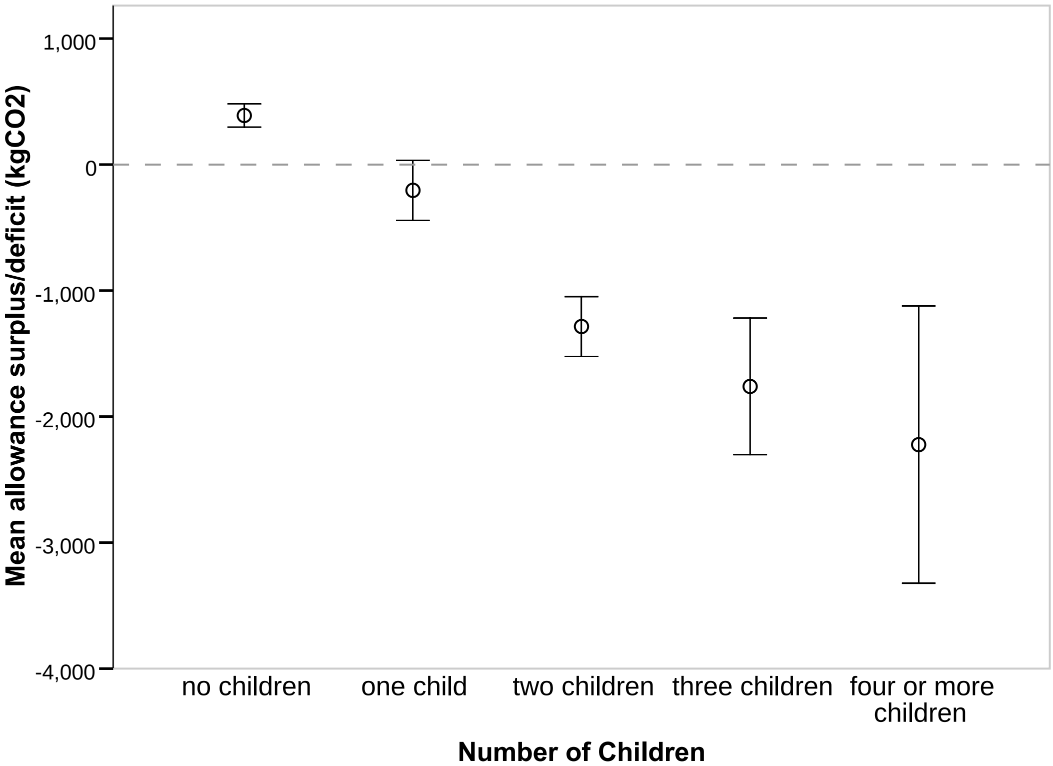
Figure 12: Allowance surplus/deficit and number of adults



4.18 Figure 12 shows that on average one-adult households experience a deficit in allowances of just under 1tCO_2, while households with three or more adults have a surplus of around 6tCO_2. Note that nearly 90% of all UK households contain less than 3 adults.

4.19 Figure 13 shows how the mean balance of allowances (allocated on a per-adult basis) varies with the number of children per household. Over 80% of households fall into the first two categories. Again, the wide error bars reflect reducing numbers of cases in the later categories, leading to reduced statistical confidence in the means.

Figure 13: Allowance surplus/deficit and number of children



4.20 The error bar plot of mean surplus/deficit in allowances against dwelling category (Figure 14) reflects that shown in Figure 5: dwelling types with the highest average per adult emissions have, on average a deficit in allowances (detached houses), and dwellings with the lower average per adult emissions have a surplus of allowances (flats). The difference between these averages is pronounced, with households living in flats having an average surplus of around 2tCO_2 and households in detached dwelling having a deficit of over 3tCO_2. The same can be said for tenure, as shown in Figure 15, with households with a mortgage having an average deficit of just over 1tCO_2 and households renting from a local authority or housing association having an average surplus of over 2tCO_2.

Figure 14: Allowance surplus/deficit and dwelling type

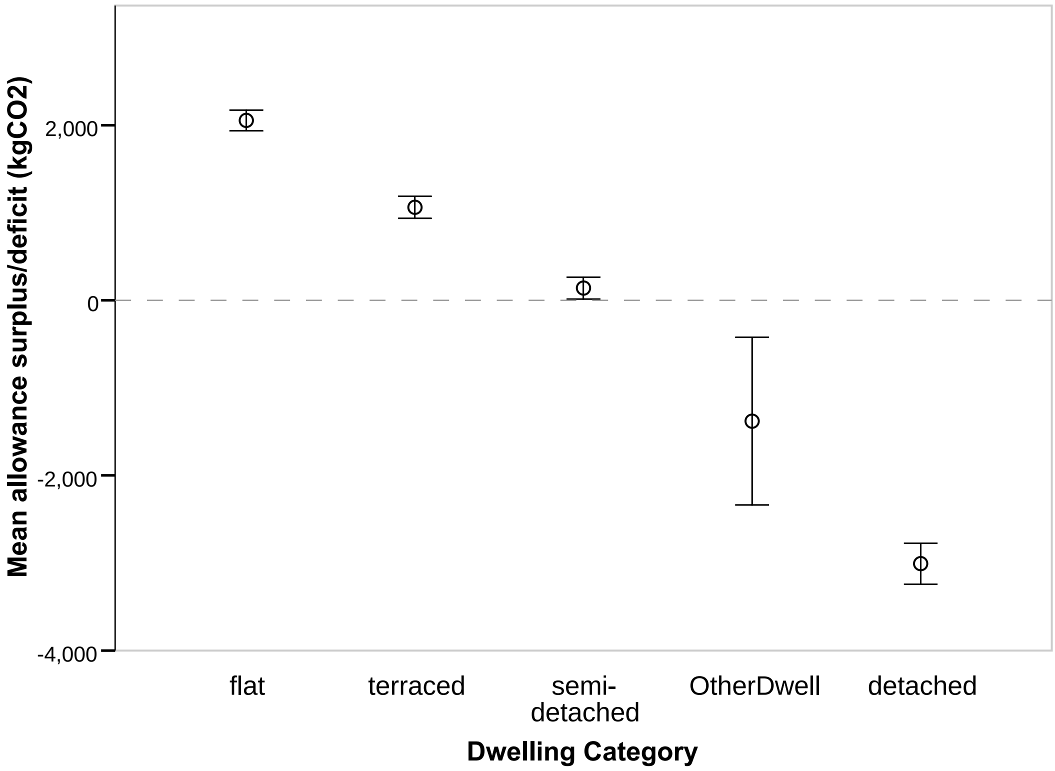


Figure 15: Allowance surplus/deficit and tenure

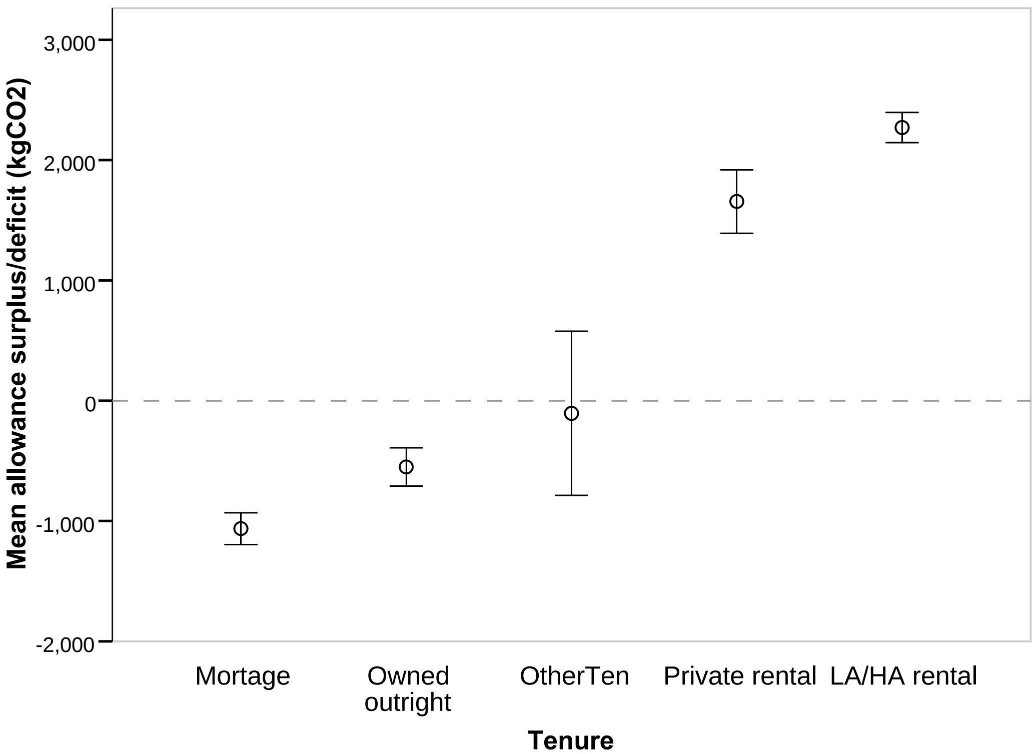
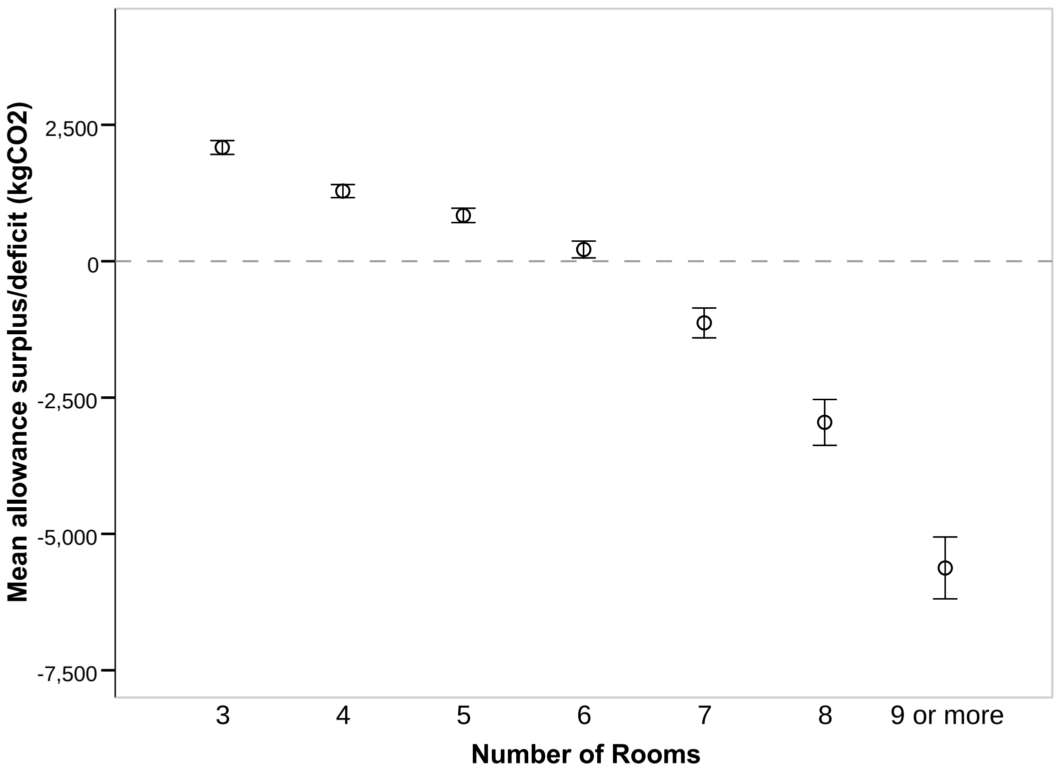


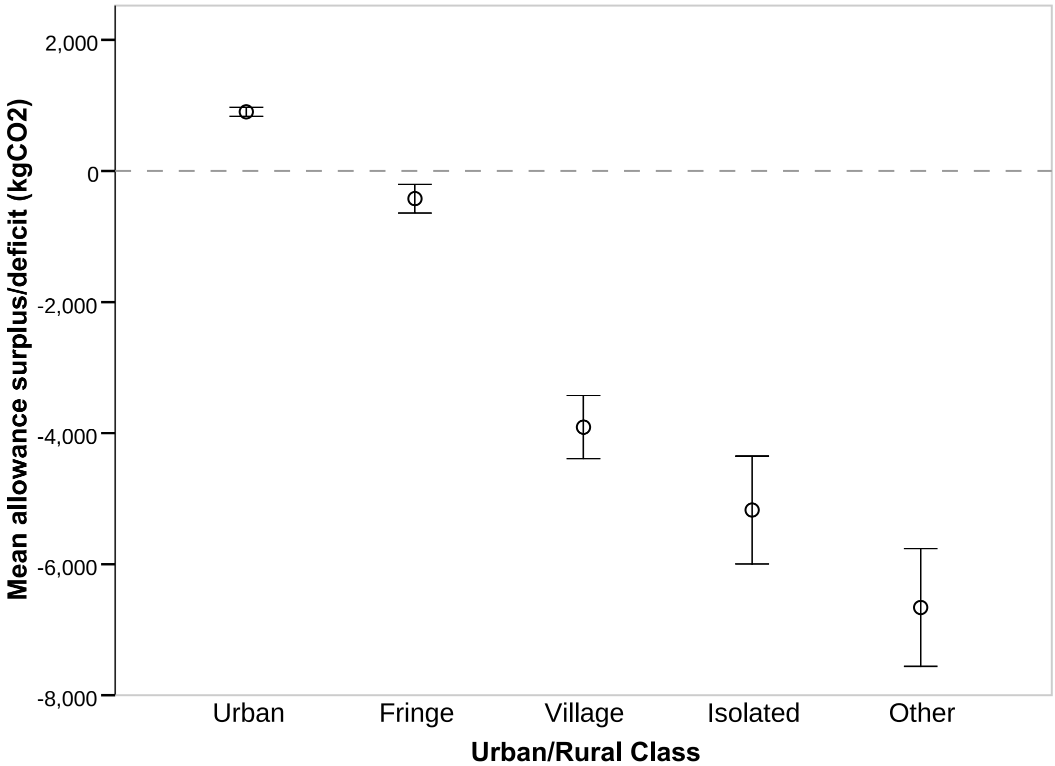
Figure 16: Allowance surplus/deficit and number of rooms



4.21 Figure 16 shows the variation in mean allowance surplus/deficit with number of rooms in the household. As would be expected from the trend shown earlier in Figure 8, the larger the number of rooms, the greater the average deficit in allowances. The difference, on average, between houses with three rooms and houses with nine or more rooms is very pronounced at over 7.5tCO_2. It is worth reiterating here that multiple effects are likely to be behind the apparently simple relationship shown in these figures.

4.22 Finally, Figure 17 shows how mean surplus/deficit in allowances varies with rurality. The mean surplus/deficit for urban and fringe areas (together representing about 90% of households) are 1tCO_2 surplus and 0.5tCO_2 deficit respectively. Rural households have on average a greater deficit in allowances, of approximately 4-6tCO_2. These trends are discussed in further detail in Section 5.

Figure 17: Allowance surplus/deficit and urban/rural classification



Multivariate Regression Analyses

4.23 Next, we used multiple linear regression analysis to explore the relationship between variables of interest in the EFS and the two dependent variables (CO_2 emissions per adult and degree of allowance credit/deficit per household) in more detail, at a multivariate level.

4.24 A wide range of candidate variables were entered into the regression modelling process. Those found not to have a significant relationship with the dependent variables were rejected by the process. The 'successful' variables are listed below. More detail on the specification and performance of the linear models is given in Annex C.

Influences on overall per adult household emissions

4.25 Fifteen variables were found to have a significant relationship with per-adult carbon emissions (i.e. these were accepted by the model). These variables are listed below, by parent[4] variable name, and ranked in order of relative importance to the model.

Table 4: Multiple linear regression analysis: significant variables (in order of relative importance) for per adult emissions

Parent variable name
Number of Adults
Number of Vehicles
Central Heating Type
Number of Rooms
Number of Children
Income (equivalised)[5]
Tenure
Number of Appliances
Age of HRP[6]
Dwelling type
Government Office Region
Economic position of HRP
Rural/ urban classification
Only adults over 65 in household
Sex of HRP

4.26 The multiple linear model was found to explain 46% of the variation in per-adult emissions (with outliers filtered) – that is, the model had an R^2 value of 0.46 (where a value of 1 represents a perfect model fit).

4.27 If the factors represented by the independent variables identified in the modelling process have a causal relationship with household emissions in the real world (as opposed to in the EFS dataset), the strength of this relationship (expressed as the model R^2 value) should increase as the dependent variable becomes more representative of real household emissions. The opposite should also hold: as the dependent variable becomes less representative of real household emissions, the strength of the modelled relationship should decrease.

4.28 As discussed in paragraph 3.9, the distribution of expenditure on household fuel and petrol and diesel (and hence the consumption and emissions quantities we derive from this expenditure) in the EFS is wider than the real

[4] In many cases dummy variables were created representing categories of these parent variables, either to address issues of non-normal distributions, or to allow the use of categorical variables in the linear regression model.
[5] The OECD equivalised income variable corrects disposable household income based on the number and age breakdown of the dependents in a household.
[6] HRP stands for Household Reference Person, which is defined as the householder with the highest income (or the oldest of two or more householders with the same income).

distribution of expenditure in the population it represents. Hence the set of predictor variables in the model may actually explain more than 46% of the variation in real emissions (although it is not possible to say how much more, since we don't have access to the real distribution).

4.29 In any case, it is certain that these variables can explain less than 100% of the variation, since there are numerous factors influencing personal emissions that are not represented in the model. These include housing age, condition and SAP rating, vehicle engine size and annual mileage, local climate and weather conditions, access to public transport, and fuel price variations to name but a few.

Influences on household allowance surplus/deficit

4.30 The same set of independent variables was entered into a second linear regression model, this time with the difference between allowance and household emissions as the dependent variable. The outputs in terms of variables selected as significant and their relative importance is very similar to the model with per adult emissions, with the exception that gender of HRP was rejected in this second model. The R^2 for this model was 0.54 (with outliers removed[7]) - that is, the independent variables in this model explain 54% of the variation in the dependent variable (allowance surplus/deficit).

Table 5: Multiple linear regression analysis: significant variables (in order of relative importance) for allowance surplus/deficit

Parent variable name
Number of Adults
Number of Vehicles
Central Heating Type
Number of Rooms
Number of Children
Income (equivalised)
Tenure
Age of HRP
Number of Appliances
Government Office Region
Dwelling type
Economic position of HRP
Rural/urban classification
Only adults over 65 in household

[7] See Annex C: removal of a small number of outlying cases improves model fit.

4.31 The R^2 value is different (and greater) for this model partly because a subset of cases with non-zero values were used in the per-adult emissions model, while all cases were used in the allowance credit/deficit regression. In addition, the model fit may be expected to be better given that the dependent variable shows a strong correlation with number of adults in the households-, which is one of the predictor variables.

4.32 The regression outputs are discussed in more detail in Annex C. This difference in model fit is not important in terms of the objectives of the regression exercise, which is not to develop a predictive model of per-adult emissions, but to identify a set of variables for use in a classification process.

5 Analysis: classification of households

Introduction

5.1 Because the EFS is not representative at individual household level, it is necessary to create reasonably large (200+) groups of cases, from which the mean of the quantity of interest can be calculated. This requires a procedure which can create such groups based on values of the predictive variables identified in Section 3, and predicted values (in practice equal to the mean value for each group) of the dependent variable – in this case the annual allowance surplus/deficit per household.

5.2 This approach also has the advantage of creating clusters of similar (in terms of the values of the independent variables) households which can be analysed from a socio-economic and demographic perspective in terms of the between-group variations.

5.3 After discussion with experts at the University of Bristol, we selected a method known as exhaustive CHAID ('for Chi-Squared Automatic Interaction Detector'). CHAID is a method used to study the relationships between a dependent variable and a set of predictor variables which may interact with one another. The 'exhaustive' version of CHAID is more computationally intense, but yields more accurate results. More detail on CHAID is given in Annex C.

5.4 In our case the end result of the CHAID analysis is the clustering of the EFS dataset into groups of cases with similar values for the predictor variables. We then take the mean surplus/deficit for each group as characteristic of that group, ignoring the distribution about the mean, which is distorted by the EFS diary methodology, and hence unreliable (see Section 2).

5.5 One of the challenges in using the CHAID classification process is achieving an output that is on the one hand detailed enough to be meaningful and accurate, and on the other, not too complex to interpret and draw conclusions from. The results from the regression analysis, along with our understanding and knowledge of variables of policy relevance and interest were used to guide the selection of variables for inclusion in the classification.

5.6 The independent variables used in the classification are listed below (Table 9). Note that we excluded number of vehicles, number of electrical appliances, and type of heating system from the CHAID process, although these were found to be predictors of allowance credit/deficit in the regression modelling. This was done in order to limit the classifying variables to those considered to be most useful for characterising the population from a social and political perspective, and to reduce the complexity of the final classification.

5.7 In addition, the number of vehicles owned by a household has a strong positive correlation with income, while information on the number of appliances is limited to the 13 different appliances named specifically in the EFS. This does not quantify actual numbers of each appliance, only whether there is one in the household; a household with three DVD players, for example, would appear no different in the dataset to a household with one DVD player (with the exception of televisions, where the actual number of sets is included).

5.8 A very large number of different classifications could be obtained from the dataset, by varying both the set of predictor variables, and the detailed settings for the CHAID process, but it is beyond the scope of this project to analyse more than one classification.

5.9 When heating system type is entered into the list of independent classification tree variables, the urban/rural classifier is no longer significant, and is automatically rejected by the classification process. However, the bivariate analysis showed very clear distinction between rural/urban emissions and surplus/deficit allowances (paragraph 4.14, Figure 9 and paragraph 4.22, Figure 17). This therefore suggests that some or all of the effect of the urban/rural classifier in fact results from the predominance of oil-fired heating systems in non-urban areas. As Table 6 shows, oil central heating accounts for over one third of all heating systems in isolated areas, and just under a third in villages, compared to less than 1% in urban areas.

5.10 In addition, analysis of household emissions compared to road transport emissions, shows that (perhaps surprisingly) household fuel use accounts for a higher proportion of total emissions in rural areas compared to urban areas (Table 7), despite vehicle ownership being greater in rural areas (Table 8).

This could be expected to increase the importance of the heating system variable in non-urban areas (which would be an example of an interaction effect between urban/rural classification and heating system).

5.11 Although number of vehicles was not used in the classification, we analysed the values of this variable when investigating the characteristics of the classification groups in Section 5.

Table 6: Central heating type and rural/urban classification

	No central heating	Electric	Gas	Oil	Solid	Other
Urban	6.1%	7.3%	85.2%	0.4%	0.5%	0.5%
Fringe	3.8%	8.6%	81.6%	3.3%	1.7%	1.0%
Village	5.1%	14.0%	42.4%	27.9%	4.4%	6.1%
Isolated	6.9%	15.3%	27.4%	36.3%	7.8%	6.3%
Other	2.8%	6.5%	8.0%	76.0%	5.4%	1.3%

Table 7: Household and road transport emissions by rural/urban classification

	Mean % of total emissions		Mean subtotal $kgCO_2$		Mean Total kg CO_2
	Road Transport	Household	Road Transport	Household	
Urban	29%	71%	2,079	5,090	7,169
Fringe	32%	68%	2,723	5,787	8,510
Village	27%	73%	3,284	8,880	12,164
Isolated	25%	75%	3,382	10,147	13,529
Other	19%	81%	2,840	12,106	14,946

Table 8: Number of vehicles and rural/urban classification

	0	1	2	3	4	Mean
Urban	28%	43%	22%	5%	1%	1.1
Fringe	18%	43%	30%	7%	2%	1.3
Village	11%	39%	38%	9%	3%	1.5
Isolated	7%	42%	37%	9%	5%	1.6
N.I.	25%	46%	25%	4%	1%	1.1

5.12 The cost of the choice to not include central heating type (along with vehicles and appliances) as an independent variable is a weakened CHAID model, while the benefit is a simpler and more useful and relevant set of classifications. Nevertheless, and as noted above, alternative CHAID model runs could in future be undertaken which include these variables, and the results compared to those presented here.

Classification results

5.13 Table 9 below lists (in final order of importance to the CHAID model – all were accepted by the model) the seven variables entered as the independent variables in the exhaustive CHAID process.

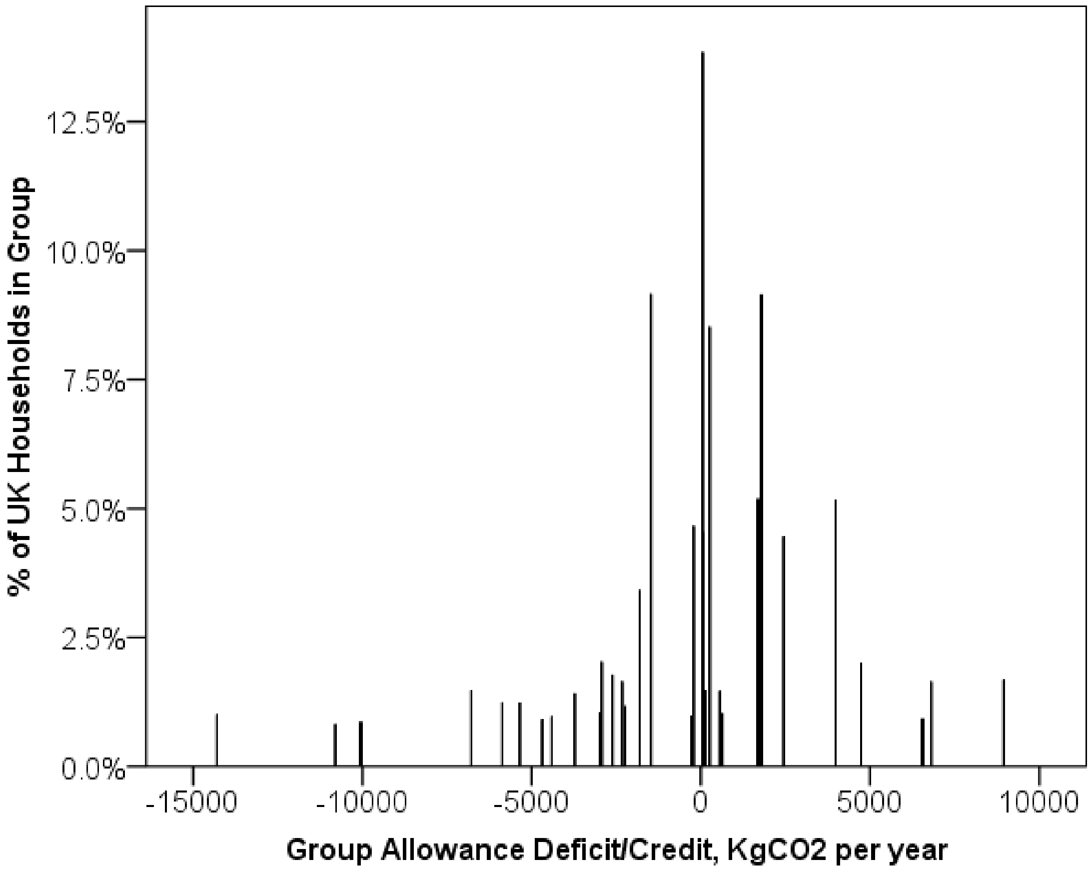
Table 9: List of variables entered and accepted in the CHAID process

Variable
Urban/rural classification
Number of rooms
Tenure
Equivalised income decile
Number of adults,
Housing type (terraced, detached, etc)
Number of children

5.14 This resulted in a classification tree consisting of 65 nodes, of which 33 were terminal nodes – that is, groups of cases with no further splits below them in the tree. Our focus from here on will be on these 33 terminal nodes, which between them contain the entire dataset, split on various combinations of the independent variables listed above.

5.15 Figure 18 below shows the distribution of these 33 groups in terms of the number of households in each group (y-axis), and the mean allowance deficit/credit for each household group (x-axis). A larger scale version of the chart is used in Section 5 for identifying various groups of interest for further analysis and discussion. Note that there are roughly 25m households in the UK, and so 2.5% on the Y-axis represents around 625,000 households.

Figure 18: Distribution of CHAID classification groups by allowance surplus/deficit



5.16

5.17 Figure 19 and Figure 20 below show respectively the full classification tree, and a detail at a zoom level allowing the text to be read. We include these images for illustration purposes – the tree structure itself is of interest in terms of a detailed investigation of the relative importance of the independent variables, and for identifying interaction effects between variables, but these are beyond the scope of the current project. For the purposes of this report, we will focus on the characteristics of the cases in the terminal nodes.

Figure 19: Final CHAID Classification Tree

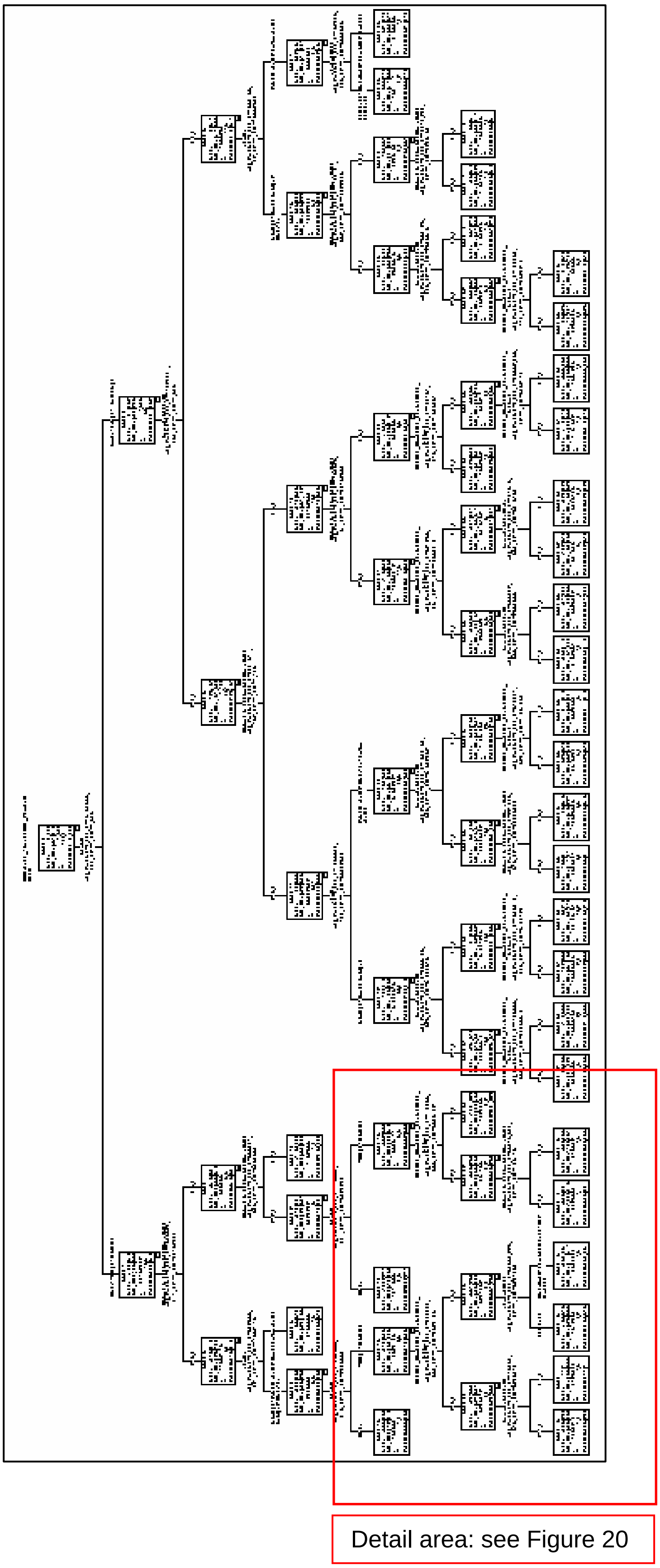
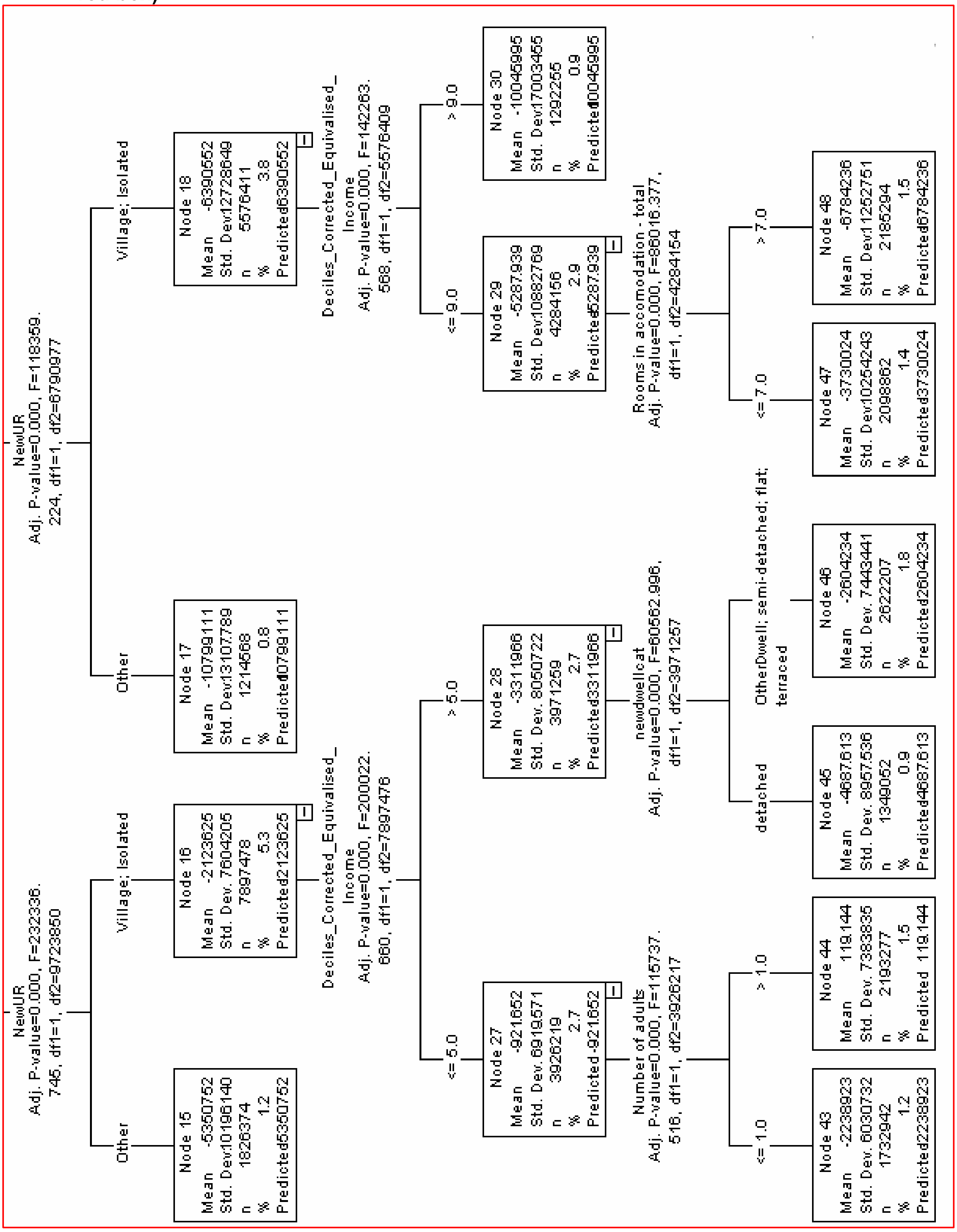


Figure 20 Detail of a section of the classification tree shown in Figure 2 above (area of red box)



Note: In this diagram, terminal nodes are those with no child nodes. Examples are nodes 15, 43 and 44. Parent nodes such as 16, 27, and 28 are not analysed in detail in this report.

6 Winners and losers

Introduction and headline results

6.1 This section presents the analysis of which types of household would be expected to gain or lose under the PCT system based on a per-adult allowance allocation, and with the cap set at current emissions. Note that this analysis does not take into account the possible distributional effects of the way in which the PCT scheme running costs would be recovered. Importantly, the emissions analysed also exclude those from personal aviation, the inclusion of which could be expected to have significant effects on the distributional outcomes.

6.2 As Table 10 below shows, under the system of PCT allowances modelled here, 59% of all UK households would have a surplus of carbon allowances, while 41% would have a deficit. The following sections investigate the distributions of this gain and loss by income, housing type and tenure, geography, and household composition.

Distribution by income

6.3 The regression and classification analyses showed that income is an important factor influencing both per-adult emissions and the degree of household allowance deficit/credit. As is shown below in Table 10, there is a clear tendency for lower income households to have a surplus of allowances, and for higher income households to have a deficit. This is true for both the equivalised (Figure 21) and disposable (Figure 22) measures of income, and shows that a PCT system would be progressive overall.

6.4 As shown in Table 10, the majority of households (59%) have a surplus of allowances and of these winners, 36% are in the lowest (1-3) income deciles, compared to 23% in the highest (8-10) income deciles. Conversely, 40% of losers are in the highest three equivalised income deciles (representing 17% of all households). However, 21% of households with an allowance deficit are in income deciles 1-3, suggesting that there would still be a number of low income households made worse off by the system.

Table 10 Distribution of winners and losers by income deciles

	Income deciles (equivalised)	% of winners/losers	% of all HH's	Mean credit/deficit ($kgCO_2$)	Total
WINNERS	1 to 3	36%	21%	3,577	**59%**
	4 to 7	41%	24%	3,530	
	8 to 10	23%	13%	3,398	
LOSERS	1 to 3	21%	9%	-4,170	**41%**
	4 to 7	39%	16%	-4,532	
	8 to 10	40%	17%	-5,930	

6.5 Table 11 below shows that 71% of households in income deciles 1-3 are winners, compared to 45% in the top 3 income deciles. Conversely, 29% of the lowest income deciles lose, compared to 55% of income deciles 8-10.

6.6 Figure 21 below illustrates the information in Table 11, showing the number of households winning and losing, split by equivalised income decile. Figure 22 shows the same information by disposable income decile. Note that these figures do not show the amounts by which households are winning or losing, but simply the proportion of households that gain or lose, by any amount (the mean surplus/deficit for income deciles was shown in Figure 10).

Table 11: Summary of winners and losers by income decile groups

	Losers			**Winners**		
Equivalised income deciles	**1000s of HHs**	**% of decile group**	**% of all HHs**	**1000s of HHs**	**% of decile group**	**% of all HHs**
1-3	2,141	29%	9%	5,246	71%	21%
4-7	3,946	40%	16%	5,908	60%	24%
8-10	4,067	55%	17%	3,323	45%	13%

Figure 21: Winners and losers by equivalised income decile

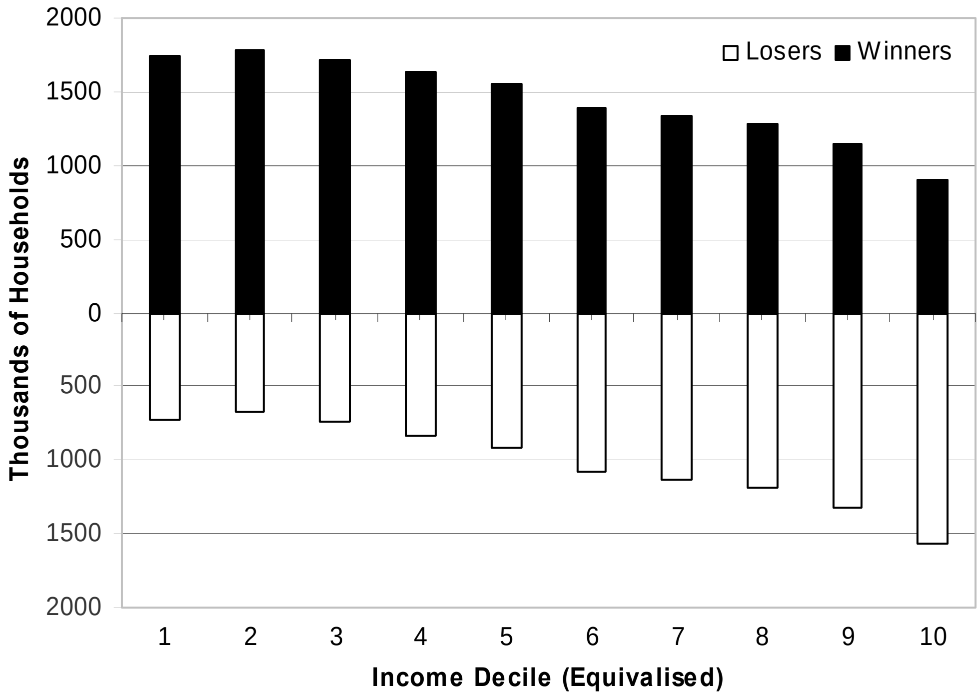
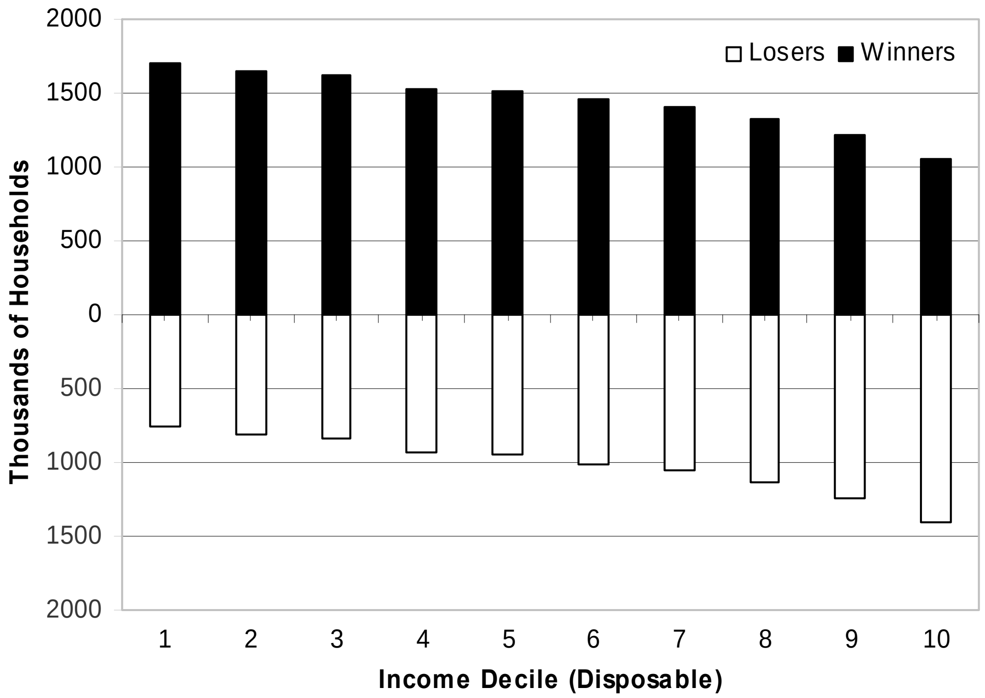


Figure 22: Winners and losers by disposable income decile



6.7 Note, however, that this analysis does not take into account the degree of surplus or deficit. A limitation of this study is that we cannot achieve certainty regarding the distribution of allowance surplus/credit, due to the EFS diary methodology. However, it may be safe to assume that the real distribution is at least as narrow as that in the EFS dataset. Table 12 below sets out this distribution, showing the number and percentage of UK households experiencing various magnitudes of allowance credit/deficit. This shows that almost 20% of all households have an allowance surplus or deficit of 1tCO_2 or less. This is mirrored within income deciles 1-3. The analysis shown in Table 10 illustrates that the mean deficit among households that lose rises with income decile. Conversely the mean surplus among households that gain falls with income decile. Taken together these trends suggest that the PCT system modelled here would be very progressive.

Table 12: Dataset distribution of allowance credit/deficit

Credit/Deficit Range +/- tCO_2	Number of HHs In range	% of HHs In range
0 - 1	4,684	19%
1 - 2	4,324	18%
2 - 3	3,766	15%
3 - 4	3,013	12%
4 - 5	2,552	10%
5 - 6	1,515	6%
6 - 7	1,201	5%
7+	3,578	15%
Total	**24,633**	**100%**

6.8 Note that in Table 12, the spuriously large number of households in the +/- 7tCO_2 and above category is an artefact of the EFS diary methodology: many of these will be households with either under- or over-estimated expenditure on fuels, leading directly to inaccurate emissions figures. In reality most are probably distributed across the other categories, narrowing the overall distribution.

Distribution by Housing Type and Tenure

6.9 As shown in Table 13 below, detached houses represent nearly a quarter of UK households and 59% of these have a deficit of allowances. Households living in flats account for just under one fifth of the UK total, and 77% of these would experience a surplus of allowances.

Table 13: Winners and losers by housing type

	Detached	Semi-detached	Terraced	Flat	Other
% winners	41%	58%	63%	77%	58%
% losers	59%	42%	37%	23%	42%
% of all HHs	*22%*	*32%*	*28%*	*17%*	*2%*

6.10 Analysis of winners and losers by tenure is shown in Table 14 below. Local authority and Housing Association (LA/HA) rented accommodation accounts for nearly one fifth of all UK households and again, 77% of all households in this tenure type are winners under this scenario. For mortgage holders (the dominant tenure), the split between winners and losers is approximately even, and for households owned outright the pattern mirrors that for the dataset as a whole.

Table 14: Winners and losers by Tenure

	LA/HA rental	Private rental	Mortgage	Owned outright	Other
% winners	77%	69%	49%	58%	56%
% losers	23%	31%	51%	42%	44%
% of UK HHs	*19%*	*9%*	*40%*	*30%*	*1%*

Distribution by Geography

6.11 Urban/rural classification was the most important variable in the classification tree process. As noted in paragraph 5.9, it appears that the main effect of the urban/rural classification may actually be related to the predominant heating systems differing between urban and rural areas. Nevertheless it was felt that of the two variables, the urban/rural definition was more relevant to the objectives of this report and was therefore included as a classification variable.

6.12 A higher proportion of households in rural areas (split into Village and Isolated categories) lose compared with households in Urban or Fringe areas (which follows from the finding in section 4 that emissions are on average higher in rural areas). This is shown in Figure 23 below. While a greater proportion of rural households suffer a deficit of allowances, it should be noted that these represent a small proportion of all UK households, as shown in Figure 24 below.

Figure 23: Proportion of winners and losers by urban/rural classification

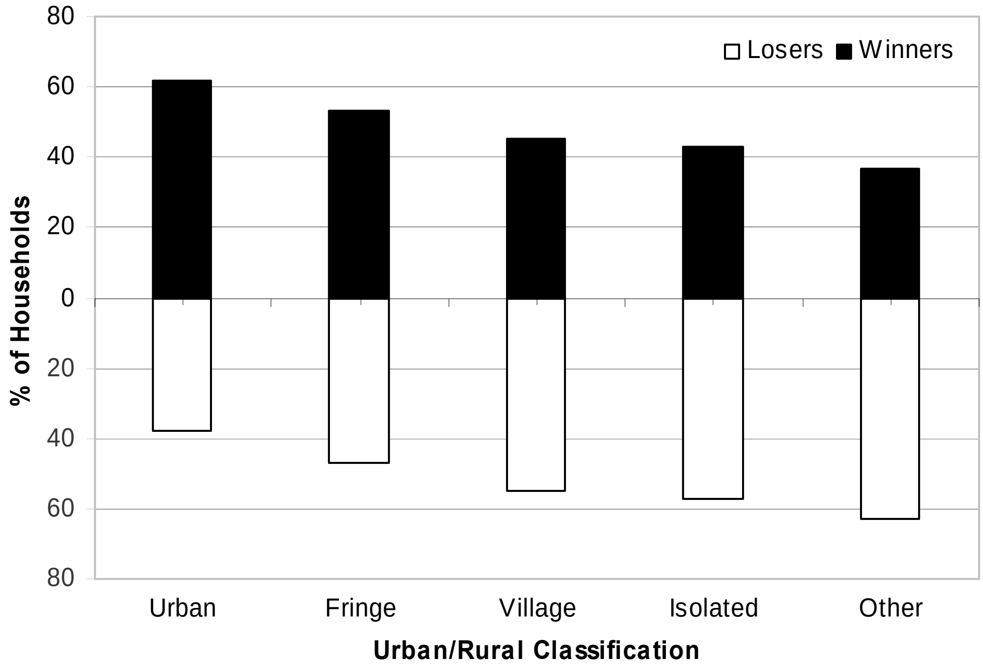
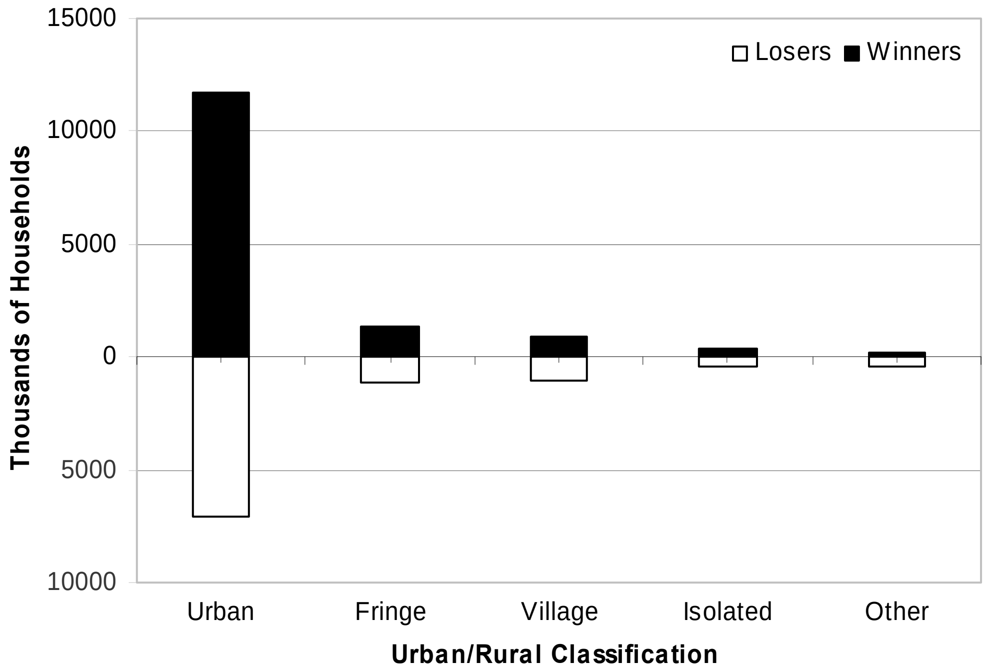


Figure 24: *Number* of winners and losers by urban/rural classification



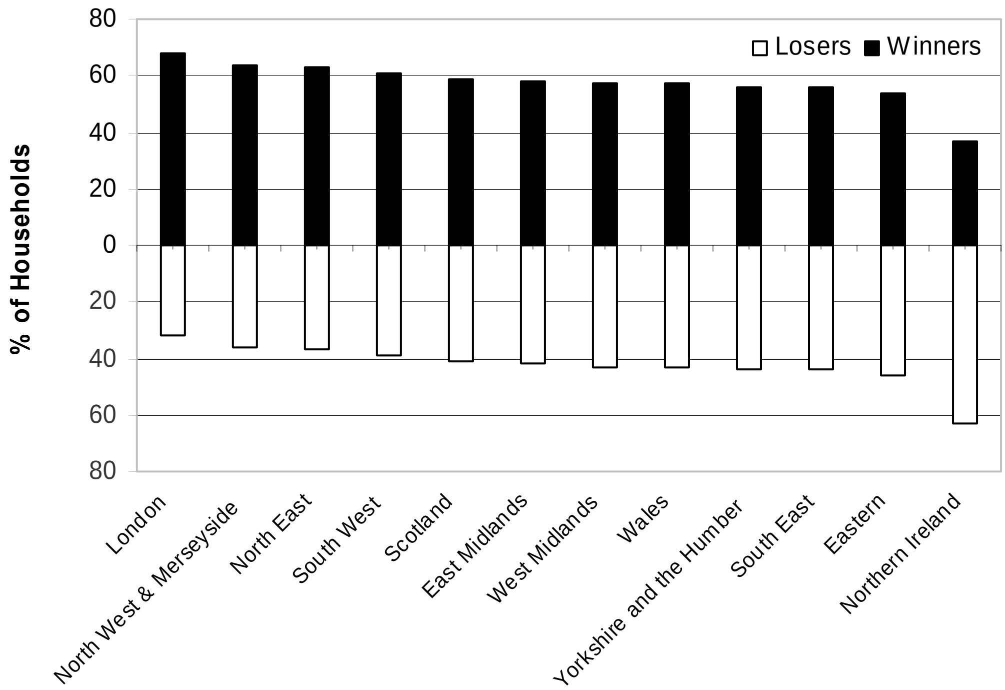
6.13 The 'Other' category in the figures above represents Northern Ireland, which is not included in the urban/rural classification used in the UK Expenditure and Food Survey. As Figures 25 shows, a higher proportion of Northern Ireland households lose compared to other regions of the UK. There may be a number of explanations for this, including that, according to the Northern

Ireland Department for Regional Development, about 35% of Northern Ireland's population lives in rural areas. This contrasts with the rest of the UK, for which the figure is around 12% of households (as opposed to people).

6.14 However the single biggest reason for Northern Ireland's personal carbon emissions being higher than the UK average is the lack of availability of natural gas as a heating fuel. This is confirmed in the Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland (1990-2005, p.19)[8] which states that:

> "CO_2 emissions from domestic combustion sources are estimated to account for 17.8% of the Northern Irish CO_2 total. As a proportion of UK domestic emissions they are estimated to represent 3.2%, which is slightly higher than would be expected from Northern Ireland's population (2.9% of UK). The reason for this is the very limited availability of natural gas resulting in the high consumption of coal, burning oil and gas oil in the domestic sector, although natural gas is becoming more widely available and domestic CO_2 emissions have shown a decrease of 18.5% since 1990".

Figure 25: Proportion of winners and losers by Government Office Region



[8] Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland (1990-2005), August 2007: http://www.airquality.co.uk/archive/reports/cat07/0709180907_DA_GHGI_report_2005.pdf

6.15 Figure 25 shows that there are differences between the proportion of winners and losers in different Government office regions, with Northern Ireland showing the biggest difference. Again, there will be a number of factors behind this trend. The mean surplus/deficit in allowances for each region is shown in Table 15 below, along with the proportion of different central heating types. Broadly speaking, regions with the largest average household deficits have the highest proportions of oil central heating (the pattern for rurality is similar but less marked, and is not shown here).

Table 15: Central heating type and mean surplus/deficit in allowances for GORs

	No central heating	Electric	Gas	Oil	Solid fuel	Other	Mean surplus/ deficit ($kgCO_2$)
London	6%	6%	86%	0%	0%	1%	1,550
North East	3%	4%	89%	2%	2%	0%	907
North West	7%	6%	84%	2%	1%	1%	767
East Midlands	4%	7%	80%	4%	3%	2%	134
West Midlands	7%	8%	81%	2%	1%	1%	88
Yorkshire & Humber	9%	6%	80%	2%	2%	1%	31
Scotland	4%	14%	75%	5%	2%	1%	-79
South West	8%	11%	69%	9%	1%	2%	-119
South East	5%	10%	80%	4%	0%	1%	-249
Wales	4%	5%	78%	7%	3%	2%	-513
Eastern	5%	10%	75%	9%	1%	1%	-838
Northern Ireland	3%	6%	8%	76%	5%	1%	-6,661

6.16 As with Government office region, rurality itself is not a direct cause of allowance deficit. There are a number of associated factors, which, taken together, explain much of the effect. For example:

- Heating systems
- Housing age, type, and size
- Vehicle type, ownership and use
- SAP rating
- Microclimate (no urban heat islands)

6.17 Further analysis of the dataset shows that households with oil-fired central heating systems have, on average, higher kWh heating energy consumption than households with gas central heating. These households are therefore more likely to have a deficit in allowances.

6.18 In addition data on English households, taken from the latest English House Condition Survey (EHCS), show that housing tends to be older in rural areas, and that average SAP ratings are lower in rural areas than urban areas (see Table 16 and Table 17 below).

Table 16: Proportion of pre-1919 dwellings by urban/rural classification (from EHCS)

Urban/ Rural Classification	% of Pre-1919 Dwellings
Urban	20.1%
Town and Fringe	19.1%
Village & isolated dwellings	33.1%

Table 17: Average SAP rating by urban/rural classification (from EHCS)

Urban/ Rural Classification	Mean Energy Efficiency (SAP05) Rating
Urban	48.8
Town and Fringe	46.1
Village & isolated dwellings	36.8

6.19 The EHCS also corroborates the finding in the EFS data that oil-fired heating systems are more prevalent in rural areas. Although the prevalence of this more expensive heating fuel will in itself tend to decrease the average SAP rating in rural areas[9], older, detached housing is very likely to be less thermally efficient than newer terraced housing and flats.

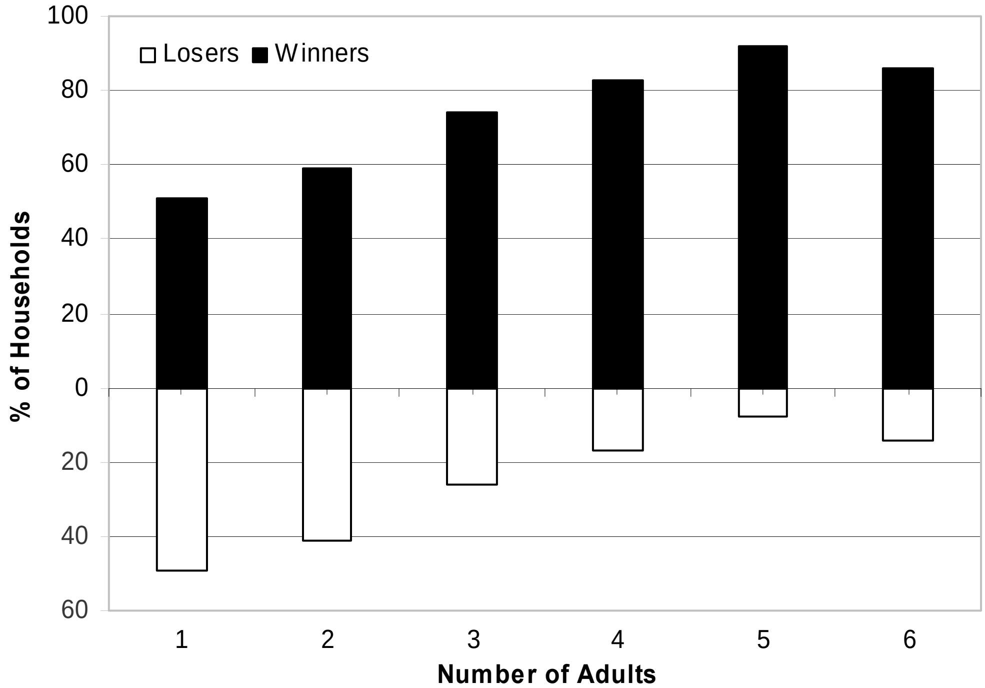
6.20 Furthermore, rural temperatures tend to be lower than urban temperatures under similar weather conditions, due to the urban heat island effect. This can be expected to increase the demand for heating in rural areas compared to urban areas. These factors all also help to explain the pattern identified in sections 4 and 5, that emissions in rural areas are on average higher than urban areas, and a higher proportion of these are accounted for by household emissions, rather than road transport, despite higher vehicle ownership in rural areas (see paragraphs 5.9 and 5.10).

Distribution by Household Composition

[9] SAP index is based on the modelled cost per unit floor area to maintain certain indoor temperatures, and oil-fired central heating is more expensive to run than gas-fired systems. Therefore replacing an oil fired heating system with a gas system would in itself increase the SAP rating of a house.

6.21 Figure 26 below illustrates that single person households are more likely to lose than households of multiple occupancy. Note that 87% of all households are in the first two categories (1 or 2 adults). This trend is a consequence of the fact that a household's per-adult emissions fall with rising numbers of adult occupants, while (under the assumptions of this study) a household's total allowance increases in direct proportion to the number of adults. Note that the balance of winners and losers for households with 6 adults appears not to follow the trend towards higher numbers of winners seen in the rest of Figure 26. This is because there are so few cases in the EFS with 6 or more adults that the data is unreliable.

Figure 26: Winners and Losers by number of adults in the household



6.22 Table 18 summarises the distribution of winners and losers, split by the number of children in the household. This shows that as the number of children in a household increases, the more likely it is to lose under the per-adult PCT system being modelled here. This is a consequence of the fact that adding children to a household is associated with a slight increase in energy use, while (under the system modelled here), additional children do not result in additional allowances.

Table 18: Winners and losers by number of children

Number of Children	0	1	2	3	4
% Winners	62%	57%	47%	44%	39%

% Losers	38%	43%	53%	56%	61%
% of UK HH's	*70%*	*13%*	*12%*	*4%*	*1%*

6.23 Table 19 shows the distribution of winners and losers for households in which all occupants are aged 65 or over. These represent just over one fifth of all UK households, and 66% of them are winners. This shows that households with older occupants tend to gain under a per-adult PCT system.

Table 19: Winners and losers by age of household

	All occupants ≥ age 65	**At least one occupant < age 65**
% Winners	66%	57%
% Losers	34%	43%
% of all HH's	*21%*	*79%*

Winning and losing: Classification Groups

6.24 The following section sets out the detail of the classification groups created using CHAID. As explained in Section 4, the CHAID classification process produced 33 different groups of households from the 20,631 EFS cases. The classification process assigns a ‘predicted value’ of surplus/deficit in allowances to each group, which is equivalent to the mean for the group (see ‘Surplus allowances’ column in). CHAID classifies cases into groups based on combinations of factors that result in a significant difference in the dependent variable (i.e. the allowance credit/deficit). Hence groups will be made up of cases with varying surplus/deficit values; this may result in a case with a negative value in the original dataset being classified into a group whose mean is positive. This case would therefore be considered as a ‘winner’ in the classification, but a ‘loser’ in the original dataset. The overall proportion of winners and losers according to the classification groups will therefore be different from those given in the headline results, which are taken from the full dataset.

6.25 The classification is useful at the group level, where the mean and characteristics for the group as a whole are reliable and meaningful. The characteristics of all groups resulting from the classification process are summarised in Figure 27 and Table 20 below. Only those variables used in the classification process are shown in Table 20. However, it is possible to explore the characteristics of groups according to other EFS variables, as is shown later in this section, in the group descriptions.

6.26 Note that as with the mean surplus/deficit value, the table represents a summary of the dominant characteristics for each group, while there may be variation within the groups. For example, Group 33 has been characterised as ‘detached’: although detached houses account for 82% of the group, it also includes a small proportion of all other dwelling types.

6.27 Later in this section the characteristics of certain classification groups are discussed in detail. These groups are highlighted in Table 20 and labelled in Figure 27 for ease of reference.

Figure 27: Distribution of household classification groups by allowance deficit/credit. Groups of interest are labelled.

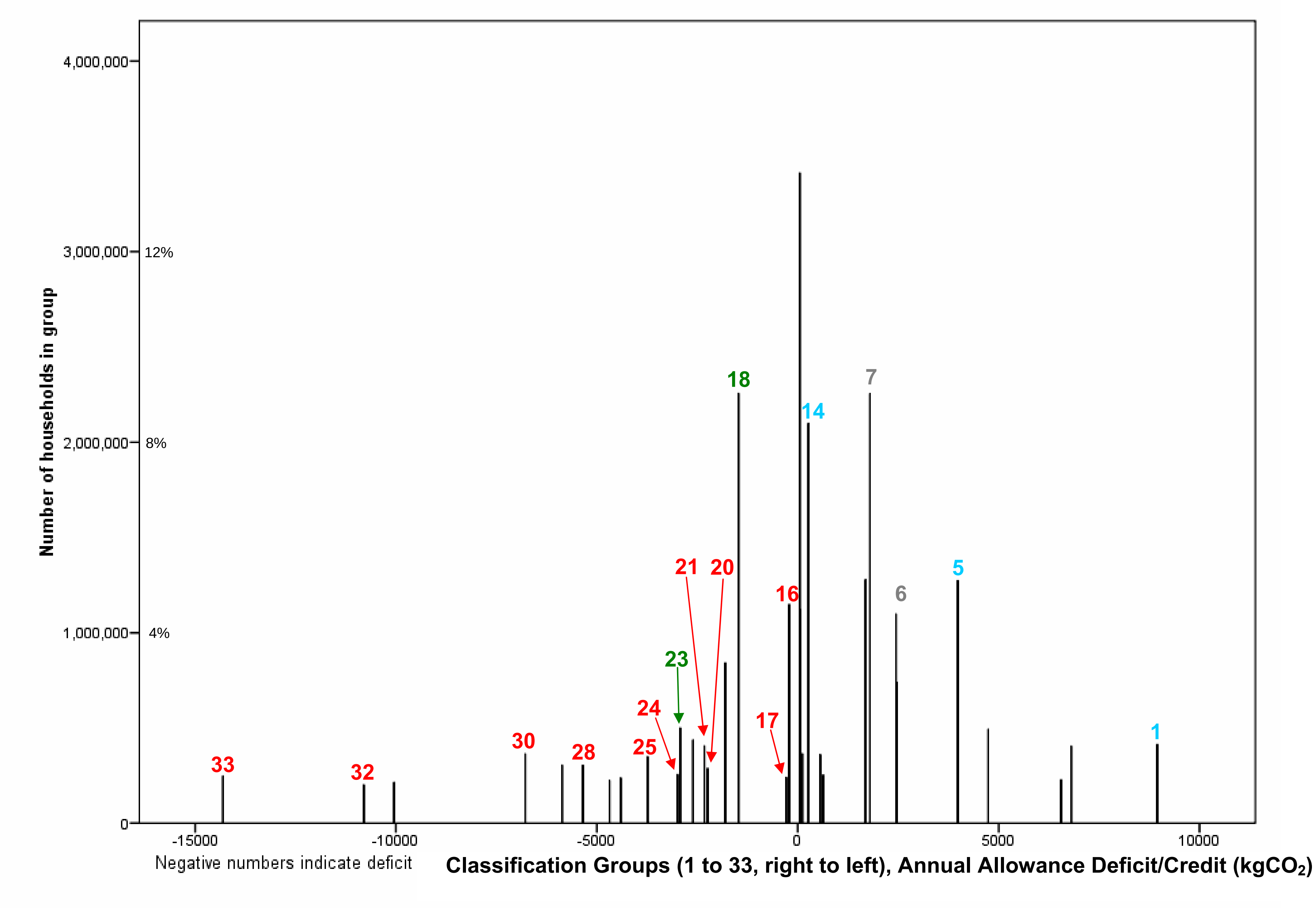


Table 20: Dominant characteristics of all groups, shading indicates groups of interest

	Group	# HHs (1000's)	% of UK HHs	% HHs in income decile 1-3	Surplus Allowances	Income tendency	Mean Adults	Mean Children	Rurality	Housing Type	Tenure	Mean Number of Rooms	Elderly-only Households
WINNERS	1	414	1.7%	38%	8948.71	Non/Med-Low	3.4	0.6	Urban	terrace/flat	Rented	5	0%
	2	405	1.6%	12%	6810.91	Non/High-Med	4.2	0.3	Urban	semi/terrace	Mortgage/OO	6	0%
	3	229	0.9%	33%	6552.11	Non/Med-Low	3.4	0.7	Urban	semi	LA Rented	6	0%
	4	493	2.0%	22%	4738.90	Med-Low	3.0	0.5	Urban	semi/terrace	Mortgage/OO	6	1%
	5	1274	5.2%	76%	3980.51	Low	2.0	0.8	Urban	terrace/flat/semi	LA Rented	4	20%
	6	739	3.0%	0%	2470.32	High	3.0	0.3	Urban	semi/terrace/detached	Mortgage	6	0%
	7	1098	4.5%	0%	2446.25	Med-High	2.0	0.5	Urban	flat/terrace/semi	Rented	4	3%
	8	2254	9.2%	44%	1795.56	Med-Low	2.0	0.6	Urban	semi/terrace	OO/Mortgage	5	35%
	9	1279	5.2%	67%	1686.24	Non/Low-Med	1.0	0.0	Urban	flat	LA Rented	3	44%
	10	254	1.0%	8%	635.64	Non/High-Med	3.4	0.7	Urban	detached	Mortgage	10	0%
	11	361	1.5%	60%	562.81	Non/Low-Med	1.6	0.5	Village/Rural	semi/terrace	All LA Rented	4	31%
	12	2100	8.5%	68%	266.84	Non/Low-Med	1.0	0.7	Urban	terrace/flat	LA Rented	5	25%
	13	366	1.5%	43%	119.14	Med-Low	2.1	0.5	Village/Rural	detached/semi	OO/Mortgage	5	31%
	14	1122	4.6%	100%	56.04	Low	1.0	0.1	Urban	terrace/semi	Owned	5	68%
	15	3413	13.9%	0%	52.94	High-Med	2.0	0.5	Urban	semi/terrace	Mortgage	5	7%
LOSERS	16	1149	4.7%	22%	-211.20	Med-Low	2.0	1.0	Urban	semi/detached	Mortgage/OO	7	23%
	17	242	1.0%	6%	-283.55	Non/High-Med	3.3	0.6	Urban	detached	Mortgage/OO	8	0%
	18	2256	9.2%	0%	-1472.36	Med-High	1.0	0.1	Urban	terrace/semi/terrace	Mortgage/OO	5	29%
	19	841	3.4%	0%	-1799.31	High	1.8	0.0	Urban	detached/semi	Mortgage/OO	7	13%
	20	289	1.2%	64%	-2238.92	Low-Med	1.0	0.2	Village/Rural	detached/semi	Owned	5	55%
	21	407	1.7%	49%	-2320.44	Med-Low	1.0	0.4	Urban	semi/detached/terrace	Owned	7	52%
	22	437	1.8%	0%	-2604.23	High-Med	1.8	0.4	Village/Rural	semi/terrace	Mortgage	5	9%
	23	501	2.0%	0%	-2922.10	High	2.0	1.7	Urban	detached/semi	Mortgage	7	0%
	24	257	1.0%	21%	-2987.80	Med-Low	1.8	1.0	Urban	detached/semi	OO/Mortgage	10	24%
	25	350	1.4%	19%	-3730.02	Non/Med-High	2.0	0.5	Village/Rural	detached	OO/Mortgage	7	25%
	26	239	1.0%	0%	-4406.12	High	1.9	1.3	Urban	detached	Mortgage/OO	10	11%
	27	225	0.9%	0%	-4687.61	High-Med	2.0	0.2	Village/Rural	detached	Mortgage/OO	5	10%
	28	304	1.2%	34%	-5350.75	Non/Med-Low	1.8	0.6	NI	terrace/semi	Mortgage/OO	5	20%
	29	306	1.2%	0%	-5864.06	High	1.9	0.8	Urban	detached	Mortgage	10	6%
	30	364	1.5%	13%	-6784.24	Non/Med-High	2.0	0.7	Village/Rural	detached	OO/Mortgage	8	20%
	31	215	0.9%	0%	-10045.99	High	2.1	0.5	Village/Rural	detached	Mortgage/OO	8	8%
	32	202	0.8%	26%	-10799.11	Non/Med	2.2	1.0	NI	detached	Mortgage/OO	8	11%
	33	248	1.0%	7%	-14300.02	Non/High	2.3	0.9	Village/Rural	detached	Mortgage/OO	11	12%

NOTE: 'Non' in column 6 indicates that the income trend is not very pronounced

Characterising the Groups

6.28 Using the information summarised in the table above, groups of interest can be identified and their characteristics explored in more detail. Four main categories of group have been investigated: high income winners; high income losers; low income winners; and low income losers, (as shown in Table 21 below, where the colour coding corresponds to that in Table 20 and Figure 27).

Table 21: Categories of group investigated (numbers refer to group number)

	Winners	Losers
High Income	6, 7	18, 23
Low income	1, 5, 14	16, 17, 20, 21, 24, 25, 28, 30, 32, 33

6.29 From a social equity perspective the groups of main concern are those that include a proportion of low-income households made worse off by the PCT system ('low income losers'). This is on the basis that low income households will be less able to pay for additional allowances to meet their households demand, and/or take action to reduce their emissions (for example through energy efficiency measures).

6.30 While there is no single losing group composed exclusively of households in the lowest three income deciles, the groups in the bottom-right quadrant of Table 21 all include a proportion of households in income deciles 1 to 4, hence these have been explored in more detail below. It is important to note, however, that several of these groups consist of only a small proportion of low income households, (as shown in the 4th column of Table 20, *"% HHs in income decile 1-3"*). Therefore the large number of groups in the bottom-right quadrant of Table 21 does not imply a high proportion of low income losers in the dataset as a whole (in fact as we have seen, the opposite is true).

6.31 A selection of low income winning groups, as well as high income winning and losing groups are also discussed below, to give a flavour of some of their key characteristics. Less attention is given to these groups as they are not considered vulnerable, and details on the characteristics of all groups are shown in Table 20 (Note that in the summary tables that follow, low income households include income deciles 1-4).

Low income losers

6.32 Northern Ireland

Group 28	Northern Ireland – oil central heating
Deficit in allowances	5,350
Total HH's in group	304,000
% of UK HHs	1.2%
No. of low income HHs	145,000
% of UK HHs	0.6%
Group 32	**Northern Ireland – oil central heating, large, detached houses**
Deficit in allowance	10,799
Total HH's in group	202,000
% of UK HHs	0.8%
No. of low income HHs	70,000
% of UK HHs	0.3%
Description	
These two losing groups are made up entirely of households in Northern Ireland. As discussed earlier in the report, a significant proportion of NI households use oil for heating and therefore are likely to have a higher than average consumption and resulting deficit in allowances. This holds true for these groups. Group 32's deficit in allowances is double that of group 28: the data suggests one possible explanation for this being due to larger houses (a higher proportion of detached houses, with an average of 8 rooms compared to an average of 5 in group 28). Together these two groups overall represent just over 2% of households.	

6.33 Families, large, rural, hard-to-treat houses (Group 33 – biggest losers of all the groups shown here)

Group 33	Families, large, rural, hard-to-treat houses
Deficit in allowance	14,300
Total HH's in group	248,000
% of UK HHs	1.0%
No. of low income HHs	27,000
% of UK HHs	0.1%
Description	
This group has the greatest deficit in allowances of all groups, but consists of only a small proportion of low income households (7% in income deciles 1-3). The group can be characterised by large houses, with children and high vehicle ownership. All households in this group are in rural areas, with at least 10 rooms and predominantly detached. Nearly 70% of households are off-gas, with over 50% having oil central heating and therefore can be considered 'hard-to-treat'. (A house may be considered hard-to-treat if it is off-gas and therefore reliant on less efficient and more carbon intensive heating types, or has solid walls, or both).	

6.34 Large, detached, rural, hard-to-treat houses (Group 30)

Group 30	Large, rural, hard-to-treat
Deficit in allowance	6784
Total HH's in group	364,000
% of UK HHs	1.5%
No. of low income HHs	81,000
% of UK HHs	0.3%
Description	
This group is very similar in characteristics to Group 33, with a high deficit in allowances. All households in this group are in rural areas and have 8 or 9 rooms. They are predominantly detached houses, occupied by couples and 60% have no children. Nearly half have oil central heating and for the lower income deciles only, household emissions account for 83% of their total emissions (despite relatively high vehicle ownership). This 83% is high compared to an average of 76% for the group, which suggests the low-income households in particular in this group have issues with hard-to-treat housing.	

6.35 Rural, off-gas, empty-nesters (Group 25)

Group 25	Rural, off-gas, empty-nesters
Deficit in allowance	3730
Total HH's in group	350,000
% of UK HHs	1.4%
No. of low income HHs	100,000
% of UK HHs	0.4%
Description	
Households in this group all have 7 rooms, are predominantly detached and occupied by couples, and over 70% have no children. These characteristics suggest this group may be 'empty-nesters'- fairly large households, assumed to be previously occupied by a family with now only the parents remaining, approximately half of whom still work and half are retired, with most owning their property outright, and some still with a mortgage. In addition, there is high vehicle ownership and over half the households do not have gas central heating, which adds further explanation of the deficit in allowances.	

6.36 Urban, empty-nesters, large houses (Group 24)

Group 24	Urban, empty-nesters, large houses
Deficit in allowance	2320
Total HH's in group	407,000
% of UK population	1.7%
No. of low income HHs	259,000
% of UK population	1.1%
Description	
This group is similar to group 25, but in an urban location. All households in this group have at least 8 rooms (with an average of 10). They are mainly detached or semi-detached properties and occupied by couples, with an average age of 55. The size of the house is likely to be an important contributing factor in the deficit experienced by this group.	

6.37 Retired, under-occupied, urban households (Group 21)

Group 21	Retired, under-occupied, urban
Deficit in allowance	2320
Total HH's in group	407,000
% of UK HHs	1.7%
No. of low income HHs	259,000
% of UK HHs	1.1%
Description	
Households in this group are all one adult only and predominantly retired/ over 65. All have 7 or 8 rooms, and with only one adult and predominantly no children, this suggests under-occupation. For all households in this group CO_2 emissions from household energy use account for 85% of their total emissions and this rises to nearly 90% when considering the lower four income deciles only. This suggests hard-to-treat housing is also a feature of this group.	

6.38 Retired, one adult, rural households (Group 20)

Group 20	Retired, one adult, rural
Deficit in allowance	2238
Total HH's in group	289,000
% of UK HHs	1.2%
No. of low income HHs	105,000
% of UK HHs	0.4%
Description	
This group is similar to Group 21, but in a rural setting. All households in this group have less than 7 rooms and only one adult. They are predominantly occupied by retired adults (over half are over 65) and without children. Household emissions for this group account for 84% of total emissions (with road transport accounting for only 16%). This is higher than the national average of 72% and suggests that although central heating may not itself be a significant issue for this group (no one central heating type dominates), it is likely that these households are 'hard-to-treat'.	

6.39 Urban, multiple-occupancy, with vehicles (Group 17)

Group 17	Urban, multiple occupancy, with vehicles
Deficit in allowance	283
Total HH's in group	242,000
% of UK HHs	1.0%
No. of low income HHs	25,000
% of UK HHs	0.1%
Description	
This group of households have only a small deficit of allowances and low income households account for only 6% of the group, therefore on the whole this group represents higher income households. All households in this group are in urban areas, have 8 rooms, 3 or more adults and are owned outright or with a mortgage. The high number of adults and tenure combination suggest these could be families with children over 18 yet to leave home. Houses are predominantly detached and there is high vehicle ownership (80% of households have 2 or more vehicles) which relates to road transport emissions for this group accounting for 36% of their total household emissions (compared to a UK average of 27%).	

6.40 Urban couples with vehicles (Group 16)

Group 16	Urban couples with vehicles
Deficit in allowance	211
Total HH's in group	1,149,000
% of UK HHs	4.7%
No. of low income HHs	407,000
% of UK HHs	1.7%
Description	
This group of households only just have a deficit of allowances and may not be significant cause for concern. They do, however, comprise 22% low income households (income deciles 1-3), hence their inclusion in this section. This group of households are all in urban areas, have two adults and 7-8 rooms. They are predominantly semi-detached or detached and own vehicle(s). Approximately half these households have children, and nearly half are retired.	

Low-income winners

6.41 Single, over-65s, urban, lowest income (Group 14)

Group 14	Single, elderly, urban, lowest income
Surplus in allowance	56
Total HH's in group	1,122,000
% of UK HHs	4.6%
No. of low income HHs	1,122,000
% of UK HHs	4.6%
Description	
This group of households just falls into the winner's category with a mean surplus of allowances of just over 50kgCO_2. These households are all in urban areas, with less than 7 rooms and consist of one adult only, with 90% having no children. The majority of adults are retired and own their property outright (80%). 68% of households consist only of adults over 65 and the average age for the group is 67. All households in this group are income deciles 1 to 3.	

6.42 Urban, couples with children, local-authority rented housing (Group 5)

Group 5	Urban, couples, LA rented housing
Surplus in allowance	3,981
Total HH's in group	1,274,000
% of UK HHs	5.2%
No. of low income HHs	1,274,000
% of UK HHs	5.2%
Description	
This group of households are all couples, in urban areas and rented accommodation, (with 78% in Local Authority rented) with less than 7 rooms. All households are in the lower 4 income deciles, nearly half have children and 36% of households HRP are 'unoccupied'. With surplus allowances of nearly 4tCO_2, this group is an example of low income households that potentially stand to gain from selling excess allowances.	

6.43 Urban, multiple-occupancy, rented (Group 1 - biggest winners of all groups shown here)

Group 1	Urban, multiple-occupancy, rented
Surplus in allowance	8,949
Total HH's in group	414,000
% of UK HHs	1.7%
No. of low income HHs	198,000
% of UK HHs	0.8%
Description	
This group has the largest mean allowance surplus of all groups, at just under 9tCO_2. All households are in urban areas, in rented accommodation, with 3 or more adults. Dwellings are either terraced houses or flats (with the former accounting for nearly 70%) which vary in size, with the average being 5-6 rooms. Just over 40% of household HRPs are in full-time employment and one third unoccupied[10] (this group therefore includes students). One third of all households in this group are in London.	

High-income losers

6.44 Single adult, without children, urban, affluent (Group 18)

Group 18	One adult, without children, urban, affluent
Deficit in allowance	1,472
Total HH's in group	2,256,000
% of UK HHs	9.2%
No. of low income HHs	351,000
% of UK HHs	1.4%
Description	
Nine percent of all UK households (over 2.25m households) fall into this group. Although there are no households in income deciles 1-3, nearly one third are over 65, and, with an allowance deficit of nearly 1.5 tCO_2, may therefore be considered vulnerable. This group consists entirely of one-adult households with 90% having no children. The majority own their property outright or with a mortgage. All houses have 6 or less rooms, but there is no distinct dwelling type, being nearly one quarter flats, and a two-thirds semi-detached or terraced. Over half the population are in full-time employment and with income for this group being medium to high, the deficit in allowances is likely to stem from a relatively high energy consumption, for a one adult household.	

[10] The EFS defines 'unoccupied' as: "persons under national insurance retirement age who are not working, nor actively seeking work. This category includes certain self-employed persons such as mail order agents and baby-sitters who are not classified as economically active".

6.45 Wealthy, young, urban families (Group 23)

Group 23	Wealthy, young, urban families
Deficit in allowance	2,922
Total HH's in group	501,000
% of UK HHs	2.0%
No. of low income HHs	0%
% of UK HHs	0%
Description	
Half a million households fall into this group of wealthy (all income deciles 8-10) urban families (mainly 2 adults and at least one child). All households have 7 or 8 rooms, with over half in detached houses and 65% having 2 vehicles. The average age of the Household Reference Person (HRP) is relatively low at 41, and the majority of houses are owned with a mortgage, suggesting these are young families.	

High-income winners

6.46 Urban, multiple-occupancy, professionals with vehicles (Group 6)

Group 6	Urban, multiple occupancy, professionals with vehicles
Surplus in allowance	2,470
Total HH's in group	739,000
% of UK HHs	3.0%
No. of low income HHs	0.0
% of UK HHs	0.0%
Description	
All households in this group are in the upper 4 income deciles and in urban areas. All households have 3 or more adults, have a mortgage or own the house outright and the majority are in full-time employment. Road transport emissions for this group account for 37% of all household emissions, (nearly 10% higher than the national average), which is not surprising given that 72% of households in this group have 2 or more vehicles and 30% have 3 or more. Average total emissions for this group of households are much higher than the national average (11tCO_2 compared to 8tCO_2) but with three adults in the household this group does not experience a deficit in allowances.	

6.47 Urban, couples, rented flats (Group 7)

Group 7	Urban, couples, rented flats
Surplus in allowance	2,446
Total HH's in group	1,098,000
% of UK population	4.5%
No. of low income HHs	0.0
% of UK population	0.0%
Description	
All households in this group are in urban areas, in rented accommodation, with 57% being privately rented. Households consist of 2 adults, in income deciles 5 and above, in a mixture of dwelling types (41% in flats, compared to the national average of 17%), all with less than 7 rooms. Household emissions for this group account for 65% of their total- lower than the national average of 72%- yet vehicle ownership varies little from the national average. This suggests it may be the energy-efficiency of the dwellings that results in low household emissions.	

Per capita versus per adult – the implications of giving children allowances

6.48 The following section addresses briefly the effect of changing the allowance allocation rules by varying the quantity of allowances given to children.

6.49 Figure 28 illustrates the potentially distortive effect of allocating a full allowance to every child. The benefit to large families of doing so (shown by the unshaded bars) is far greater than the cost to large families of not doing so (shown by the black shaded bars).

6.50 Allocating only the first child a full allowance benefits one-child households the most, which is not surprising, given that for them this represents the equivalent of a per-capita allowance. Nevertheless households with more than one child still, on average, have a surplus of allowances under this scheme.

6.51 A scheme giving one third of an allowance for children may represent an acceptable compromise, as it leads to the lowest average loss of all schemes shown here, and less pronounced differences in allowance surplus/deficit between different households types. It also minimises the average loss to retired and over 65 households.

6.52 Figure 29 highlights one of the problems with a full per-capita allowance system in terms of disproportionate impacts on households with all occupants over the age of 65 and suggests a fraction of an allowance to children may represent a fairer system.

6.53 Figure 30 shows the average household allowance surplus/credit resulting from the five different schemes, split by economic position of Household Reference Person. This shows that a system allocating 1/3 of an allowance to children would in fact lead to a small average surplus for retired households.

Figure 28: Differential average effect of five possible allowance schemes by number of children in household

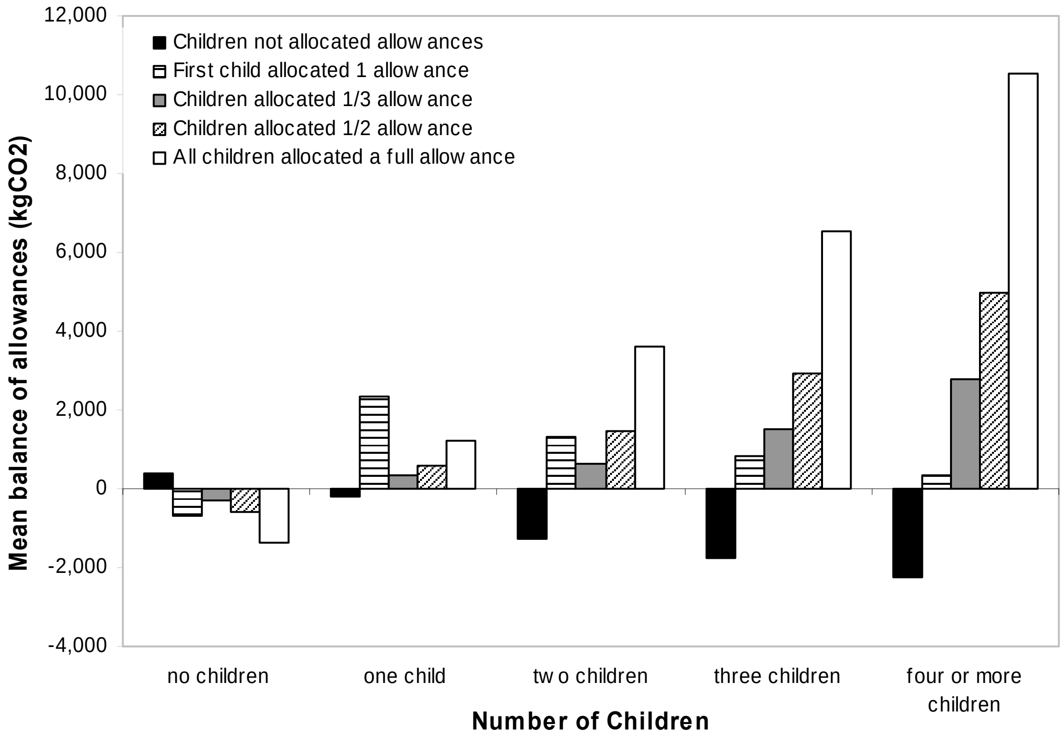


Figure 29: Differential effect of five possible allowance schemes by adults over 65 households

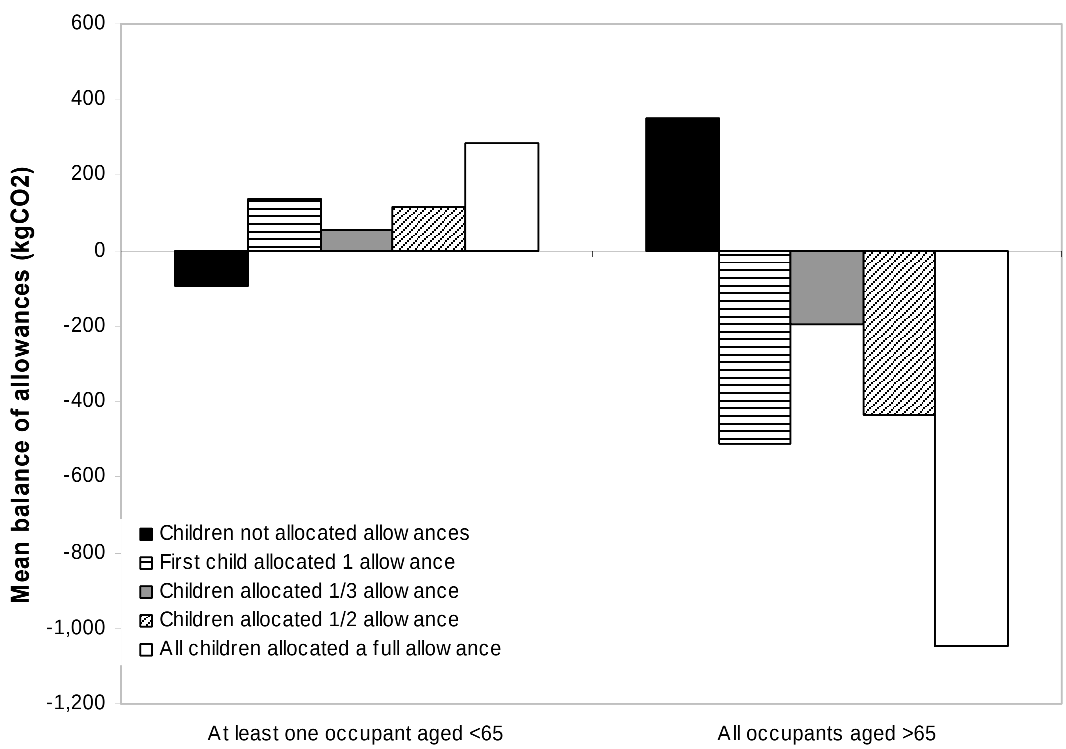
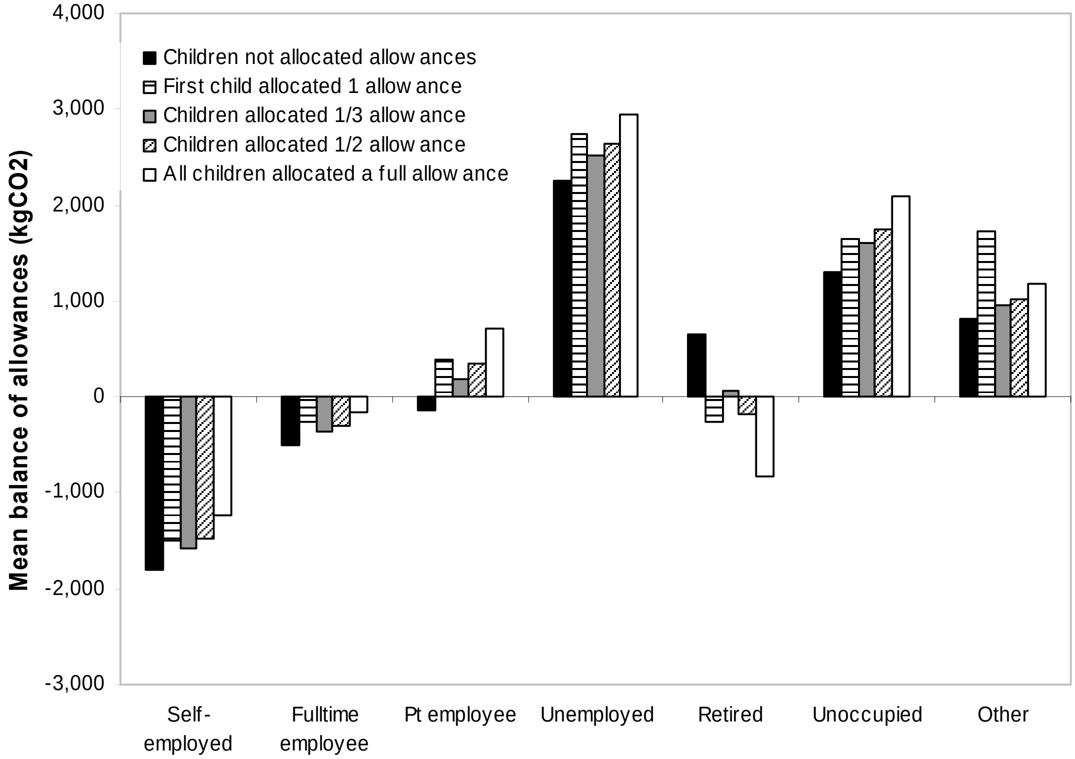


Figure 30: Differential effect of five possible allowance schemes by economic position of HRP



7 Conclusions

7.1 Approximately three fifths of UK households would have more allowances than they currently need under a PCT scheme based on equal per capita allowances for adults with the system cap set at current emissions. The distribution of these ‘winners’ is progressive: 71% of low income households are in this category, whereas 55% of high income households are ‘losers’.

7.2 This progressiveness is enhanced by the fact that for households that lose, average allowance deficits tend to increase with income, and for households that gain, average allowance surpluses fall with income. As a result, low income households tend to gain more and lose less than high income households.

7.3 Of the 2.1 million ‘loser’ low income households that would receive insufficient allowances to meet their current emissions:

- a high proportion live in rural areas (where their often solid-walled homes are typically harder to heat and a lack of access to gas has led to the use of more carbon-intensive fuels);
- many are living in (or ‘under-occupying’) larger-than-average homes (characterised as ‘empty-nesters’ and single pensioners still living in family houses);
- the allowance ‘deficit’ is driven by their heating rather than their transport emissions. Perhaps counter-intuitively, road transport contributes a smaller proportion of household emissions in rural areas than urban areas.

7.4 In addition, principally as a result of the heavy dependence on oil for central heating, households in Northern Ireland (and low income households in the province in particular) are disproportionately represented amongst the ‘losers’.

7.5 Under a PCT scheme in which only adults received allowances, two thirds of pensioner-only households are ‘winners’. This would obviously change if children were also given full or partial allowances. Indeed, modelling of a PCT scheme in which each child gets 1/3 of an allowance produces an outcome with fewest ‘loser’ households overall.

7.6 This characterisation of the low income ‘losers’ indicates where 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. It is likely that such initiatives would also have the benefit of addressing fuel poverty, which is also prevalent in lower income rural ‘hard-to-treat’ homes and in ‘under-occupied’ homes in both rural and urban areas.

7.7 Of course, the work presented here can only present a partial picture of the distributional impacts of a PCT system. To gain a full understanding, further analysis would be required to build upon the analysis undertaken for this study. This would include:

- Inclusion of aviation and public transport emissions;
- An assessment of the distributional impacts of different ways of recovering the likely costs of operating the PCT scheme. For example, recovering costs as a % levy on allowance transactions would have a different impact than a single annual charge (though both would change the net financial impact of PCTs on each household).
- Developing an understanding of the distribution of ‘opportunities to act’ to cut emissions and the costs of such action. This can depend on housing type, current thermal performance, cost of improvements, access to public transport, potential impact of behavioural change on meeting basic needs (e.g. for warmth), etc.
- Modelling the distribution of household carbon emissions over time as

the cap in a PCT scheme starts to tighten. Since different households will have different opportunities at different costs to curb their emissions, it is likely that the distributional pattern of ‘winners’ and ‘losers’ would change over time.

7.8 In addition, there would be merit in including additional questions in future national surveys, such as the English House Condition Survey (and its devolved administration equivalents), to gather actual fuel bill and road fuel consumption data alongside its existing detailed housing and income data. This would significantly improve the dataset for analysis of the distributional impacts of carbon emission reduction policies including PCT.

7.9 In the mean time, it should be noted that the dataset and analytical framework developed for and used in this study could now be used to assess the distributional impacts of other existing or potential carbon reduction policies, such as the CERT, carbon taxes, upstream cap-and-trade (with different approaches to revenue recycling), the Renewables Obligation (and other renewables support mechanisms).

Annex A: Defra common assumptions on PCT

Background

A.1. The Government is looking into the potential value of personal carbon trading (PCT). This is just one of a number of potential long-term options being explored for making individuals better informed about, and involved in, tackling climate change. We are now carrying out a pre-feasibility study to assess whether personal carbon trading might be a practical and feasible policy option, compared with other measures for constraining emissions. This work programme complements the research and academic work being undertaken by researchers and academics such as The Tyndall Centre for Climate Change, the Environmental Change Institute and the Royal Society for Arts.

PCT Project

A.2. The PCT work programme as a whole incorporates four workstreams (listed below). The outcomes of this work will be brought together to provide a summary of the key findings and recommendations on whether further work is necessary, and if so, in which areas.

- Economic value of PCT and its strategic fit;
- Equity and distributional impacts;
- Public acceptability;
- Technical & cost issues (allocation and subsequent management)

Context/ Purpose of the assumptions crib sheet

Due to time and budget constraints it is necessary to provide a broad description of a PCT scheme, including assumptions about preferred scheme design and treatment of a number of factors, e.g. inclusion of children, industry, etc. This is to ensure the four workstreams are compatible and can be brought together in a synthesis report. Although analysis should be on the basis of this particular description of a PCT scheme, we welcome (and indeed encourage) consideration of these assumptions as variables within the analysis - time and cost permitting.

Note! This does by no means indicate a preference for any particular scheme design, nor does it signify the Government's views on any specific elements of scheme design (e.g. inclusion/ exclusion of children). It is merely a baseline upon which the project can be based.

Assumed scheme design and implications

A.3. We have opted to examine PCT on the basis of the most downstream, radical design proposal – Domestic Tradeable Quotas (DTQs) (formally Tradeable Energy Quotas (TEQs)). It should be noted that this proposal would make very strong assumptions about the nature of the policy landscape into which PCT is introduced. Though these assumptions may not be met in practice, by considering the DTQ scheme we will provide a best case benchmark against which the real circumstances into which a PCT scheme is introduced could be compared. It will provide the best insight into the merits or otherwise of downstream emissions trading from a strategic perspective. A key assumption of this design proposal is that PCT can work alongside the EU Emissions Trading Scheme (EU ETS). It would also require that the design of the Supplier Obligation did not place a cap on domestic energy suppliers.

Description of DTQ model

A.4. An economy-wide system involving all individuals and organisations, where 40% of the economy's allowable carbon emissions are allocated to adults only free of charge on an equal per capita basis, and 60% is auctioned off to ‘primary dealers’ who then sell on to organisations in a secondary market. ‘Credits’ would be surrendered to cover the carbon content of electricity, and heating (e.g. gas, oil) and personal transport fuel purchases, with public transport and aviation covered (dependent on its status internationally) indirectly through the organisations responsible for fuel purchases . All individuals and organisations have access to the market to trade their credits. It is anticipated that individuals would also be able to opt-out of trading by selling their credits immediately upon allocation to an intermediary for cash, and that smaller organisations would similarly be able to refrain from direct trading by paying the carbon cost of energy/ fuel on purchase.

Summary of assumptions

A.5. Assumptions include:

1. Economy-wide system with 40% free allocation to individuals and 60% allowances auctioned. No explicit interaction with the EU ETS or Supplier Obligation.
2. A mandatory scheme.
3. Sectors included are household energy use, private road transport and flights.
4. 50 million individuals will participate in the scheme (meaning children are exempt)
5. An allowance unit of kg
6. An equal allocation of 4 tonnes CO2 to every participant (4000 allowances of 1kg each). There would initially be allowances to cover 500 million tonnes, with a total of 200 million tonnes of allowances being allocated to individuals.

7. We must look at the equity impacts of PCT in the context of how it might impact today, as analysis will be based on current energy use and emissions. However, the public acceptability workstream will need to set the scene of a PCT scheme in a post-2012 landscape where abatement options are limited (as many of the easier abatement options have already been taken up) . [N.B. Any scheme start date is still very much unknown, other than ‘no earlier than 2013, but could well be later.]

8. That household energy efficiency will improve evenly across income and geographical groups in the future, as well as demand for energy services (there will be an equal percentage increase in demand for energy services across all income groups). Though a strong assumption, this will allow inferences to be made from the data produced in the equity workstream

9. A PCT scheme would be owned by Government, but sub-contracted to the private sector for day-to-day management.

10. The allowances will be issued in denominations to the nearest Kg. Rounding issues will be settled within the cash transaction (so if they use 10.5kg of carbon, will use 11 kg of allowances, and the additional 0.5kg will be ‘sold’ to the market at the point of sale at current market price).

11. Central prediction for the market price of allowances will be £20/t. For sensitivity analysis, a range of £10/t to £30/t should be used. That is a price of 2p for each allowance of 1 kg.

12. PCT data would need to be managed within the UK, however, the development of such a system could be led outside the UK.

13. Visitors to the UK (and those without the facility to surrender allowances at the point of purchase) would purchase allowances from the market at the market price (rather like a tax).

14. Trading volumes - 60% would be auctioned and of the 40% allocated for free. It is assumed that 10% of all allowances will be traded on the secondary market.

Annex B: Calculating emissions from EFS data

Expenditure and Food Survey

A.6. The Expenditure and Food Survey (EFS) has been conducted annually by the Office of National Statistics since 2001/02, when it replaced the Family Expenditure Survey and the National Food Survey. Its primary purposes are: (1) to gather a nationally representative sample of household expenditure for the purposes of calculating the retail price index (RPI); and (2) to gather data on national patterns of food consumption and nutrition.

A.7. The EFS gathers data from about 7,000 households across the UK, throughout the year, every year, using a combination of a face-to-face interview and expenditure diaries. The resulting data comprises (1) socio-demographic information on household composition, age, gender, benefit units, accommodation and tenure, and (2) detailed weekly expenditure patterns on a very wide range of items.

A.8. Three years of EFS data were used in this study (2003/04, 2004/05 and 2005/06). These three years were combined to create one dataset of approximately 24,000 records. Each surveyed household is assigned a weighting based on its representivity across all UK households. With the three datasets joined, these weights were adjusted such that the data remains representative of one year.

A.9. Income variables were also adjusted in the joined dataset, to take account of price inflation over the three years. The middle of the three survey years (2004/5) was chosen as a the base year to minimise the size of the correction factors. We used the ONS CHAW index (13/1/1987 = 100), covering all items including mortgage interest.

A.10. The corrections were made using the ratio of the average RPI in the base year to the average RPI in the year to be corrected. The table below sets out the factors.

Year	Average RPI (CHAW)[11]	Income Correction factor
2003/4	182.475	1.0311
2004/5	188.15	1
2005/6	193.1083	0.9743

Converting expenditure to consumption

A.11. The expenditure data in the EFS was combined with fuel price data to calculate household energy consumption. The table below summarises the source of price data for the different household fuels and payment methods.

Fuel and Payment method		Format	Source
Gas	Credit	Average annual pence per kWh for Government Office Regions	DBERR: Average annual domestic electricity/gas bills for selected towns and cities in the UK and average unit costs (tables 2.2.3 and 2.3.3) http://www.berr.gov.uk/energy/statistics/publications/prices/tables/page18125.html
	Direct Debit		
	Pre-payment		
Electricity	Credit		
	Direct Debit		
	Pre-payment		
Bulk LPG		Regional (South, SW & Wales, Midlands, Northern England, SE, Scotland, Northern Ireland. Bi-annual (May and October)	Sutherland Tables of Comparative Domestic Heating Costs
Bottled Gas Propane			
Heating Oil			
Coal			
Wood		Government Office Region, annual or bi-annual	BRE 2004 and Willoughby (http://www.johnwilloughby.co.uk/)

A.12. In addition to the data listed above, energywatch supplied summary data on price changes for electricity and gas throughout the years 2003-06 (supplier and date specific). This data was then used to adjust the annual price data as necessary to correspond as closely as possible with EFS data. (The EFS is carried out throughout every month of the year across the UK: this could therefore be matched with fuel price data for a specific area at a specific time of year).

A.13. Petrol and diesel prices were obtained from the Automotive Association

[11] http://www.statistics.gov.uk/StatBase/tsdataset.asp?vlnk=229

Fuel Price Report[12], which provide the average monthly forecourt price of petrol and diesel by region. The format of this data enabled simple conversion from the EFS monthly, regional expenditure data.

A.14. Fuel consumption was then converted to carbon emissions, using factors shown in the table below[13]. The value for wood is not zero as this allows for planting, harvesting, processing, and delivery to point of use[14].

Fuel	kg CO_2 per unit
Gas (kWh)	0.19
Electricity (kWh)	0.52*
Bulk LPG (kWh)	0.214
Bottled gas propane (kWh)	0.214
Heating oil (kWh)	0.245
Coal (kWh)	0.32
Wood (kWh)	0.025
Petrol (litre)	2.3154
Diesel (litre)	2.6304

*A rolling average of emission factors for the last 5 years for which data is available (2001-2005). Also from http://www.defra.gov.uk/environment/business/envrp/pdf/conversion-factors.pdf

[12] The AA Motoring Trust Fuel Price Report uses data sourced from Catalist Ltd & Arval PHH Business Solutions Ltd (www.catalist.com). They are an average of mid-month fuel prices from the regions for the month. The AA Fuel Price Survey is predominantly a survey of prices in the main centres of population - ie where most fuel is bought. http://www.theaa.com/motoring_advice/fuel/fuel-price-archive.html

[13] Factors for gross calorific value from http://www.defra.gov.uk/environment/business/envrp/pdf/conversion-factors.pdf

[14] http://www.bre.co.uk/filelibrary/rpts/eng_fact_file/CO2EmissionFigures2001.pdf

Annex C: Linear Regression and CHAID

Multiple Linear Regression Analysis

A.15. Linear regression estimates the coefficients of the linear equation, involving one or more independent variables, that best predict the value of the dependent variable. Two linear regression models were run for this study, for the two different dependent variables of interest: per adult CO_2 emissions and the difference between allowance and household emissions.

A.16. To run the linear regression model successfully, normal distributions have to be achieved for continuous variables and 'dummy' variables have to be created for the categorical variables. The outputs from the bivariate analysis were used to guide these processes.

A.17. Dummy variables are created by recoding a categorical variable to become a binary variable. This results in one categorical variable being represented in the regression analysis by (n-1 of) its components. For example, there are five categories within 'tenure'; this would be represented in the model by four binary variables, e.g. 'council', 'private rented', 'mortgage' and 'owned outright', with the fifth, 'other', being the reference variable and therefore left out of the analysis (inclusion of n dummy variables would lead to multicolinearity between the dummy variables).

A.18. Backward elimination was chosen as the variable selection method in the linear regression analysis. SPSS provides the following descriptions of this procedure:

> *"Backward elimination enters all variables into the equation and then sequentially removes them. The variable with the smallest partial correlation with the dependent variable is considered first for removal. If it meets the criterion for elimination, it is removed. After*

the first variable is removed, the variable remaining in the equation with the smallest partial correlation is considered next. The procedure stops when there are no variables in the equation that satisfy the removal criteria."

A.19. The default settings for the stepping method criteria were used (use of probability of F at 0.05 for entry and 0.10 for removal).

A.20. Using the backward elimination method a number of variables of interest and relevance (as shown through the bivariate analysis) were entered into a linear regression model for the two dependent variables. The studentised residual (SRE) was saved for each model and using this variable, outliers could be identified, filtered and the model re-run to investigate the effect on the model fit (as shown by the R^2 value). The results of this, for both models, are summarised below. For the per adult CO_2 dependent variable, all cases with a value of less than or equal to zero were filtered, to ensure a normal distribution in the dependent variable.

Dependent variable	**Per Adult CO_2**	**Difference (allowance & hh CO_2)**
Filters	All cases =< zero	None
R^2	0.37	0.43
Outliers filter criteria	Abs SRE <= 2.2	Abs SRE <= 2.2
R^2 (outliers filtered)	0.46	0.54

A.21. The model fit and regression coefficient outputs from the two dependent variable linear regression models, with outliers removed, are shown below.

Per adult CO_2: outputs from linear regression

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.679	0.461	0.461	2.27915

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	181,278.8	41	4,421.4	851.2	.000(i)
Residual	211,899.0	40,793	5.195		
Total	393,177.9	40,834			

Excluded Variables

	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics		
					Tolerance	VIF	Minimum Tolerance
Urban	-.005	-0.051	0.960	0.000	0.001	718.267	0.001
PTemployee	-.002	-0.408	0.684	-0.002	0.597	1.675	0.186
WestMidlands	.002	0.567	0.571	0.003	0.791	1.264	0.186
East	.001	0.155	0.877	0.001	0.760	1.317	0.186
Disabled	.003	0.656	0.512	0.003	0.900	1.112	0.186
SemiDetached	-.014	-1.101	0.271	-0.005	0.077	13.010	0.077
gasCH	-.017	-1.190	0.234	-0.006	0.064	15.686	0.064
London	-.007	-1.445	0.148	-0.007	0.647	1.546	0.185

Coefficients

Variable name	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Correlations Zero-order	Correlations Partial	Correlations Part	Collinearity Statistics Tolerance	Collinearity Statistics VIF
Adult1	5.78	0.06	0.71	103.32	0.00	0.14	0.46	0.38	0.28	3.61
Adults2	2.94	0.05	0.47	63.47	0.00	0.07	0.30	0.23	0.24	4.10
No_vehicles	-2.51	0.06	-0.31	-45.38	0.00	-0.25	-0.22	-0.16	0.29	3.48
oilCH	3.33	0.07	0.24	49.15	0.00	0.35	0.24	0.18	0.57	1.75
Vehicle1	-1.33	0.04	-0.21	-30.14	0.00	-0.03	-0.15	-0.11	0.27	3.73
sqrtnrooms	1.41	0.04	0.16	31.81	0.00	0.31	0.16	0.12	0.50	1.99
Adults3	1.33	0.05	0.16	26.77	0.00	-0.11	0.13	0.10	0.39	2.58
Child0	-0.97	0.06	-0.14	-17.18	0.00	-0.14	-0.08	-0.06	0.19	5.38
cbrteqinco	0.21	0.01	0.11	21.56	0.00	0.25	0.11	0.08	0.53	1.87
mortgage	0.61	0.04	0.10	14.62	0.00	0.19	0.07	0.05	0.30	3.38
Vehicles2	-0.63	0.04	-0.09	-14.94	0.00	0.18	-0.07	-0.05	0.34	2.95
sqrappliances	0.01	0.00	0.08	17.01	0.00	0.22	0.08	0.06	0.57	1.76
electricCH	-0.99	0.05	-0.08	-20.38	0.00	-0.14	-0.10	-0.07	0.87	1.15
Child1	-0.65	0.06	-0.07	-10.94	0.00	0.02	-0.05	-0.04	0.31	3.28
owned	0.46	0.04	0.07	10.78	0.00	0.03	0.05	0.04	0.33	3.04
Flat	-0.59	0.04	-0.06	-13.14	0.00	-0.20	-0.06	-0.05	0.58	1.74
solidfuelCH	-1.80	0.11	-0.06	-16.63	0.00	-0.06	-0.08	-0.06	0.94	1.06
sqrtagehrp	0.16	0.02	0.06	9.58	0.00	-0.04	0.05	0.03	0.34	2.98
Retired	-0.40	0.05	-0.05	-7.47	0.00	-0.11	-0.04	-0.03	0.26	3.89
NorthernIreland	1.08	0.09	0.05	11.48	0.00	0.17	0.06	0.04	0.65	1.54
NorthWest	-0.50	0.04	-0.05	-12.80	0.00	-0.06	-0.06	-0.05	0.83	1.20
SouthWest	-0.51	0.04	-0.05	-11.56	0.00	0.00	-0.06	-0.04	0.85	1.18
Isolated	0.78	0.07	0.04	10.72	0.00	0.12	0.05	0.04	0.83	1.21
Child2	-0.36	0.06	-0.04	-6.11	0.00	0.12	-0.03	-0.02	0.33	3.03
Village	0.40	0.05	0.03	8.42	0.00	0.14	0.04	0.03	0.78	1.28
noCH	-0.45	0.05	-0.03	-8.54	0.00	-0.09	-0.04	-0.03	0.95	1.05
Detached	0.21	0.03	0.03	6.40	0.00	0.26	0.03	0.02	0.65	1.53
Adults65	-0.24	0.05	-0.03	-4.52	0.00	-0.07	-0.02	-0.02	0.34	2.94
private	0.30	0.05	0.03	5.82	0.00	-0.13	0.03	0.02	0.57	1.75
Scotland	0.27	0.04	0.02	6.02	0.00	0.01	0.03	0.02	0.84	1.19
Terraced	-0.16	0.03	-0.02	-5.55	0.00	-0.12	-0.03	-0.02	0.73	1.36
OtherTen	0.64	0.11	0.02	5.70	0.00	0.02	0.03	0.02	0.91	1.10
YandH	0.23	0.04	0.02	5.34	0.00	0.01	0.03	0.02	0.86	1.16
EastMidlands	-0.24	0.05	-0.02	-5.16	0.00	0.00	-0.03	-0.02	0.86	1.16
Fringe	0.20	0.04	0.02	5.27	0.00	0.04	0.03	0.02	0.93	1.07
SouthEast	-0.14	0.04	-0.02	-3.90	0.00	0.02	-0.02	-0.01	0.81	1.24
Unemployed	-0.36	0.10	-0.01	-3.67	0.00	-0.06	-0.02	-0.01	0.92	1.08
FTemployee	-0.08	0.04	-0.01	-2.13	0.03	0.11	-0.01	-0.01	0.39	2.59
selfemployed	-0.10	0.05	-0.01	-1.97	0.05	0.07	-0.01	-0.01	0.66	1.51
Female	0.06	0.03	0.01	2.15	0.03	-0.01	0.01	0.01	0.86	1.16
Wales	-0.09	0.06	-0.01	-1.66	0.10	0.01	-0.01	-0.01	0.90	1.11
(Constant)	7.89	0.18		43.88	0.00					

Difference between allowance and household CO_2: outputs from linear regression

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.737	0.543	0.542	39,613.5

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	7.7823E+13	39	1.9955E+12	1,271.6	.000
Residual	6.5604E+13	41,807	1.5692E+09		
Total	1.4343E+14	41,846			

Excluded Variables

	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics		
					Tolerance	VIF	Minimum Tolerance
Fringe	-.004	-0.058	0.954	0.000	0.003	379.283	0.001
SemiDetached	.002	0.197	0.844	0.001	0.080	12.525	0.065
OtherTen	-.001	-0.374	0.708	-0.002	0.919	1.088	0.065
Female	-.002	-0.619	0.536	-0.003	0.877	1.141	0.065
selfemployed	.002	0.720	0.472	0.004	0.931	1.074	0.065
East	-.001	-0.132	0.895	-0.001	0.634	1.576	0.065
WestMidlands	-.002	-0.538	0.590	-0.003	0.652	1.534	0.065
Adults65	.004	0.763	0.446	0.004	0.334	2.990	0.065
PTemployee	-.001	-0.252	0.801	-0.001	0.944	1.059	0.065
FTemployee	-.007	-1.444	0.149	-0.007	0.530	1.887	0.065

Coefficients

Variable name	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations			Collinearity Statistics	
	B	Std. Error	Beta			Zero-order	Partial	Part	Tolerance	VIF
Adult1	-141,238.50	979.44	-0.96	-144.20	0.00	-0.16	-0.58	-0.48	0.25	4.04
Adults2	-97,452.46	846.64	-0.82	-115.10	0.00	-0.18	-0.49	-0.38	0.21	4.66
No_vehicles	52,139.05	950.57	0.36	54.85	0.00	0.21	0.26	0.18	0.26	3.87
Adults3	-54,656.98	901.55	-0.34	-60.63	0.00	0.18	-0.28	-0.20	0.35	2.82
Vehicle1	34,552.43	779.07	0.29	44.35	0.00	0.02	0.21	0.15	0.25	3.93
oilCH	-73,531.44	2,165.87	-0.26	-33.95	0.00	-0.38	-0.16	-0.11	0.19	5.32
Vehicles2	18,438.55	753.50	0.14	24.47	0.00	-0.17	0.12	0.08	0.32	3.09
sqrtnrooms	-23,176.04	771.28	-0.14	-30.05	0.00	-0.25	-0.15	-0.10	0.50	2.00
Child0	17,094.71	966.37	0.14	17.69	0.00	0.11	0.09	0.06	0.19	5.39
cbrteqinco	-3,907.62	157.66	-0.11	-24.78	0.00	-0.23	-0.12	-0.08	0.58	1.73
mortgage	-9,381.62	667.38	-0.08	-14.06	0.00	-0.16	-0.07	-0.05	0.34	2.92
sqrtagehrp	-3,715.99	285.86	-0.07	-13.00	0.00	0.00	-0.06	-0.04	0.35	2.83
electricCH	16,474.39	2,046.45	0.07	8.05	0.00	0.08	0.04	0.03	0.14	7.20
sqrappliances	-84.79	6.06	-0.06	-13.99	0.00	-0.15	-0.07	-0.05	0.56	1.79
Child1	10,221.35	1,014.55	0.06	10.07	0.00	0.00	0.05	0.03	0.30	3.28
solidfuelCH	29,460.61	2,581.02	0.06	11.41	0.00	0.04	0.06	0.04	0.47	2.14
owned	-6,380.55	705.38	-0.05	-9.05	0.00	-0.05	-0.04	-0.03	0.36	2.77
noCH	12,241.72	2,098.31	0.05	5.83	0.00	0.08	0.03	0.02	0.17	5.87
SouthWest	8,342.79	785.63	0.04	10.62	0.00	-0.01	0.05	0.04	0.78	1.28
gasCH	5,754.47	1,941.48	0.04	2.96	0.00	0.10	0.01	0.01	0.06	15.43
Child2	6,767.82	1,015.26	0.04	6.67	0.00	-0.11	0.03	0.02	0.33	3.03
Detached	-5,113.54	568.72	-0.04	-8.99	0.00	-0.26	-0.04	-0.03	0.66	1.52
NorthernIreland	-14,686.97	1,755.42	-0.04	-8.37	0.00	-0.18	-0.04	-0.03	0.59	1.69
Retired	4,804.93	732.36	0.03	6.56	0.00	0.03	0.03	0.02	0.41	2.45
NorthWest	6,101.99	708.65	0.03	8.61	0.00	0.04	0.04	0.03	0.74	1.35
Isolated	-11,087.42	1,371.40	-0.03	-8.08	0.00	-0.13	-0.04	-0.03	0.73	1.38
Urban	3,596.69	664.38	0.03	5.41	0.00	0.24	0.03	0.02	0.49	2.05
Terraced	3,095.36	504.49	0.02	6.14	0.00	0.14	0.03	0.02	0.73	1.37
YandH	-4,434.59	777.52	-0.02	-5.70	0.00	-0.01	-0.03	-0.02	0.79	1.27
EastMidlands	3,886.06	834.57	0.02	4.66	0.00	0.00	0.02	0.02	0.81	1.24
private	-3,141.94	855.35	-0.02	-3.67	0.00	0.12	-0.02	-0.01	0.62	1.62
Village	-3,409.17	990.73	-0.02	-3.44	0.00	-0.15	-0.02	-0.01	0.57	1.76
Unemployed	6,464.19	1,561.86	0.01	4.14	0.00	0.06	0.02	0.01	0.95	1.05
SouthEast	2,284.45	665.98	0.01	3.43	0.00	-0.03	0.02	0.01	0.71	1.42
Wales	3,111.09	976.96	0.01	3.18	0.00	0.00	0.02	0.01	0.85	1.17
London	2,001.86	730.13	0.01	2.74	0.01	0.12	0.01	0.01	0.65	1.54
Scotland	-2,143.57	796.78	-0.01	-2.69	0.01	0.00	-0.01	-0.01	0.75	1.33
Flat	1,712.15	767.76	0.01	2.23	0.03	0.13	0.01	0.01	0.54	1.86
Disabled	1,607.90	698.95	0.01	2.30	0.02	0.10	0.01	0.01	0.93	1.08
(Constant)	561,311.91	3,606.35		155.65	0.00					

CHAID

A.22. CHAID, which stands for 'Chi-squared Automatic Interaction Detector', constructs trees, where each (non-terminal) node identifies a split condition, to give the best possible prediction of the dependent variable (in the case the difference between allowance and household CO_2).

A.23. The table below details the specification for the CHAID model. (Note that the number of cases specified for parent and child nodes is very large. This is because to ensure that all cases were included in the CHAID model, a new weight had to be calculated (SPSS only includes integer weights when running CHAID; as such any weighting of less than 0.5 is taken as zero and these cases are therefore excluded). This new weighting effectively increased the sample size by a factor of 6,000 (the multiplier required to increase the smallest weight to 1). The node sizes specified in the model are therefore equivalent to 200 cases in the normally weighted dataset).

Model Summary		
Specifications	Growing Method	EXHAUSTIVE CHAID
	Dependent Variable	Difference_TonnesCO2_PerAdultBasis
	Independent Variables	newdwellcat, newten, NewUR, Number of adults, Number of children, Adults65, Deciles_Corrected_Equivalised_Income , Rooms in accomodation - total
	Validation	None
	Maximum Tree Depth	6
	Minimum Cases in Parent Node	1200000
	Minimum Cases in Child Node	1200000
	Significance level for splitting & merging nodes	0.05 (default)
	Method for adjusting significance values	Bonferroni (default)
Results	Independent Variables Included	NewUR, Rooms in accomodation - total, newten, Deciles_Corrected_Equivalised_Income , Number of adults, newdwellcat, Number of children
	Number of Nodes	65
	Number of Terminal Nodes	33
	Depth	6

A.24. The following paragraphs explain the CHAID classification process in more detail. This text is borrowed and adapted from the Statsoft website[15] and more detailed information can be obtained here.

A.25. The CHAID tree is produced through two key steps, beginning with merging categories. For each predictor (independent variable) the pair of categories that is least significantly different with respect to the dependent variable (the allowance deficit/surplus) are identified; for regression problems (where the dependent variable is continuous, as it is here), this is done using an F test.

A.26. If the F test for a given pair of predictor categories is not statistically significant (as defined by an alpha-to-merge value of 0.05 in this case), then CHAID will merge these categories and repeat this step (i.e., find the next pair of categories, which now may include previously merged categories).

A.27. If the F test for the respective pair of predictor categories is significant (less than the respective alpha-to-merge value of 0.05), then CHAID will compute a Bonferroni adjusted p-value for the set of categories for the respective predictor.

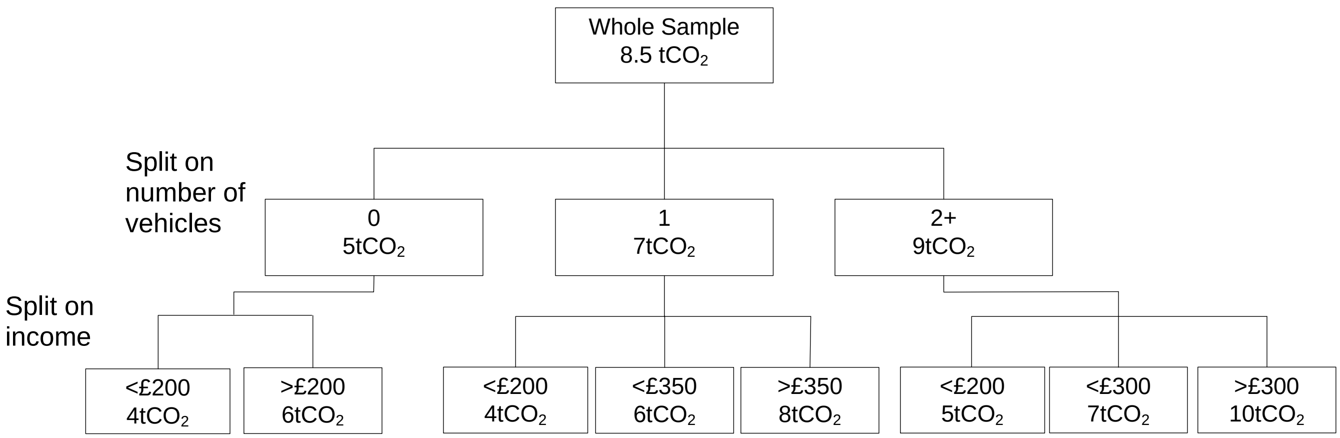
A.28. For example, for the categories within the predictor variable tenure, if the surplus/deficit in allowance is not found to be significantly different for private rented and local-authority categories, these would be merged. If this new category of private rented and local authority rented are found to not yield a significant difference in the dependent variable, they would be further merged; if there was a significant difference mortgage would remain a category on its own.

A.29. The next step in the CHAID classification is to choose the predictor variable that will yield the most significant split; if the smallest (Bonferroni) adjusted p-value for any predictor is greater than some alpha-to-split value, then no further splits will be performed, and the respective node is a terminal node.

[15] http://www.statsoft.com/textbook/stathome.html?stchaid.html&1

A.30. This process is continued until no further splits can be performed (given the alpha-to-merge and alpha-to-split values).

A.31. The diagram below provides a further example and simple illustration of the CHAID classification process (based on fictional scenario).



A.32. Exhaustive CHAID is the same as CHAID except it performs a more thorough merging and testing of predictor variables, and hence requires more computing time. This was not issue for this study, therefore exhaustive CHAID was the selected method.

A.33. Note that there are a large number of possible CHAID classification models available using different specifications and input variables. The model used in this study is one example of how the data can be grouped and factors associated with a surplus or deficit in carbon allowances analysed. Changing the specifications of the model, or increasing the number of input variables would result in a different set of nodes, or groups.

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