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The distribution of total greenhouse gas emissions by households in the UK, and some implications for social policy

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Contents

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Abstract

This paper maps the distribution of total direct and embodied emissions of greenhouse gases by households in the UK and goes on to analyse their main drivers. Previous research has studied the distribution of direct emissions by households, notably from domestic fuel and electricity, but this is the first to cover the indirect emissions embodied in the consumption of food, consumer goods and services, including imports. To study total emissions by British households we link an input-output model of the UK economy to the UK Expenditure and Food Survey. Results are presented as descriptive statistics followed by regression analysis. All categories of per capita emission rise with income which is the main driver. Two other variables are always significant: household composition, partly reflecting economies of scale in consumption and emissions in larger households, and employment status. This 'standard' model explains 35% of variation in total emissions, reflecting further variation within income groups and household types. We also compute the distribution of emissions derived from the consumption of welfare state services: here, lower income and pensioner households 'emit' more due to their greater use of these services. To take further account of the social implications of these findings, we first estimate emissions per £ of income. This shows a reverse slope with emissions per £ rising as one descends the income scale. The decline with income is especially acute for domestic energy, housing and food emissions, 'necessary' expenditures with a lower income elasticity of demand. Next, we move away from per capita emissions by assuming children under 14 emit half that of adults, which reduces disparities between household types. To implement personal carbon allowances, further research will be needed into the carbon allowances of children and single person households. Current government policies to raise carbon prices mainly in domestic energy are found to be especially regressive, but tracking total carbon consumption within a country would require radical changes in monitoring carbon flows at national borders. In the meantime, poorly targeted policies to compensate 'fuel poor' families should give way to more radical 'eco-social' policies, such as house retrofitting, coupled with 'social' tariffs for domestic energy.

JEL Classification: H23 and I32
Keywords: household income distribution, greenhouse gas emissions, carbon policies, social policies, direct and embodied emissions

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1. Introduction

This paper charts the distribution of total embodied emissions of greenhouse gases by households in the UK. Previous research has studied the distribution of *direct* emissions by households, notably from household heating fuel and electricity, and sometimes petrol and diesel for private cars. However, these expenditures account for a minority of total household emissions in all rich countries. The majority are the indirect emissions embodied in the consumption of food, consumer goods and services, a good proportion of which are not even produced in the UK. To study the total emissions of British households we use the REAP input-output model of the UK economy, and to study their distribution we use the UK Expenditure and Food Survey (EFS). Together this enables us to allocate all household emissions, direct and embodied, and study their distributional consequences. This is important in order to devise appropriate social, economic and environmental policies to mitigate their distributional impact on different households.

The UK is now committed to a sharp reduction of greenhouse gases (GHG). The Climate Change Act 2008 requires the UK to reduce GHG emissions by at least 80% by 2050 and by at least 34% by 2020, compared with the base year of 1990. Furthermore it has set three intermediate Carbon Budgets: of an average of 604 MtCO2e in 2008-12, 556 MtCO2e in 2013-17 and 509 MtCO2e in 2018-22. The main mechanisms to achieve this will be the EU Emissions Trading Scheme (ETS), and a range of 'mandated market' policies to encourage energy suppliers to move to renewables and to improve carbon efficiency. The major burden of such carbon mitigation policies will fall on energy consumers, both commercial and households. Since those imposed on commercial users will also in some part be passed on to final consumers it is household consumers that will mainly foot the bill – and this is intended (Marden and Gough 2011).

However, it has long been recognised that raising energy prices will be regressive – that, while fuel, electricity and petrol consumption rise with income, they fall quite sharply as a share of income, thus any increase in prices will impact more heavily on lower income groups. On the other hand it has been found that there is great variation within income groups, according to household type, location, tenure and other factors. Thus to compensate 'losers' from higher carbon prices is no easy matter, and attention turns to other policies, such as retrofitting dwellings with insulation and other energy efficient improvements, more discriminating tax policies, possibly tradable personal carbon allowances, and various forms of behaviour change to modify preferences and actions based on these.

One purpose of this paper is to consider what further policies might be needed when we extend our purview to include embodied as well as direct emissions. The UK GHG targets mentioned above are *production*-based emissions figures, and do not include the carbon emitted in producing goods in China and elsewhere in the world which are then consumed in Britain. Table 1 compares the Department of Energy and Climate Change (DECC) estimates for 2006 with the consumption-based figures from the Stockholm Environment Institute's REAP model. It shows a wide divergence: UK CO2 emissions are 33% higher when offshore production of goods we consume is taken into account. This is close to the 37% gap reported for 2000 by an OECD report (Nakano et al 2009: Table 8). The table also reveals the UK's consumption based emissions of *all* greenhouse gases to be an astonishing 51% higher than its production of greenhouse gases – one of the widest gaps in the world.

According to Helm et al (2007), this reverses the success of the UK record. While on the UNFCCC basis, UK greenhouse gas emissions have fallen by 15% since 1990, on a consumption basis, emissions have *risen* by 19% over the same period' (see also Nakono 2009). Not surprisingly there is increasing criticism of the Kyoto production-based calculation. Hence the need to consider the wider distributional impact of all GHG emissions, both direct and indirect.[1]

Table 1: Comparison of production- and consumption based UK emissions

UK, 2006	Carbon emissions CO2			All greenhouse gas emissions: CO2e		
	Production-based	Consumption-based	Difference	Production-based	Consumption-based	Difference
Total emissions	551mT	733mT	+182mT	650mT	984mT	+334mT
Emissions per capita	9.1T	12.1T	+3.0T	10.7T	16.2T	+5.5T

Sources:
Production-based: DECC, UK Greenhouse Gas Emissions 1990-2009, Table 1: headline results. Available at http://www.decc.gov.uk/en/content/cms/statistics/climate_change/gg_emissions/uk_emissions/2009_final/2009_final.aspx
Consumption-based: Stockholm Environment Institute, Biology Department, University of York, Footprint Results from BRIO model, October 2009. Available at http://www.resource-accounting.org.uk/downloads

There are several good studies of the distribution of *direct* carbon emissions, notably those by Dresner and Ekins (2006), Druckman and Jackson (2008) and Thumin and White (2008). Dresner and Ekins study household fuel and electricity use using the English House Condition Survey (EHCS) 1996 coupled to the Expenditure and Food Surveys (EFS) 1999-2001. They find that income is less important than other factors, such as household size and composition, in driving carbon emissions. Druckman and Jackson also study energy used within households, in 2004-5, using the EFS and a set of conversion factors to translate energy expenditure into CO2 emissions. They construct a highly disaggregated model showing that type of dwelling, its tenure, household composition and rural/urban location are significant alongside income. Thumin and White build on this methodology, but include spending on petrol and diesel for private cars, to model the distributional effect of a Personal Carbon Allowance and Trading (PCAT) scheme on 'winners and losers'. As expected a PCAT is overall progressive and would create most losers among the highest income group, but again there is great variability. Low income losers include: large families in rural, hard-to-heat houses, 'empty-nesters' in large houses and houses without gas central heating, retired under-occupied urban households, and urban households with vehicles (not an exhaustive list). Low income winners include various urban dwellers, such as couples with

1 An earlier attempt to construct a consumption-based model of embodied carbon emissions in the UK was developed by Jackson et al (2007) based on 2002 data. It uses input-output methodology to allocate emissions according to ten higher-level consumer need categories, but it does not analyse the distribution of these across different types of household.

children in council housing. Additional policy implications include addressing under-occupancy and, in developing personal carbon allowances, explicitly addressing the carbon needs of children.[2]

However, to our knowledge there is no study which analyses the distribution of all household emissions in the UK, including the carbon embodied in food, many forms of transport including aviation, consumables, and the vast array of private and public services.[3] Another difference is that we study all GHG emissions, going beyond carbon to include methane, nitrous oxide, hydroflourocarbons and others. It is to this agenda that we now turn.

The plan of this paper is as follows. In the next section we describe the methodology and data sources used to compute total embodied greenhouse gas emissions and their distribution between households. Section 3 then presents our results on the distribution of per capita household emissions in two stages: descriptive statistics, followed by regression analysis. Section 4 then analyses per capita emissions *per £ of household income*, which is critical in understanding the distributional implications of any form of carbon mitigation policy. Section 5 then introduces further concepts and measures necessary when comparing the emissions of different household sizes and types: we calculate emissions *per adult equivalent* rather than per head and analyse their determinants. The final section discusses some of the implications of these findings for social policy in the UK.

2. Methodology and data sources

Input-output analysis and allocation of carbon and GHGs

We require input-output tables to transform industry-based emissions into consumption based emissions. We use data produced by the Stockholm Environment Institute's (SEI's) *Resources and Energy Analysis Programme* (REAP) to calculate UK carbon emissions at a per capita level (Paul et al 2010). REAP is an input-output based software tool that calculates the environmental pressures (footprint) associated with consumption activities (as opposed to production activities). REAP is a two region model that distinguishes between products produced in the UK and products imported from the 'rest of the world' for 178 individual sectors over a year. The sectors cover a range from agricultural and

2 There are also researches into the emissions of different 'lifetsyle groups' by Druckman and Jackson (2009) and Baiocchi et al (2010), which we do not consider here.

3 Studies do exist for some other countries. An early analysis of the Netherlands in 1990 by Vringer and Blok (1995) found that indirect emissions accounted for 54% of the total. They found income to be the main driver of total household emissions, with an income elasticity of 0.63. Their approach used a combination of input-output and process analysis; and this was later applied to the UK, Sweden and Norway (Kerkhof et al 2009). An ambitious study of household environmental accounts in Sweden used I-O analysis to break emissions down into three groups: direct, indirect emissions from production in Sweden and indirect emissions embodied in imports (Wadeskog and Larsson 2003). This also found that 54% of all emissions were indirect. After equivalising incomes it continued to find income the main driver, but also developed an early estimate of the effects of time and commodification on household emissions (see below).

manufacturing industries to transport, recreational, health and financial services, classified using the Standard Industrial Classification System (SIC). These are converted into consumption categories using the I-O model. REAP uses UK environmental accounts together with International Energy Agency and global databases (GTAP, EDGAR) to distinguish between the environmental impact of industrial sectors in the UK and the rest of the world. By modelling the combination of industries needed to produce different products, the impact per pound spent of 356 product groups and over 50 distinct consumption categories can be calculated.

I-O models differ in complexity. Single region models assume the same input-output coefficients within industry groups for foreign production as for domestic production – an untenable assumption. Multi-region input-output (MRIO) models are superior since they take into account the different production and technology structures of our trading partners, such as China and Germany, but are much more demanding to compute. Weber and Matthews (2008) develop a modified MRIO for the US using data on its seven largest trading partners which account for 60% of US trade. The REAP two-region model takes a weighted average of the I-O coefficients of all trading partners, which is less data-demanding and less sensitive. However, Baiocchi et al (2010), citing Wiedmann et al (2008) conclude that this is unlikely to affect estimates at high aggregation levels such as we develop, as errors tend to cancel out.

Total GHG emissions for the UK for each 'Classification of Individual Consumption by Purpose' (COICOP) sector were provided by the SEI. The sectors cover all macro-economic expenditure categories: investment, government spending and exports, as well as consumption categories. Our study excludes investment and exports, and in most of the tables government spending as well. However, we do in special tables also include emissions from government spending on health and education and other services.

We divide all emissions stemming from private consumption into five large categories:

- domestic energy and housing
- transport
- food
- consumables
- private services

These do not map directly on to the distinction between direct and indirect emissions noted above. So in addition we use a restricted definition of direct emissions to cover only household fuel and electricity and fuel for private cars. Everything else is defined as indirect. These are crude distinctions: Jackson et al (2007) provide a much more sophisticated distinction between 'domestic functional uses' and 'high level consumer needs' but our data do not permit us to replicate this.

Distribution of expenditures

To understand the distribution of these emissions across income deciles and household types, we use expenditure data from the government's 2006 *Expenditure and Food Survey*[4]. The EFS is a voluntary sample survey of private households, with the basic unit the household. Each individual is asked to keep diary records of daily expenditure for two weeks and information about regular expenditure, such as rent and mortgage payments, is obtained from a household interview along with retrospective information on certain large, infrequent expenditures such as those on vehicles. The data also includes information from simplified diaries kept by children aged between 7-15. The EFS sample for Great Britain in 2006 is a multi-stage stratified random sample with clustering, drawn from the small users' file of the postcode address file. 6,164 households in GB cooperated fully in the survey in 2005-06. Overall response rate was 57%.

EFS is designed primarily as a survey of household expenditure on goods and services but also gathers detailed information on the income of household members. EFS does not include withdrawal of savings, loans and money received in payment of loans, receipts for maturing insurance policies, proceeds from the sale of assets (e.g. a car), winnings from bettings or windfalls such as legacies. However, recorded expenditure may of course reflect these items as well as the effects of living off savings, using capital, and borrowing. In fact, measured expenditure substantially exceeds measured income at the bottom end of the income distribution, and vice versa at the top.

We find below in Figure 6 considerable variation of expenditure and emissions *within* income deciles. Previous studies have found that the regression of household carbon footprints on household expenditure is much more robust than on household income – R^2 around 0.7 compared with 0.5, according to Weber and Matthews (2008). This may be attributable in part to deficient data on incomes, especially among the self-employed, and fuels the arguments of some that poverty should be estimated on expenditure rather than an income basis. Or it may in part reflect a reality where households, especially low to middle income households, incur debt to finance consumption, which questions whether such consumption is sustainable.

Nevertheless, we use deciles of disposable household income as our measure. However to make comparisons between households of different sizes and composition, these incomes must be converted using an equivalence scale. Equivalised income is calculated by firstly assigning an equivalence value from the McClements Equivalence Scale to each household member. These individual values are then summed to give a total equivalence number for the household. The household disposable income is then divided by this total equivalence number to produce the equivalised disposable income. Equivalisation drastically alters the composition of each income decile. For example, one-person retired households account for 41% of households in the lowest income decile, but when income was equivalised the share fell to 10%. On the other hand the number of households with children in the lowest income

4 SN 5986 -Expenditure and Food Survey, 2006. Available at the UK Data Archive: www.esds.ac.uk/findingData/snDescription.asp?sn=5986. Specifically, we used the household characteristics data file - 2006_dvhh_ukanon.sav in SPSS version.

decile rose to 41% compared with the 15% found when simply using total household incomes. This reflects the common-sense view that an income supporting three people yields less welfare than the same income supporting one person. One result of this processing is that equivalised deciles are more heterogenous in terms of household composition.

Household size and composition plays a prominent role in our report, so we also analyse emissions data according to seven household categories, based partly on theoretical considerations and partly on data availability:

1. Households, with only one person, aged 60+
2. Households including at least two people aged 60+ and no adults 16-59 (excluding single parent families)
3. Households with only one person, under 60
4. Households with two adults (including one under 60), no children
5. 1Single parent households
6. Households with two+ adults, and children
7. Households with three+ adults, no children

Household categorisation was applied *after* creating income deciles meaning that, whilst every income decile included roughly the same weighted number of respondents across all household types, this did not apply within household type. Table 2 shows the sample numbers by income and household type. Taking 20 as a minimum acceptable sample size led to four cells, single parent households in the higher income brackets, being excluded.

Table 2: Sample household numbers according to composition and income level

	Equivalised Income Deciles										
Household category	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	***All***
Households, with only one person, aged 60+	76	256	188	151	95	72	52	45	26	23	*984*
Households with two or more people aged 60+	54	141	179	145	123	88	62	53	46	44	*935*
Households with only one person under 60	47	44	47	41	51	87	77	91	127	122	*834*
Households with two adults (including one under 60), no children	75	57	78	66	95	125	171	193	199	247	*1,306*
Households with three+ adults no children	28	21	36	40	70	59	76	59	65	26	*480*
Households with two+ adults and children	132	103	128	199	222	202	192	190	144	137	*1,649*
Single parent households	177	58	53	47	39	28	17	16	14	8	*457*
All	**689**	**680**	**709**	**689**	**695**	**661**	**647**	**647**	**621**	**607**	**6,645**

Mapping expenditure to GHG emissions

Mean expenditure was calculated, using weighted data, for each income decile for each household category, for 80 expenditure categories, chosen to best line up with the COICOP categorisation used in the Stockholm Environment Institute (SEI) data. There was generally a good fit between the two sets of categories.[5] The categories derived from the SEI and the EFS can be supplied on request.

However, there is an inherent problem in using expenditure surveys combined with IO tables: 'The IO framework assumes that all households purchase similar priced items within each aggregate commodity group. This is clearly not true, and leads to an overestimation of elasticities if higher-expenditure households purchase higher-priced goods' (Weber and Matthews 2008: 387). Overestimation occurs because the actual emissions associated with differently-priced goods in the same category (eg £3 orange juice cartons vs. 50p ones) are similar. But if higher-income households buy more expensive goods, in the same quantities, within that category, they appear to be buying more goods, but are actually just spending more money on the same volume of goods. They therefore in reality are contributing the same volume of carbon emissions - but will, on the estimate, appear to be producing more. We shall encounter some problems arising from this assumption later in some of our regressions.

For all these categories, once spending estimates were established, the process of estimating GHG emissions is relatively straightforward. Based on the total GHG emissions for the UK as a whole, the average per household emissions could be calculated for each COICOP category. From the EFS, we have the mean expenditure on each category across all respondents. Then, the difference between a given household group's expenditure on a category and the mean expenditure on the category can be used to estimate their per household emissions related to that category. So, if average spending on fruit and vegetables was £10 per week, but a given household category spends £5 per week, and the total UK emissions associated with fruit and vegetables works out at 0.6 kt CO2e per household per year, then that household category's emissions associated with this expenditure category can be assumed to be 0.3 kt CO2e.

The values calculated as a result of this approach are per household. Per capita values were calculated by dividing these figures by the mean household size for each household type for each income decile. In doing so, children were treated as equal to adults. (But see below for some complications).

Given that some of the cell sizes are small and that some households undertake large expenditures within the survey periods which are not corrected for by the EFS, some lumpy figures were obtained in some cells. The final step we take is to smooth the figures across the

5 The biggest complications were in COICOP category 01 food and 07.3 transport services. For food, some spending categories needed to be combined (e.g. different types of meat) and some assumptions were made (for example category 01.1_M Grain mill products was assumed to just include rice and pasta). For transport, spending on 'combined fares' was distributed between rail and bus, and ancillary transport was assumed to include 'other transport' minus 'air transport' and 'water transport'.

income spectrum by averaging the figures for the income decile in question with the income deciles immediately adjacent to it, but weighting doubly the income decile in question. So, for example smoothed spending $\{Ex_d\}$ (where d is the decile) is:
$\{Ex_d\} = (Ex_{d-1} + 2Ex_d + Ex_{d+1})/4$ and for deciles 1 and 10 we used $\{Ex_d\} = (2Ex_d + Ex_{d+1})/3$.

Public services
We consider the emissions associated with the consumption of *public* services separately, for principled and data reasons. The principled reason is that services such as education, health and social work are provided free of charge or heavily subsidised and their consumption is mediated by law, regulation and the judgement of professionals concerning need and entitlement. The drivers are quite distinct from those affecting private consumption. The EFS does not provide data on the use of these services, so we must turn to the ONS study *The Effect of Taxes and Benefits on Household Income 2005/06*. This provides data on use of public services in kind by income and for some household types; but note - most services other than education, health and social work are assumed to 'benefit' all persons equally. Mean figures for income deciles all household types come from Table 14 from this document. Separate distributions are presented for retired households (Table 18), for households with children (Table 21) and for households without children (Table 20). Emissions associated with other public services which might be expected to be targeted more towards poorer income deciles (such as social work) distributed between deciles according to the sum of the in kind benefit from health and education across all household types.

3. Results

Consumption-based emissions in the UK in 2006 averaged 33.2 tonnes CO2e per household, according to our REAP-based data (see Table 3). On a per capita basis, the average household emitted 15.2 tonnes GHG.[6] Of this public services accounted for 1.8 tonnes, and private consumption for 13.4 tonnes. The table also shows the breakdown between the major private expenditure items. This shows that direct emissions – household domestic energy use and petrol for private cars - account for only 20% of total private emissions.

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6 Table 2 also shows emissions per adult equivalent – something we address later in section 5.

Table 3: Household emissions by emissions type and sector

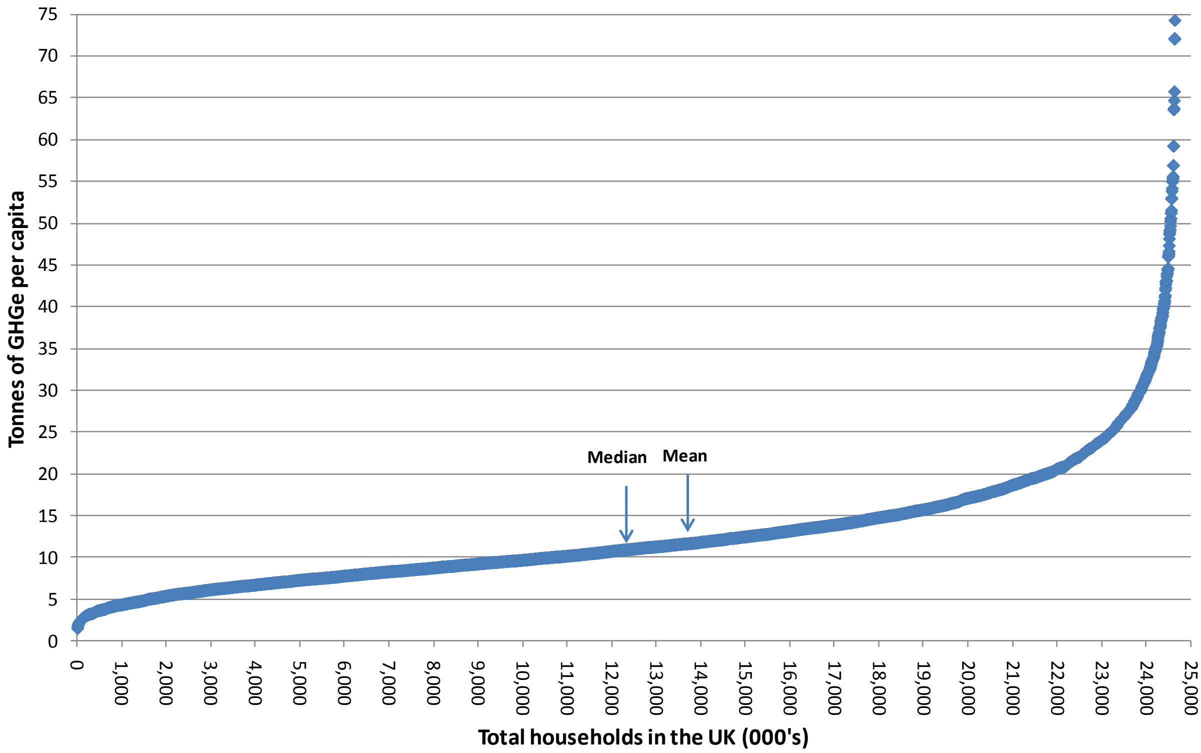
	Per Capita emissions		Household emissions		Per Equivalent adult emissions	
Sector	Average in tonnes	%	Average in tonnes	%	Average in tonnes	%
Direct emissions	2.71	20.2	5.71	19.8	2.88	20.2
Indirect emissions	10.69	79.8	23.19	74.0	11.39	79.8
Domestic Energy and Housing	3.98	26.2	8.17	24.6	4.23	25.9
Food	2.07	13.6	4.54	13.7	2.21	13.5
Consumables	1.83	12.1	4.07	12.2	1.96	12.0
Private Services	1.68	11.1	3.73	11.2	1.81	11.1
Transport	3.78	24.9	8.39	25.2	4.04	24.7
Public Services	1.78	11.7	4.26	12.8	2.02	12.4
Total emissions (incl other	15.18	100.0	33.22	100.0	16.35	100.0

Other studies show a lower share of embodied emissions within the household sector: Druckman and Jackson (2010) show 66% and (Baiocchi et al 2010) 70%, compared with our 80%. This will partly reflect different definitions of what constitutes ‘direct emissions’. Thus we include only direct fuel use in the home (including electricity) and exclude ‘distribution of electricity, gas and other fuels’.[7] At 33.2 tonnes our figure for average household emissions looks high, compared with Druckman and Jackson’s (2010) figure of 26 tonnes for 2004. However, subtracting the emissions credited to the consumption of public services (4.26 tonnes) yields a roughly comparable figure of 29 tonnes for average household emissions from all private consumption.

Figure 1 shows all households ordered according to their total private emissions per head. The relationship is curvilinear with a tail of extremely high emissions. As a result the mean per capita emission per household (13.40t) exceeds the median (10.94t). Part of this extreme dispersion will be due to expenditures in a few households on big items, such as cars, holidays abroad, fitted kitchens and furniture etc, during the survey period; we attempt to smooth out this lumpiness in some of the statistics below.

[7] This may also reflect deficiencies in the REAP data which do not discriminate within the electricity sector between the carbon intensities of industry and households.

Figure 1: Household per capita emissions for the UK



This section presents our findings on the distribution of emissions in two parts. First, we give a descriptive account of the impact of income and other significant variables on per capita emissions. We also show the breakdown between the different categories of emission shown above. Second, we present multi-variable regression analysis of the determinants of total per capita private consumption emissions, followed by similar regressions for each category of emission.

Most of the tables that follow show on the vertical scale emissions of greenhouse gases (GHG) in tonnes of CO2e per capita.

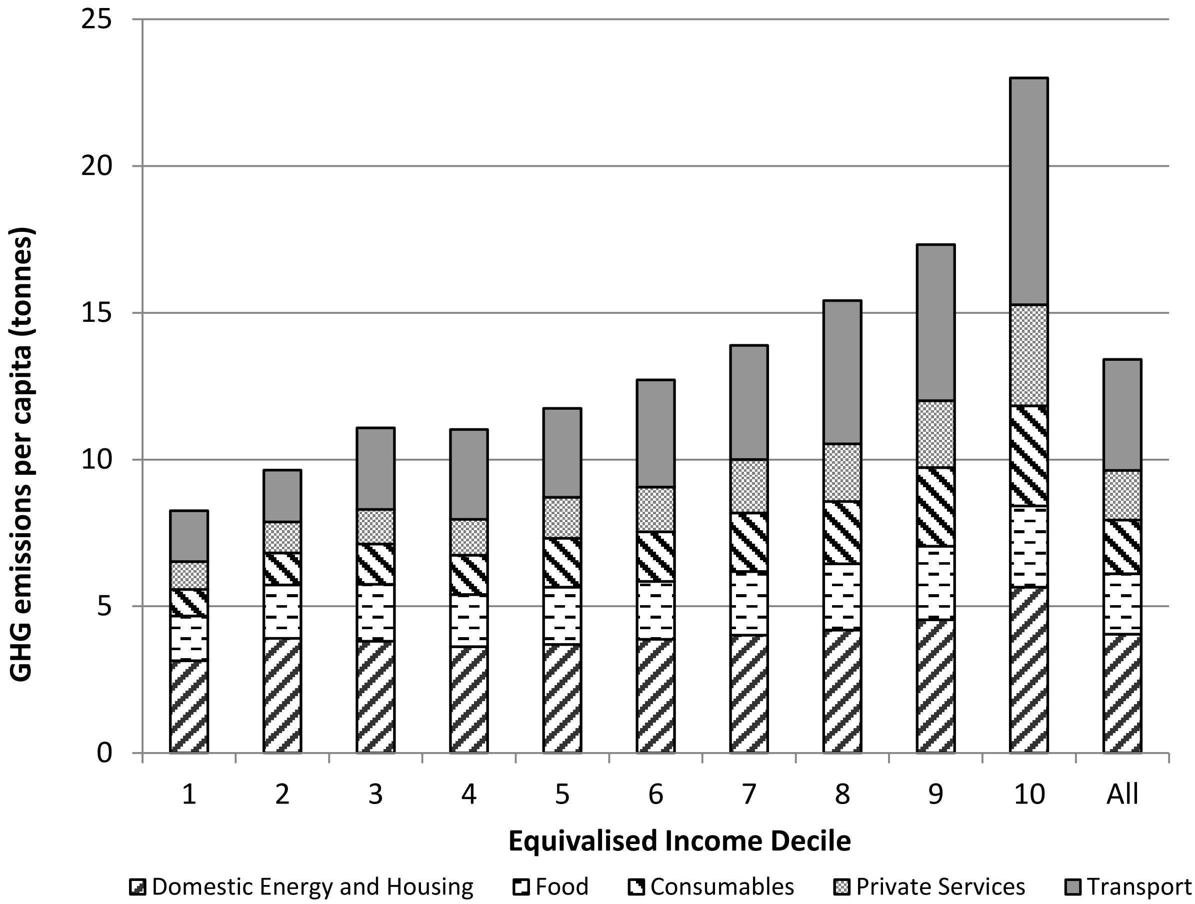
3.1 Descriptive statistics

The variables considered here are: income, household size, household composition, housing tenure, and employment status. The appendix presents tests of the significance of these variables, using Pearson correlation coefficients for the continuous variables and t-tests of pairs of the categorical variables.

INCOME

Income, as mentioned before, is calculated on an equivalised basis to take into account household size and composition, and income deciles are constructed on this basis. Table 4 and Figure 2 present the same information by income deciles, ranking them from the lowest to the highest. Emissions rise in line with income; in particular, the highest income decile is out of line, emitting 5.7 tonnes per person more than the next highest decile, indicating a long tail of high emitters.

Figure 2: Per capita GHG emissions by (equivalised) income deciles- all sectors



Income is significantly correlated with all types of emissions, but much more so with indirect than direct emissions. The last column of Table 4 shows the ratio of emissions between the highest and lowest deciles. This is 4.5x higher for transport and over 3.5x higher for private services and consumables. The income elasticity of emissions is much lower for basic goods such as food and domestic energy.[8] Income is so significantly associated with emissions that we frequently cross-tabulate it with other variables in what follows.

[8] Note that all meals eaten out are classified under private services, not food.

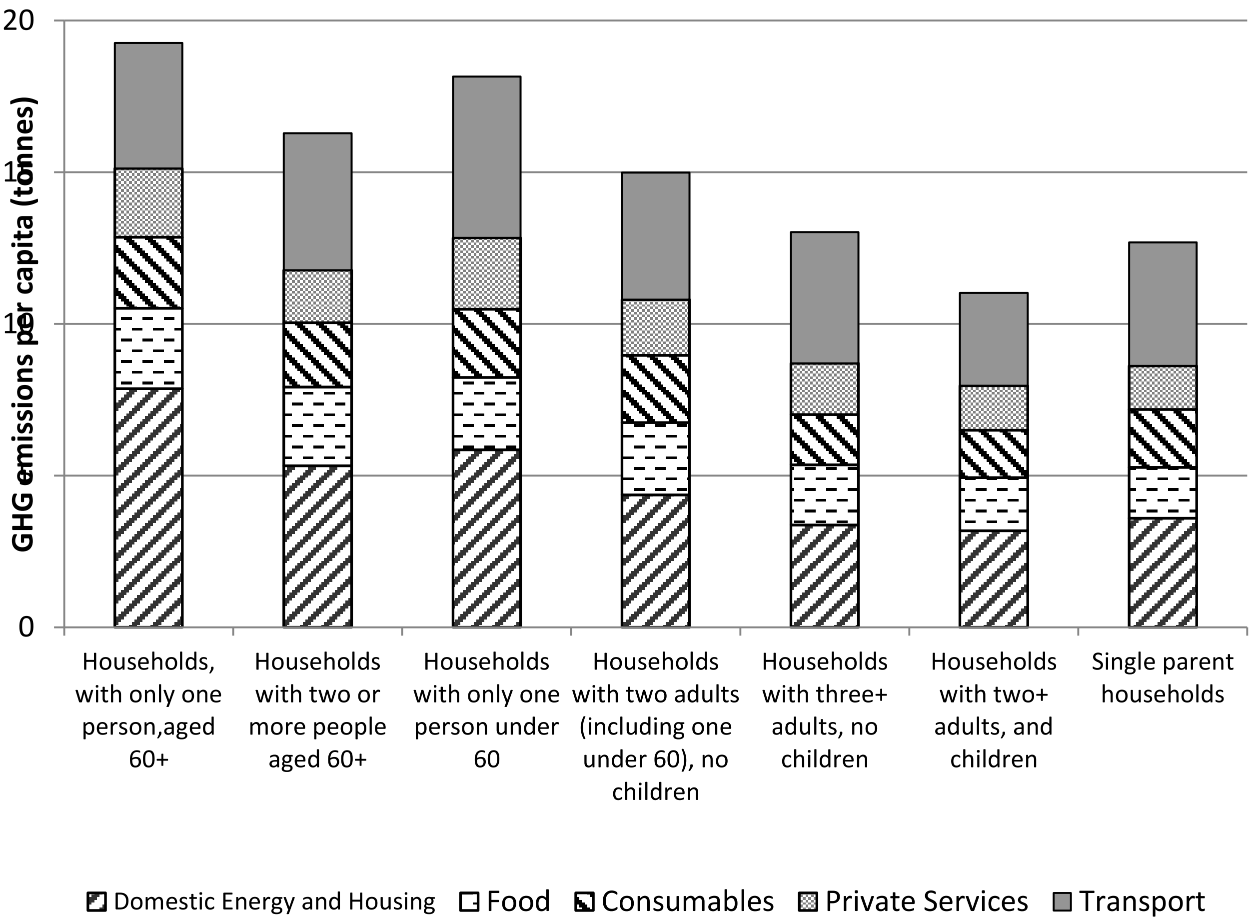
Table 4: Per Capita GHG emissions by (equivalised) income decile - all sectors in the UK (tonnes)

	Equivalised Income Deciles											
Sector	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	***Average***	***10:1 Ratio***
Domestic Energy and Housing	3.08	3.85	3.75	3.56	3.64	3.82	3.95	4.13	4.48	5.59	*3.98*	*1.82*
Food	1.53	1.81	1.93	1.78	1.96	1.97	2.17	2.26	2.50	2.77	*2.07*	*1.81*
Consumables	0.90	1.10	1.38	1.35	1.67	1.69	2.00	2.13	2.68	3.41	*1.83*	*3.78*
Private Services	0.95	1.05	1.18	1.22	1.39	1.53	1.81	1.96	2.28	3.44	*1.68*	*3.61*
Transport	1.73	1.77	2.77	3.05	3.03	3.65	3.89	4.88	5.31	7.73	*3.78*	*4.46*
Other	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	*0.06*	*1.00*
Public Services	1.96	2.14	1.97	1.83	1.70	1.75	1.67	1.64	1.58	1.52	*1.78*	*0.78*
Total	**10.22**	**11.77**	**13.04**	**12.84**	**13.44**	**14.47**	**15.55**	**17.05**	**18.89**	**24.52**	**15.18**	**2.40**

HOUSEHOLD COMPOSITION

Figure 3 show emissions by income decile for the seven types of household distinguished above. Looking first at the mean total emissions of each type, we find considerable variation, with single adult households highest, followed by two person households. Larger households and households with children have lower mean emissions, mainly due to economies of scale in consumption. All these differences are significant when we calculate t-tests for pairs of variables (see Appendix).

Figure 3: Average per capita GHG emissions by household category



The patterns of consumption also vary across household types. The domestic energy and housing emissions of single person households, whether below or above the pension age, are high, reflecting the absence of economies of scale in accommodation, heating etc. Also younger single person households spend and emit relatively high amounts on transport and personal services.

Household size

This is negatively and significantly correlated with total per capita emissions, with a correlation coefficient of -0.27, indicating the much studied presence of economies of scale within households (see also for the US Weber and Matthews 2008, Figure 4b). However, the relationship is not significant for emissions from transport and consumables.

Housing tenure

This distinguishes just three categories and displays significant though rather small differences in average emission with social housing lowest and owner-occupied highest (see Table 5 and Appendix).

Table 5: Distribution of per capita GHG emissions for household tenure categories by (equivalised) income deciles

	1	2	3	4	5	6	7	8	9	10	Average	10:1 Ratio
Social Housing	8.40	10.58	11.22	13.06	11.29	12.14	12.96	15.44	15.99	21.14	12.34	1.90
Private Housing	8.18	9.15	10.27	9.81	10.91	20.72	17.60	16.29	19.42	20.13	14.25	2.46
Owner Occupied Housing	8.05	9.61	10.32	10.87	11.82	12.06	13.60	14.77	17.12	23.46	13.17	2.91
All	**8.25**	**9.63**	**11.07**	**11.01**	**11.74**	**12.71**	**13.88**	**15.41**	**17.32**	**23.00**	**13.40**	**2.79**

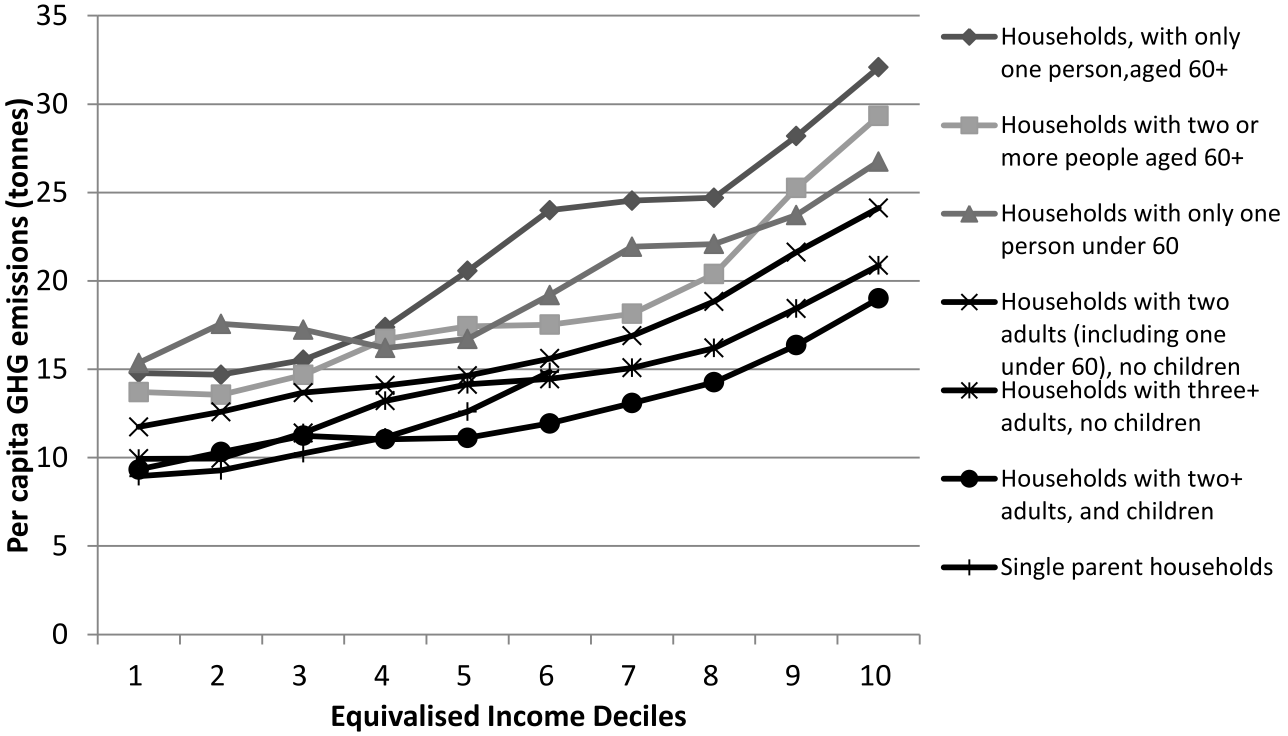
Table 6: Distribution of per capita GHG emissions for household categories by (equivalised) income deciles

	Equivalised Income Deciles											
Household Category	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	***Average***	***10:1 Ratio***
Households, with only one person,aged 60+	12.54	11.85	12.44	15.33	16.46	24.18	21.32	21.36	24.68	32.49	*19.26*	*2.59*
Households with two or more people aged 60+	11.51	10.72	11.23	15.52	14.66	15.05	15.48	16.61	22.82	29.31	*16.29*	*2.55*
Households with only one person under 60	10.59	19.07	14.41	14.64	15.15	16.21	23.64	18.82	21.78	27.25	*18.16*	*2.57*
Households with two adults (including one under 60), no children	9.71	10.59	12.83	12.30	13.15	14.43	15.02	17.82	19.51	24.49	*14.99*	*2.52*
Households with three+ adults, no children	8.92	7.00	10.49	11.57	13.58	12.46	14.01	14.65	16.40	21.17	*13.03*	*2.37*
Households with two+ adults, and children	7.05	7.98	10.41	8.51	9.47	10.01	11.28	12.84	13.25	19.45	*11.02*	*2.76*
Single parent households	6.88	6.50	8.49	9.00	9.88	13.85					*9.10*	
Total Emissions	**8.25**	**9.63**	**11.07**	**11.01**	**11.74**	**12.71**	**13.88**	**15.41**	**17.32**	**23.00**	**13.40**	2.79

HOUSEHOLD TYPE AND INCOME

Since we use only one year of the EFS the numbers of cases in each cell reduces when cross-tabulating. Some households undertake exceptional expenditures (e.g. a car, furnishings or a holiday abroad) during the weeks of the survey, which are not corrected for in the EFS, resulting in aberrant figures in some cells. To try to correct for this, we have 'smoothed' the results of table 5, shown in figure 4, though it does not entirely remove the anomalies.

Figure 4: Household category per capita GHG emissions by (equivalised) income deciles - smoothed



EMPLOYMENT STATUS

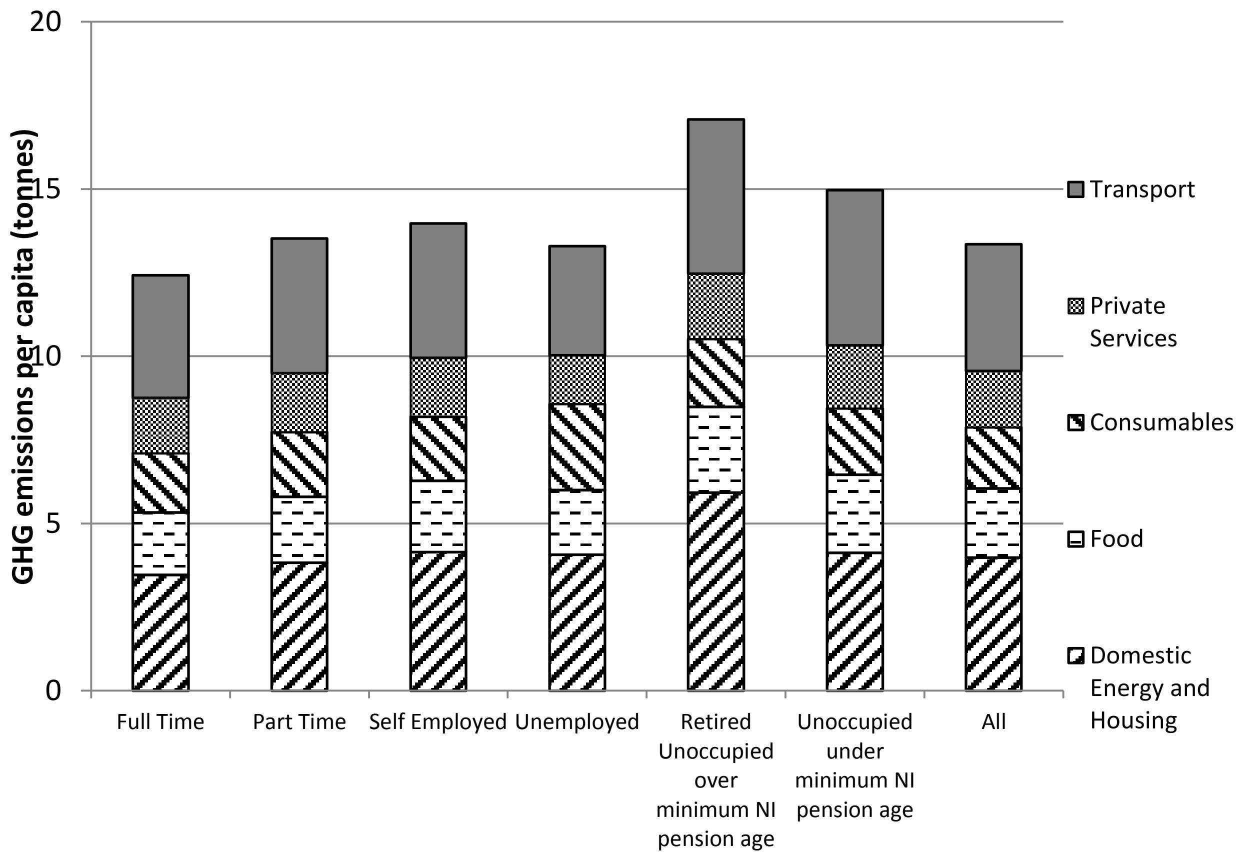
The hypothesised impact of employment status and of time use on household emissions can take two opposing forms. On the one hand, work-rich households would spend more on commuting and may substitute purchased commodities and services for household production which might be expected to raise their carbon emissions. On the other hand, workless households, and especially pensioner households, might be expected to spend more time at home incurring heating and other energy costs. To study the effects of employment status on GHG emissions we use two measures: the employment status of the 'household reference person' (HRP) and the combined employment status of all adults in the household.[9] [10] The first distinguishes HRPs who are:

9 The household reference person is the person who: a. owns the household accommodation, or b. is legally responsible for the rent of the accommodation, or c. has the household accommodation as an emolument or perquisite, or d. has the household accommodation by virtue of some relationship to the owner who is not a member of the household. If there are joint householders the household reference

- Full Time
- Part Time
- Self Employed
- Unemployed
- Retired (unoccupied over minimum NI pension age)
- Unoccupied under minimum NI pension age

Figure 5 shows little difference between the group means except for retired households who emit some two tonnes more per head. Not all of these differences are significant.

Figure 5: Average per capita GHG emissions by employment status - all sectors



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person will be the one with the higher income. If the income is the same, then the eldest householder is taken.

10 We attempted to use a third data source, the Time Use Survey 2005, to provide more detailed data on time use. Unfortunately, it proved impossible to link this to the EFS and REAP databases in a way that inspired confidence in the results.

Our second measure brings in other household members to distinguish ‘work-rich’ and ‘work-poor’ households, identifying five categories:

- Two adult households:

Both in employment (full-time or part-time)
One in employment, one not
Neither in paid employment

- One adult households:

In work
Out of work

Table 7 below shows the distribution of these household’s per capita emissions across income deciles. ‘Workless’ households emit significantly more than those with one or more members in employment, supporting the second hypothesis, but of course this may be the result of confounding variables such as household size and composition.

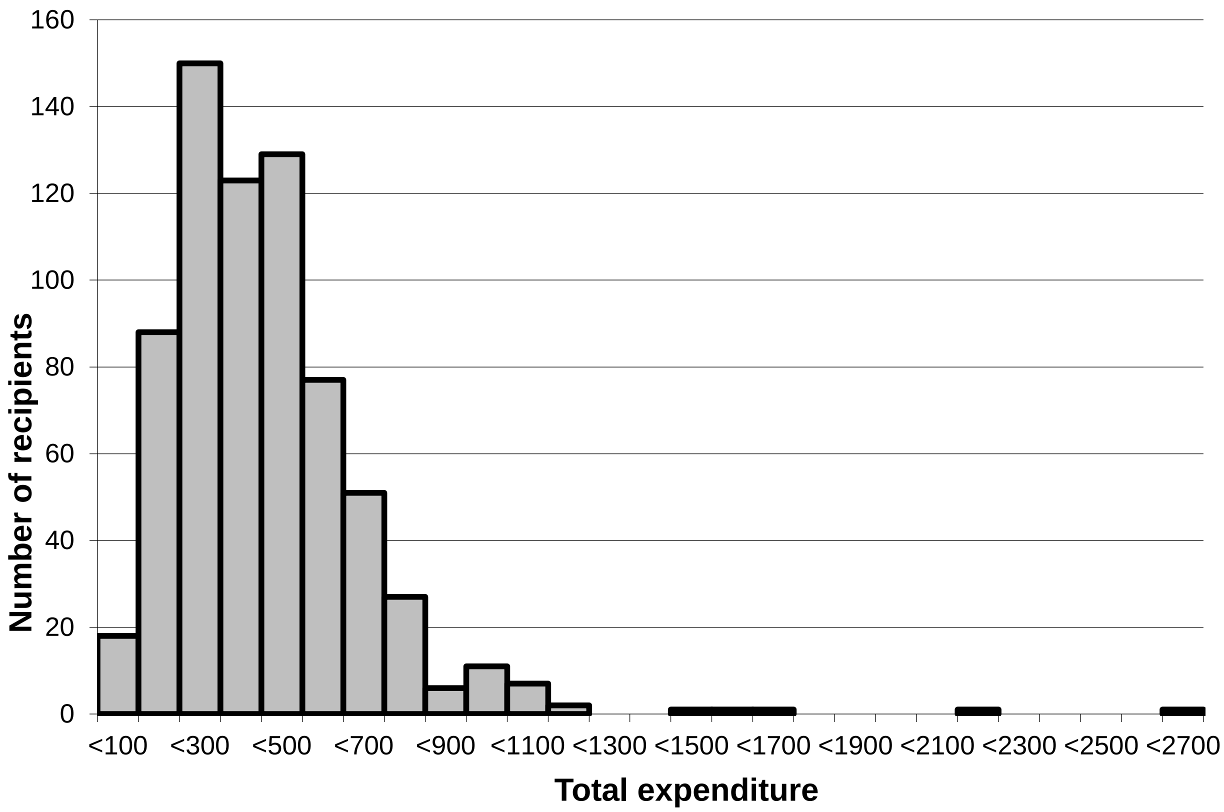
Table 7: Distribution of per capita GHG emissions for household employment status by income deciles

Household Employment Status	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	***Average***	***10:1 Ratio***
2 Adult households												
Both in employment	11.09	10.19	9.28	8.73	10.52	10.66	11.64	13.63	15.30	21.60	*12.27*	*1.95*
Neither in paid employment	7.68	9.00	9.90	13.57	12.42	13.80	15.05	20.36	19.36	24.64	*14.58*	*3.21*
One in employment, one not	7.89	7.52	11.35	9.38	10.92	12.05	13.73	13.93	19.07	22.09	*12.79*	*2.80*
1 Adult households												
In work	12.17	16.68	10.04	10.03	11.92	14.25	15.69	17.25	19.72	24.87	*15.26*	*2.04*
Out of work	7.85	9.96	11.00	13.35	14.33	23.06	28.29	19.59	23.91	29.68	*18.10*	*3.78*
All	**8.25**	**9.63**	**11.07**	**11.01**	**11.74**	**12.71**	**13.88**	**15.41**	**17.32**	**23.00**	**13.40**	**2.79**

DISPERSION OF EXPENDITURE AND EMISSIONS WITHIN INCOME DECILES

It is clear that factors other than income determine emissions. However one factor that might explain this is the variation of consumption expenditure within income groups (Roberts 2008). This is revealed in the EFS: see Figure 6 which gives the distribution of total weekly expenditure by households within just the 5th decile, showing considerable variation and a long tail of high spenders. This may be attributable in part to deficient data on incomes, especially among the self-employed, and fuels the arguments of some that poverty should be estimated on expenditure rather than an income basis. Or it may in part reflect a reality where households, especially low to middle income households, incur debt to finance consumption, which questions whether such consumption is sustainable. Whatever the reason, it requires that we examine variations in emissions within income groups.

Figure 6: Histogram of total expenditure within the 5th decile



Ideally we would want to show measures such as the inter-quartile and inter-decile (top and bottom) range of emissions within each income group. However, given the methodology we have had to adopt this cannot be directly calculated. Instead we have tracked expenditure differences by calculating the average spending of the top and bottom quintile of spenders within each of the ten income groups. From this we can then calculate one measure of the range of emissions within them. When this was first done we found very wide variations which seemed hard to explain. However, this mainly reflects large differences in mean household sizes between the high and low spending households – see Table 8.

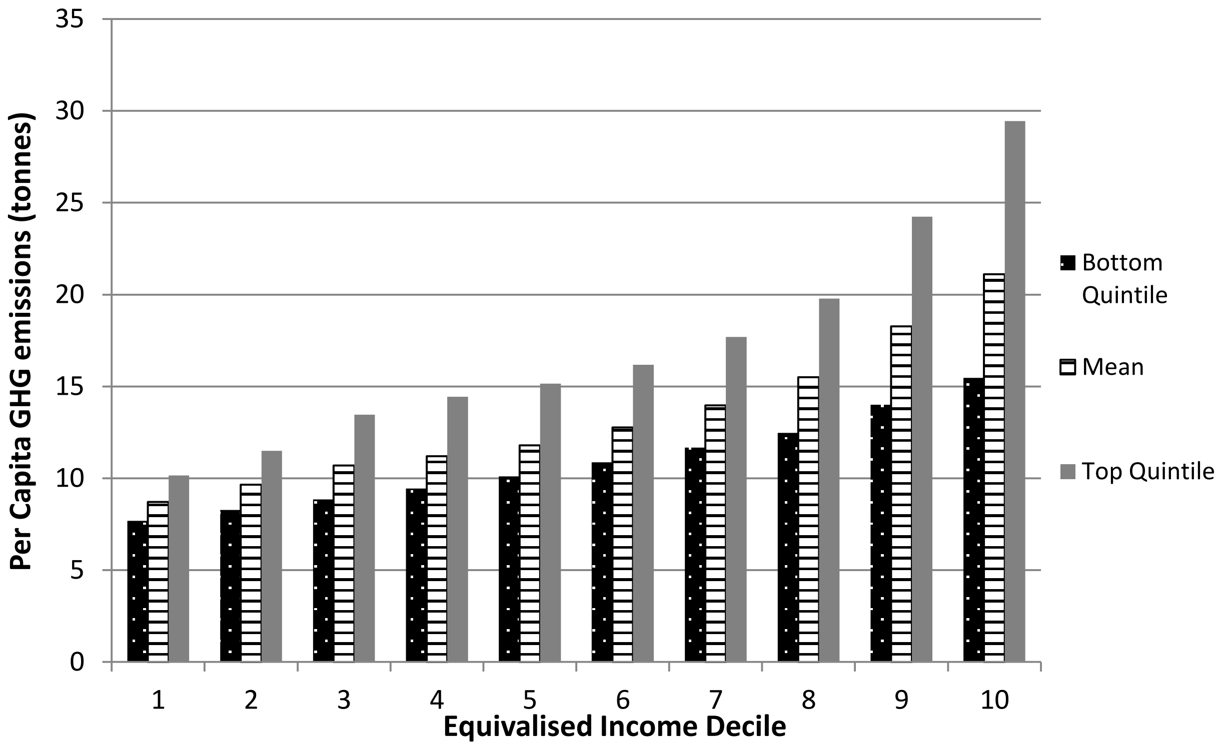
Table 8: Average household size within top and bottom quintiles of income deciles

	1	2	3	4	5	6	7	8	9	10	Average
All	2.41	2.02	2.20	2.48	2.62	2.48	2.52	2.47	2.29	2.16	*2.36*
(1) Bottom Quintile	1.36	1.18	1.29	1.31	1.47	1.33	1.53	1.39	1.43	1.41	*1.37*
(2) Top Quintile	3.86	3.52	3.41	3.78	3.60	3.55	3.40	3.44	3.18	2.88	*3.46*

When emissions are divided by these different household sizes, much but not all of the variation disappears – see Figure 7. We also observe that dispersion increases in the top income groups, which confirms the findings of Baiocchi et cl (2010) and Weber and Matthews (2008, Figure 3) for the US. This has important implications for carbon mitigation policies.

Any carbon cap would impact first on the highest income groups and then work its way down the distribution. Nevertheless, a cap of 15 tonnes per head would impact on high emitting households down to the sixth decile. Thus compensating for carbon reduction measures could not rely in any simple way on extending existing social benefits and tax credits.

Figure 7: Variation of emissions within income deciles: comparing top and lower quintiles of spenders - smoothed



PUBLIC SERVICES

As argued above, emissions associated with the use of public services, such as health, education and social welfare, pose different methodological and data issues. We use government data on the money value of the use made of these services by different households, together with SEI data on their overall emissions, to impute the emissions to different categories of household – see table 9 for the distribution by income decile. Public sector emissions amount to 1.8 tonnes per person, with health services and 'public administration & other' being the main emitters. The distributional pattern is quite distinct from private consumption: due to the redistributive nature of the welfare state the result is an inverse relationship with equivalised income. This is especially strong for social services and for education, due to the concentration of children in low income households (and also possibly to the presence of some higher education students as low income householders). Table 10, presenting variations by household type, also shows up a higher usage and emissions among pensioner householders, mainly reflecting health care costs.

TOTAL PER CAPITA EMISSIONS

Finally Table 11 combines public and private sector emissions to exhibit the distribution of all household emissions. As expected, this reduces the range of emissions between the highest and lowest income deciles – from 2.8:1 when considering private consumption to 2.4:1.

Table 9: Distribution of per capita GHG emissions from public services by equivalised income decile

Sector	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	***Average***	***10:1 Ratio***
Education	0.30	0.29	0.22	0.20	0.18	0.19	0.17	0.17	0.15	0.10	*0.20*	*0.35*
Health services	0.57	0.76	0.72	0.60	0.52	0.54	0.49	0.47	0.44	0.46	*0.56*	*0.82*
Social work	0.24	0.23	0.17	0.17	0.15	0.16	0.15	0.14	0.13	0.10	*0.16*	*0.41*
Public administration & other *	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	*0.86*	*1.00*
All	**1.96**	**2.14**	**1.97**	**1.83**	**1.70**	**1.75**	**1.67**	**1.64**	**1.58**	**1.52**	**1.78**	**0.78**

*Public administration & other includes public administration and recreational services
Source: ONS (2006) The effects of taxes and benefits on household income, 2005/06

Table 10: Distribution of per capita emissions by public services: income and household category

Household Category	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	***Average***	***10:1 Ratio***
Households, with only one person,aged 60+	2.43	2.59	2.47	2.54	2.39	2.53	2.40	2.65	2.40	2.09	*2.45*	0.86
Households with two or more people aged 60+	2.40	2.59	2.45	2.54	2.38	2.53	2.40	2.63	2.38	2.08	*2.44*	0.87
Households with only one person under 60	2.04	1.73	1.61	1.48	1.41	1.40	1.36	1.29	1.34	1.31	*1.50*	0.64
Households with two adults (including one under 60), no children	1.79	1.64	1.54	1.42	1.36	1.35	1.32	1.26	1.31	1.29	*1.43*	0.72
Households with three+ adults, no children	1.68	1.61	1.51	1.40	1.34	1.34	1.30	1.25	1.30	1.28	*1.40*	0.76
Households with two+ adults, and children	1.96	2.00	1.92	1.81	1.72	1.76	1.72	1.74	1.67	1.60	*1.79*	0.82
Single parent households	2.19	2.20	2.12	2.07	1.91	1.94					*2.07*	
Total Emissions	**1.96**	**2.14**	**1.97**	**1.83**	**1.70**	**1.75**	**1.67**	**1.64**	**1.58**	**1.52**	**1.78**	**0.78**

Source: ONS (2006) The effects of taxes and benefits on household income, 2005/06

Table 11: Distribution of average per capita emissions by household category and income decile including private and public services

Household Category	1	2	3	4	5	6	7	8	9	10	*Average*	*10:1 Ratio*
Households, with only one person,aged 60+	14.96	14.45	14.91	17.87	18.85	26.71	23.73	24.00	27.07	34.58	*21.71*	*2.31*
Households with two or more people aged 60+	13.91	13.31	13.68	18.06	17.05	17.58	17.88	19.23	25.20	31.39	*18.73*	*2.26*
Households with only one person under 60	12.63	20.80	16.02	16.12	16.56	17.61	25.00	20.11	23.12	28.56	*19.65*	*2.26*
Households with two adults (including one under 60), no children	11.49	12.24	14.38	13.73	14.51	15.78	16.34	19.09	20.81	25.78	*16.42*	*2.24*
Households with three+ adults, no children	10.60	8.61	12.00	12.97	14.91	13.80	15.31	15.90	17.70	22.46	*14.43*	*2.12*
Households with two+ adults, and children	9.01	9.98	12.33	10.33	11.20	11.77	13.00	14.57	14.92	21.05	*12.81*	*2.34*
Single parent households	9.07	8.71	10.61	11.08	11.79	15.78					*11.17*	
Total Emissions	**10.22**	**11.77**	**13.04**	**12.84**	**13.44**	**14.47**	**15.55**	**17.05**	**18.89**	**24.52**	**15.18**	**2.40**

3.2 Multivariate regressions

In order to disentangle the overall influence of all the factors discussed above, we turn to multivariate analysis. The dependent variable is per capita GHG emissions, but since the distribution of emissions is heavily skewed we log the series to create a more normal distribution. We begin with total emissions and then consider each major consumption category in turn: our focus is on private consumption and the public sector is not considered here. A list of all models tested is given in Appendix 1.

TOTAL EMISSIONS

To identify the best fit model we compare the adjusted R^2 of various combinations of variables. According to Wooldridge (2003: 198-9), the primary attractiveness of the adjusted R^2 is that it imposes a penalty for adding additional independent variables to a model. R^2 can never fall when a new independent variable is added to a regression equation, but adjusted R^2 can go up or down. 'Everything else being equal, simpler models are better. Since the usual R^2 does not penalise more complicated models, it is better to use adjusted R^2.'

Equivalised income on its own explains around 25% of the variation found in log per capita GHG emissions and household composition on its own explains around 13%. When these two variables are combined and regressed on per capita emissions it increases the Adjusted R^2 by around 10%, indicating that equivalised income and household type explains around 34% of the variation in logged per capita GHG emissions. Employment status explains 7% of the variation in per capita GHG emissions on its own. Combined with equivalised income, it explains 28% of per capita emissions which increases the amount explained by the model by 2%. Including household type we find the adjusted R^2 increases again to explain 35% of the variation in per capita GHG emissions – see Table 12.

These were the only variables which added some value to the explanation of the variation in total per capita GHG emissions. Variables such as hours worked and housing tenure proved to be statistically insignificant when combined with the above variables. Other variables such as the household employment status and household size were significant, but proved to be less useful in the explanation of per capita GHG emissions. This three-variable model also works best for most separate categories of emissions, but in two cases we modify it to incorporate one of the other variables. The regressions run are listed in Appendix 2.

Overall the regression is significant at the 99% level shown by the F-stat and has an Adjusted R^2 of 0.35 explaining 35% of the variance in total emissions. From the various regressions run, this model has the highest R^2 and lowest root MSE meaning that as a model it performs better than others tested.

Of these variables, the dominant one is equivalised income, which is here measured on a weekly basis. Its coefficient indicates that for each £100 increase in weekly income - or £5000 increase in annual income - GHG emissions increase by 0.0688 log points or 6.9%.

Table12: ‘The standard model’: effect of equivalised income, household composition and HRP employment status on log per capita emissions

Log Per Capita GHG Emissions	Coefficients	Standard Error	T-Statistic
Intercept	2.24589	0.029	78.24
Equivalised income	0.00069	0.000	39.09
Households with two or more people aged 60+	-0.08652	0.020	-4.26
Households with only one person under 60	-0.05425	0.028	-1.91
Households with two adults, no children	-0.15412	0.026	-5.92
Single parent households	-0.48033	0.031	-15.26
Households with two+ adults, and children	-0.44042	0.026	-16.77
Households with three+ adults, no children	-0.22416	0.029	-7.62
Part time employed	0.04131	0.022	1.92
Retired	-0.04058	0.024	-1.66
Self employed	0.09268	0.021	4.45
Unemployed	-0.24104	0.042	-5.71
Unoccupied	-0.06922	0.020	-3.48
Adj R^2 =0.349			

Household type is a categorical variable, with household type 1 (single retired households) used as the reference group. The emissions of all other household types are significantly different to this type at the 5% level, except for household type 3 (other single adult households). All have negative coefficients indicating that category 1 households are the highest per capita emitters and category 5 (single parent households) are the lowest, emitting 0.48 log points less than the single retired. Thus the relationship with household type remains as before, despite regressing it with other variables: single person households emit most per capita and households with children significantly less.

For employment status as measured by the HRP, we use those in full-time work as the reference group. Part-time and retired statuses do not show significant differences at the 95% level, but the self-employed exhibit higher emissions, and the unemployed and unoccupied significantly lower emissions. (Again we need to remember here that reported self-employed income is likely to be considerably less than actual income, and that some will be running their businesses from their private dwellings). This variable performs somewhat better than the more inclusive measure of household employment status.

CATEGORIES OF EMISSIONS: REGRESSION RESULTS

We next run regressions against various sources of household emissions. Details of all these are given in Appendix 2, and the R^2 are tabulated in Table 13 below. We summarise the findings here.

Table 13: Regression results for specific categories of emissions: Adjusted R^2

	Emissions		Regression variables (other than those in the standard model)
	Per head	Per equivalent adult	
Total	.35	.28	
Direct	.22	.15	
Indirect	.34	.26	Household employment status (in place of HRP employment status)
Transport	.26	.25	
Food	.10	.05	
Consumables	.12	.12	Housing tenure
Services	.33	.31	
Energy and housing	.21	.14	

Direct emissions

Direct household emissions combine domestic energy and fuel for private vehicles and account for 20% of the total. When applied to direct emissions, the standard model has an R^2 of only 0.22. Equivalised income continues to be significant but it explains less: a £5000 increase in equivalised annual income causes a 6% increase in direct per capita GHG emissions. The impact of household type and employment status is similar to that in the general model. All household types except one significantly affect these emissions, with larger households with children showing much lower levels. The same is true for employment status, with the unemployed and unoccupied exhibiting lower emissions when holding constant the effect of income and household type. These findings back up previous research which shows weaker associations with direct emissions: other variables such as urban-rural location and type and age of housing are more important, but unfortunately cannot be tested with the data we have to hand.

Indirect Emissions

When we turn to per capita indirect GHG emissions, which account for four-fifths of the total, our standard model performs better, explaining around 34% of the variation in emissions. Equivalised income is again the most important factor, with household types second most important. In this model, a £5000 increase in annual equivalised income would cause per capita indirect GHG emissions to increase by 6.9%. The pattern of variation between household types and employment statuses is the same: households with children, and with an unemployed head, are significantly lower emitters than either the retired or those in work.

Transport

The transport sector includes all forms of transport use including aviation and holidays abroad. Here we find that our index combining the employment status of all adult members performs better than that referring solely to the HRP, so we modify the standard model (using two-worker households as the reference group). Together with income and household type it explains around 26% of the variation. The effect of income is still greater in transport: a £5000 increase in annual equivalised income results in a 9.7% increase in per capita GHG emissions in the transport sector. This reflects in great part the highly skewed nature of spending on aviation. Holding all other variables constant, single adult households below retirement age create the largest amount of per capita GHG emissions, contributing 0.137 log tonnes more emissions than single elderly households. Otherwise, household type is of little significance; nor is household employment status, except that, among two adult households, there is a significant distinction between work-rich and workless households, the former travelling and emitting more.

Food

Our standard model does least well in explaining variations in emissions from the consumption of food, explaining only 10% of their variation. This may relate to an inherent problem in using consumption surveys combined with IO tables. As we have seen this can overestimate elasticities if higher-expenditure households purchase higher-priced goods, which may well be the case with food. The contribution of income is relatively low, as would be expected from the low income elasticity of food. Per capita emissions are lowest for households with children and highest for single households, suggesting considerable economies of scale or variations in food preferences. Employment status also has a weak influence except for unemployment, which is associated with below average food emissions when holding other variables constant.

Consumables

In explaining emissions from all other consumer goods, we find perhaps surprisingly that housing tenure intrudes as a fourth independent variable (using the owner-occupied as our reference category). Yet these four variables are able to explain only 11% of the variation in per capita GHG emissions from consumables. It may be that private rented accommodation is proxying for some other, unobservable value that has a significant impact on emissions. Equivalised income has the greatest effect with little added by the other variables: a £5,000 increase in annual equivalised income causing a 9% increase in emissions. In terms of household types, the number of adults emerges as the only significant determinant. All ‘workless’ households consume and emit significantly less than those with heads in work. In this regression we also find housing tenure to be significant: using owner occupied housing as the reference group, we find that occupants of social housing consume and emit significantly more, when holding other factors constant.

Private services

The standard model explains 33% of emissions from the consumption of private services, such as hotels, eating out etc. Equivalised income has the greatest impact. In terms of household types, the number of adults in the household raises the per capita emissions from services, while having children lowers them. Looking at employment status we again find that workless households consume and emit less than those with employed heads, after taking into account the influence of income and household type.

Domestic energy and housing
The model explains 21% of the variation in emissions from domestic energy and housing. A £5,000 increase in annual equivalised income would cause a 4.3% increase in per capita GHG emissions in this sector. All household types are significantly different from one another, and their coefficients suggest the presence of economies of scale in larger households. Again, households with employed heads consume and emit significantly more than workless households.

3.3 Summary
To summarise, we have identified three variables with significant influence on carbon and GHG emissions per person arising from households' private consumption: income (equivalised), household composition and employment status. The influence of other variables correlating with emissions (household size, tenure and hours of work) disappears in the regressions, with the two exceptions noted in Table 13; other regressions tested are listed in Appendix 1. There are no doubt other significant variables which we cannot track with the EFS data at our disposal.

This 'standard' model explains 35% of variation in total emissions. Income is the dominant explanans: there can be little doubt that growing income inequality in Britain has widened the emissions gap. Household size varies inversely with per capita emissions illustrating economies of scale in consumption, but this is absorbed into the influence of our seven categories of household composition. The regression echoes the patterns in Figure 3: single person households are highest, followed by two-person households, followed by households with children. This raises issues concerning the 'emission claims' of children, discussed below in section 5. Employment status is ambiguous and not always significant; but non-retired 'workless' households emit significantly lower amounts than working households when income and composition is controlled. This provides some support for the first hypothesis discussed earlier: that work-rich households would spend more on commuting and may substitute purchased commodities and services for household production which might be expected to raise their carbon emissions.

When we discriminate between direct and indirect emissions, the standard model continues to apply. Income is dominant in both, supporting the pattern in Table 3 which shows similar ratios between the emissions of the top and bottom deciles for both categories. However, our model explains notably more of the variation in indirect emissions (34%) than direct (22%).

When we discriminate more finely between categories of consumption and the GHG emissions stemming from them, the regressions point to three broad groups. First, the standard model performs well in explaining emissions from *services*, explaining 33% of their variation. Other than income, the presence of a working head of household and the number of adults in the household boosts the consumption of private services and their accompanying emissions.

The model works well but explains somewhat less in the case of emissions from *transport* (26%) and *domestic energy and housing* (21%), but in other respects these are rather different. Income is a very powerful driver of transport emissions; and single adult households and two-earner households are also significantly higher emitters. But emissions from domestic energy and housing vary less with income and are significantly boosted by low household size and the presence of employed adults.

The model explains much less in the third group, comprising emissions from *food* (10% of variation) and *consumer goods* (11%). The income elasticity of food is lower than for consumables and the categories differ in other ways. These poor results may be explicable due to the assumption that any expenditure category has a uniform level emissions, with no account taken of price or quality. Or other factors which we cannot identify must intervene to explain these forms of GHG emission.

4. The ratio of emissions to income: further distributional issues

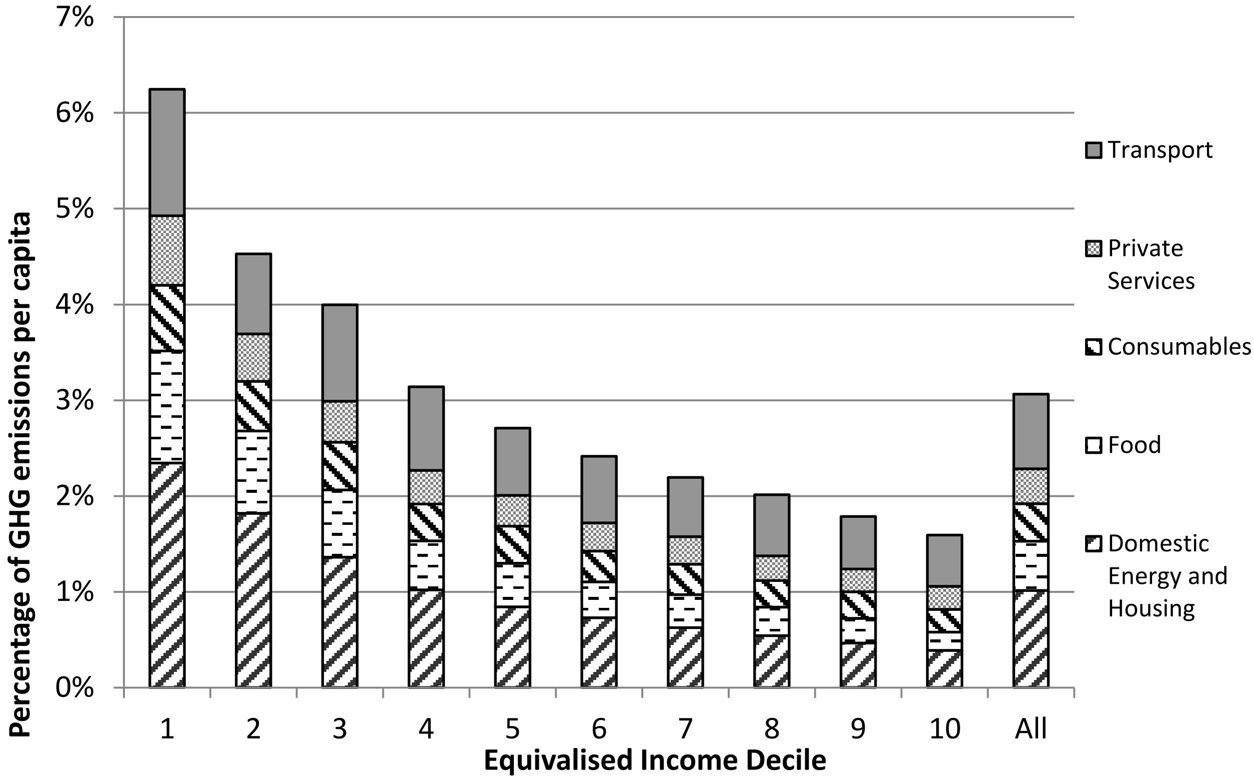
If we are concerned with the distributional implications of policies to reduce carbon emissions, we must go beyond total emissions per person to consider the ratio of emissions to income. Dividing average household emissions from all private consumption by average household incomes yields a figure of 3.1 grams CO2e per £ of income.

Table 14 and Figure 8 then disaggregate this figure by income decile and source of emission. Immediately the picture of rising lines is reversed. All per capita emissions, and all categories of emissions, are greatest in relation to income in the lowest income decile and fall as income rises. This simply reflects the fact that inequality in incomes far exceeds inequality in expenditures. The decline with income is especially acute for domestic energy and housing and food emissions, ‘necessary’ expenditures with a lower income elasticity of demand. All income elasticities are less than 1, but especially so for necessities. But for all our categories there is a clear inverse relationship with income and overall the lowest decile emits four times as much in relation to its income as the highest.

Table 14: Per capita GHG emissions by source as proportion of income: grams CO2e per £

Sector	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	***Average***	***10:1 Ratio***
Domestic Energy and Housing	2.34	1.82	1.36	1.02	0.84	0.73	0.63	0.54	0.46	0.39	*1.01*	*0.17*
Food	1.17	0.86	0.70	0.51	0.45	0.37	0.34	0.30	0.26	0.19	*0.52*	*0.16*
Consumables	0.69	0.52	0.50	0.39	0.39	0.32	0.32	0.28	0.28	0.24	*0.39*	*0.34*
Private Services	0.73	0.50	0.43	0.35	0.32	0.29	0.29	0.26	0.24	0.24	*0.36*	*0.33*
Transport	1.32	0.84	1.01	0.88	0.70	0.70	0.62	0.64	0.55	0.54	*0.78*	*0.41*
Other	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.00	*0.02*	*0.09*
Total including other	**6.29**	**4.55**	**4.02**	**3.16**	**2.72**	**2.42**	**2.20**	**2.02**	**1.79**	**1.60**	**3.08**	0.25
Mean equivalised income(£/week)	**131**	**212**	**276**	**349**	**431**	**542**	**631**	**763**	**966**	**1441**	**572**	10.98

Figure 8: Per capita GHG emissions per £ of income by income deciles - by sectors



We next regress (the log of) these figures against our different variables – Table 15. Again the same factors as in the standard model do best; indeed the adjusted R^2 increases from .35 to .42.

Table 15: Regression of log per capita emissions per £ of income

Log Per Capita GHG Emissions	Coefficients	Standard Error	T-Statistic
Intercept	-3.12494	0.032	-96.36
Equivalised income	-0.00086	0.000	-43.29
Households with two or more people aged 60+	-0.13555	0.023	-5.90
Households with only one person under 60	0.02588	0.032	0.81
Households with two adults, no children	-0.12882	0.029	-4.38
Single parent households	-0.36312	0.036	-10.21
Households with two+ adults, and children	-0.42225	0.030	-14.23
Households with three+ adults, no children	-0.27472	0.033	-8.26
Part time employed	0.13416	0.024	5.51
Retired	0.13873	0.028	5.02
Self employed	0.20633	0.024	8.77
Unemployed	0.35095	0.048	7.26
Unoccupied	0.31779	0.022	14.13
Adj R^2 =0.421			

It is interesting to compare this result with that presented in Table 11. The income coefficient is now negative but is greater still: a £5000 increase in equivalised income results in an 8.6% reduction in emissions as a share of income. Most of the coefficients for household composition are similar, but those for employment status increase in significance. The signs change for all three groups of 'workless' households - retired, unemployed and unoccupied – indicating that these household types experience higher ratios of emissions to income, compared to households with a head in full-time work. The implication is that any increase in the price of carbon will bear most heavily on low income households, and within these on workless households.

Finally Table 16 extends the findings in Table 13, by comparing the adjusted R^2 for different categories of emission of emissions per head. When we undertake separate regressions against direct and indirect emissions, and for different expenditure categories, we discover some perplexing results. In some cases, the model does better when we take ratios of emissions to income: this is notably so for food, energy and housing, and both direct and indirect emissions. For other categories of emission the model does worse – consumables and services – or much worse – transport.

Table 16: Comparison of adjusted R^2 for different categories of emission

	Emissions	
	Per head	Per £ per head
Direct	0.22	0.32
Indirect	0.34	0.43
Transport	0.26	0.08
Food	0.1	0.4
Consumables	0.12	0.07
Services	0.33	0.24
Energy and housing	0.21	0.46
Total	**0.35**	**0.42**

Summary
This section has studied the ratio of emissions to income, for different categories of household, broken down by income, composition and employment status. The standard model regression works still better in this case explaining 42% of variance. A comparison of the coefficients shows that all three factors impinge more significantly on emissions per £ of income. The income coefficient is now negative but is more powerful. Employment status increases in significance and signs change for all three groups of 'workless' households - retired, unemployed and unoccupied – indicating that these household types emit more carbon per £, when taking other factors into account. The implication is that any increase in the price of carbon will bear most heavily on low income households, and within these on workless households. The earlier findings, that higher carbon prices will bear more heavily on smaller households, also continue to hold.

5. Further thoughts on equity between households and Personal Carbon Allowances

To relate carbon emissions to social justice, redistribution and social policy it is essential to take household composition as well as income into account. The EFS shows that equivalising incomes, as we have done thus far, makes a very big difference to, for example, the number of households with children in the lowest income decile: 41% as opposed to 15% when simply using total household incomes. Yet until now we have measured emissions only *per capita*. This assumes that all persons have the same 'entitlements' to emissions, that a baby counts the same as an adult. In this section we relax that assumption.

This is a particular issue in schemes for Personal Carbon Allowances, which often propose a straight per capita allowance for all adults in the population. In so doing they tend to ignore two issues which are of great salience in social policy: the claims of children and the economies of scale achieved by larger households. When not ignored, it is usually proposed that children are awarded a vague part-allowance (Environmental Audit Committee 2008) or a specific share, such as 1/3 of the adult allowance (Thumin and White 2008) but with little justification for it. Similarly, awarding equal per capita allowances rewards people not living alone due to the economies of consumption, and thus carbon emissions, they achieve. This may well be justifiable as a disincentive to the trend towards smaller household size, but it raises many pertinent social policy issues, notably regarding separation and divorce (see Yu and Liu 2007) on the environmental impacts of divorce).

There is no reference in the climate change mitigation literature to the extensive research on equivalisation in income distribution studies. The most common scales in use in Britain for equating living standards across different household types are the McClements scale and the Modified OECD scale:

	OECD	*McClements*
First adult	1	1
Second and subsequent adults	0.5	0.64-0.75
Children aged 14 years and over	0.5	0.443-0.59*
Children under 14 years	0.3	0.148-0.41

*age 13-18

Using these, the income 'needs' of different households can be estimated; for instance, using the OECD scale a family of two adults, a teenage girl and a younger boy would require an income 2.3 times that of a single person to enjoy the same standard of living. The McClements scale discriminates between children of different ages, but its scales roughly centre around the OECD figures. The main difference occurs in the weighting given to the second adult in a household. The lower OECD figure assumes more economies of scale, apparently following a decline in the share of spending on food over time (see Chanfreau and Burchardt 2008). The HBAI switched to the OECD scale in 2007, and we use this in what follows.

Applying this equivalence scale to carbon would clearly generate PCAs very different from a straight per capita allowance. It would undermine any simple citizenship basis for PCAs by relating entitlements to household arrangements. Since these can change frequently at some stages of life, eg young people and students, it may also be very cumbersome to operate. It would mean that carbon allowances become part of the benefit/ tax credit world with all the problems this would entail. There is much to be said for retaining a simple equal entitlement for all adults whatever their household arrangements. In addition it may act as a small check on the continuing decline in average household size (from 2.9 in 1971 to 2.4 in 2003) - a significant driver of household emissions.[11]

Turning to the allowance for children, there is research to be done on the contribution of a child and two or more children, and of different ages, to household emissions. However, as a starting point we may assume that these track total household expenditure which it is the object of equivalence scales to account for. The OECD scale suggests two things. First, that children over 14 should be entitled to a carbon allowance in their own right. Second, it

11 However, these scales do illustrate that an individualised approach would penalise single person households. One way to overcome this would be to give initially an extra allowance for single person households of say 0.25, rather like the single person's rebate for Council Tax.

suggests that children under 14 should receive a carbon allowance of 30% of the adult allowance.

Here we confront the issue that equivalence scales confound two distinct issues: household economies of scale and equivalences between adults and children of different ages. If we ignore the first in the allocation of carbon allowances, as we suggest, then the contrast between the treatment of extra adults and children is magnified: a 100% allowance for the former and only 30% for the latter. For this reason we propose a 50% carbon allowance for children in this section. This roughly maintains the balance in treatment between an extra adult and an extra child in a household.[12]

We first recompute Table 3 above to show emissions per adult equivalent, assuming that the consumption and emissions of children are 50% of the adult rate. When dividing by these figures the relative emissions of all households with children rise, but noticeably so those of single parent households from 13 tonnes per person to nearly 18 tonnes per equivalent adult (see bottom segment of Table 17).

Next, we regress (log) emissions per adult equivalent in Table 18 below. As might be expected, this reduces the variance between household types, when compared with Table 11. It also reduces the overall explanatory power of the model to 27.5%.

[12] However, we are forced to accept the EFS definition of ‘child’ – anyone under 18 years of age – despite the clear evidence above that those of 14 years and over should rank as adults. This will discriminate against households with teen age children and underestimate their carbon requirements.

Table 17: Emissions per adult equivalent

Household Category	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	***Average***	***10:1 Ratio***
Households, with only one person,aged 60+	12.54	11.85	12.44	15.33	16.46	24.18	21.32	21.36	24.68	32.49	*19.26*	*2.59*
Households with two or more people aged 60+	11.51	10.72	11.23	15.52	14.66	15.05	15.48	16.61	22.82	29.31	*16.29*	*2.55*
Households with only one person under 60	10.59	19.07	14.41	14.64	15.15	16.21	23.64	18.82	21.78	27.25	*18.16*	*2.57*
Households with two adults (including one under 60), no children	9.71	10.59	12.83	12.30	13.15	14.43	15.02	17.82	19.51	24.49	*14.99*	*2.52*
Households with three+ adults, no children	8.92	7.00	10.49	11.57	13.58	12.46	14.01	14.65	16.40	21.17	*13.03*	*2.37*
Households with two+ adults, and children	7.05	7.98	10.41	8.51	9.47	10.01	11.28	12.84	13.25	19.45	*11.02*	*2.76*
Single parent households	6.88	6.50	8.49	9.00	9.88	13.85					*9.10*	
Total Emissions	**8.25**	**9.63**	**11.07**	**11.01**	**11.74**	**12.71**	**13.88**	**15.41**	**17.32**	**23.00**	**13.40**	2.79
Equivalised Households with two+ adults, and children	9.39	10.57	13.59	11.06	12.26	12.95	14.54	16.45	16.94	24.70	*14.25*	*2.63*
Eqivalised Single parent households	10.10	9.59	12.43	12.83	14.29	19.94					*13.20*	
Average (inc equivalised)	**9.05**	**10.44**	**12.09**	**11.93**	**12.76**	**14.00**	**14.97**	**17.26**	**19.05**	**23.88**	**14.61**	**2.67**

Table 18: 'The standard model' with (log) equivalent adult emissions as dependent variable

Log Per Capita GHG Emissions	Coefficients	Standard Error	T-Statistic
Intercept	2.25388	0.029	78.91
Equivalised income	0.00068	0.000	38.80
Households with two or more people aged 60+	-0.08545	0.020	-4.23
Households with only one person under 60	-0.05718	0.028	-2.02
Households with two adults, no children	-0.15563	0.026	-6.01
Single parent households	-0.12762	0.031	-4.08
Households with two+ adults, and children	-0.19329	0.026	-7.40
Households with three+ adults, no children	-0.22513	0.029	-7.69
Part time employed	0.03847	0.021	1.79
Retired	-0.04605	0.024	-1.89
Self employed	0.09418	0.021	4.55
Unemployed	-0.23813	0.042	-5.67
Unoccupied	-0.06725	0.020	-3.40
Adj R^2 =0.275			

Next, we provide an equivalent table to Table 15, which takes emissions per £ as the dependent variable, but this time considers emissions per £ per equivalent adult – see Table 19. This shows a much improved R^2 compared with the earlier table: 41% compared with 27%. The impact of income and employment status again strengthens when we regress emissions per £ of income (compared with Table 15). Again, low income households and workless households are most vulnerable to any rise in carbon costs.

Table 19: Regression of log per equivalent adult emissions per £ of income

Log Per Capita GHG Emissions	Coefficients	Standard Error	T-Statistic
Intercept	-3.11691	0.032	-96.38
Equivalised income	-0.00087	0.000	-43.84
Households with two or more people aged 60+	-0.13449	0.023	-5.87
Households with only one person under 60	0.02299	0.032	0.72
Households with two adults, no children	-0.13035	0.029	-4.45
Single parent households	-0.01040	0.035	-0.29
Households with two+ adults, and children	-0.17524	0.030	-5.92
Households with three+ adults, no children	-0.27570	0.033	-8.32
Part time employed	0.13130	0.024	5.41
Retired	0.13324	0.028	4.83
Self employed	0.20784	0.023	8.86
Unemployed	0.35412	0.048	7.34
Unoccupied	0.31961	0.022	14.25
Adj R^2 =0.408			

Finally we compute separate regressions for different sources of emissions and produce an equivalent to Table 16 above – see Table 20 below.

Table 20: Regression results for emissions per adult equivalent: Adjusted R^2

	Emissions		*Emissions per £*	
	Per head	Per equivalent adult	Per head	Per equivalent adult
Direct	0.22	0.15	0.32	0.29
Indirect	0.34	0.26	0.43	0.42
Transport	0.26	0.25	0.08	0.09
Food	0.1	0.05	0.4	0.4
Consumables	0.12	0.12	0.07	0.08
Services	0.33	0.31	0.24	0.25
Energy and housing	0.21	0.14	0.46	0.45
Total	**0.35**	**0.28**	**0.42**	**0.41**

Calculating emissions per adult equivalent reduces the power of our model in explaining emissions per head – the R^2 declining from -35 to .28. This also applies to regressions against all separate emission sources. However, when we turn to emissions per £, calculating them on a per adult equivalent basis maintains the power of our model with a high R^2 of .41. The pattern of regressions for different emission sources mirrors that of Table 16. Thus we have a powerful and convincing explanation of the distributional effects of carbon emissions, taking a more realistic view of the ‘needs’ of different households. Only emissions from transport and consumables remain inexplicable in terms of our model.

6. The distributional dilemma and some implications for social policies

The distributional dilemma

Previous research into direct household emissions, notably stemming from domestic energy use, found these to be income inelastic and thus perversely distributed: they rise in relation to income as income falls. Current government policy is to rely on emissions trading and 'mandated energy markets', which means that the burden of climate mitigation programmes falls on energy consumers, and ultimately on households – and this is intended. Thus the burden of current carbon policy is regressive, as is admitted by the Climate Change Committee and DECC. *Ceteris paribus*, this will drive up the numbers in 'fuel poverty', currently defined as a situation where a household needs to spend more than 10% of its income on total fuel in order to heat its home to an adequate standard. The research also shows how difficult it is to compensate low income losers because of the heterogeneity of dwellings, their energy efficiency, their level of occupancy, and variations in households' reliance on car transport, among other factors. The dominant programme at present is Winter Fuel Payments for pensioners, which as Boardman (2010, ch.3) and others have shown, are poorly targeted (these issues are discussed in more detail in Marden and Gough 2011). Thus carbon mitigation goals clash with social equity goals and it is difficult to reconcile these with conventional social transfers.

This report analyses the distribution of *all* emissions from household consumption – direct and indirect, domestically produced and imported. This immediately puts direct emissions into perspective: they account for only one-fifth of the total, the remaining four-fifths are embedded in the consumption of all other goods and services. Furthermore, this illustrates the dependence of UK households on goods produced and emissions recorded abroad. UK carbon emissions are one third higher when offshore production of goods we consume is taken into account, and consumption-based emissions of all greenhouse gases are half as high again – one of the widest gaps in the world.

Our analysis confirms but modifies previous findings for direct emissions. *All* forms of consumption expenditure and hence emissions rise with income, but at a lower rate than incomes rise. The emission elasticities of all the large categories that we investigate are less than one. Thus any rise in carbon prices, which is necessary to help mitigate UK emissions in line with agreed carbon budgets, will hurt lower income households more. However the degree of regressivity varies according to the category of private consumption expenditure. Expenditures on, and emissions from, domestic energy and food take a proportionately higher share of incomes lower down the income scale than spending on and emissions from transport, consumer goods and personal services. If a way could be found of raising the price of carbon and greenhouse gases embodied in all consumption goods and services, then the result would still be regressive, but not so regressive as current government policy which operates mainly on the cost of domestic gas and electricity (see below).

Other factors also affect per capita consumption and emissions. Small households emit more per person than larger, due to the absence of economies of scale in consumption. Thus higher carbon prices would penalise pensioners and others living alone. Also they would penalise 'workless' families compared with those in full or part time work. However, we do not find the same degree of heterogeneity in households' carbon emissions as in previous studies, once we control for household size, which should of course be done.

Social policy implications

How can the goals of carbon mitigation and social equity be reconciled? There are four basic options, which could be run in tandem: social transfers, eco-social investment, social energy tariffs, and personal carbon allowances.

The first is to compensate low income families for the higher price rises they face with upward adjustments to social benefits and tax credits. We have seen that previous research into direct carbon emissions finds that such compensation is inequitable and inefficient because even within income deciles dwellings and households are extremely heteorogenous in their energy requirements. These new variables are not easily introduced into existing social transfer programmes since they relate to factors such as urban-rural living, commuting distances, distance from gas supplies and the energy efficiency of dwellings. Many of these situations are due to structural 'lock-in', not unconstrained choice (Jackson and Papathansopoulou 2008). However, we find less variability within income deciles than previous research, for two reasons: we include all emissions, and we adjust for household size. This suggests that adjustments to the upcoming Universal Credit may be able to take account of part of the regressive impact of climate mitigation programmes. Further research would be needed to see how equitable and efficient this could be. One solution would be to uprate the credit using a special low-income price index, which would automatically take some account of the regressive impact of energy price rises.

The second option is to radically expand the programme of eco-social investment, by which I mean large scale investment in household energy efficiency with special help for low income households. These measures could include mass retrofitting of dwellings to reduce energy use, more public transport, provision for cycling and walking, etc. This is a goal of the upcoming Green Deal programme, which is intended to allow households to obtain energy efficiency upgrades at no upfront cost with payment coming though part of the saving in energy bills. Energy companies will be required, under the new Energy Company Obligation (ECO), to help poorer customers and those in hard to treat homes, and to provide basic heating and insulation to the poorest and most vulnerable households (see Marden and Gough 2011 for details). How far this happens remains to be seen. It is likely that any serious inroads into household energy savings would require a level of public investment that would begin to compete fiscally with current, reduced social spending on the welfare state. Advocates of a more radical proposals for Green New Deal would contend that the investment boost would benefit public finances in the longer term, but this would require a shift in current orthodox economic thinking (Nef 2008).

But even if implemented on a radical scale, this would still leave millions of households vulnerable to regressive price rises and potential 'fuel poverty' in the meantime (which could last a long time). The third alternative of social energy tariffs could then be considered in addition: to adjust the current charging policies of utility companies by lowering the marginal costs of initial units of electricity or gas consumed, and raising the marginal costs of successive units. This would recognise the 'basic need' component of the first block of household energy and the progressive choice element in successive units, and thus would be intrinsically progressive. It would also tackle fuel poverty directly since fuel poor households consume below average amounts of electricity and gas (Committee on Climate Change 2008: 409). This would not incentivise higher emissions, merely redistribute the costs from lower to higher emitters. Though this solution has been raised by the Climate Change Committee it would require a radical shift in the pricing policies and regulation of private utility companies – a reversal of the liberalisation and deregulation agenda of the past three decades.

Personal carbon allowances and trading is a fourth way forward. This tackles the distributional dilemma head-on by instituting a form of carbon rationing coupled with trading. There is a wide variety of such proposals, but all entail a cap on a country's total GHG emissions (decreasing year by year) and a division of this amount into equal annual allowances for each adult resident (usually with a lower allowance for each child) (see for example Committee on Personal Carbon Trading 2008). In effect a dual accounting standard and currency is developed – energy has both a money price and a carbon 'price'. Those who emit less carbon than the average could sell their surplus and gain, while higher emitters would pay a market price for their excess. Advocates claim many benefits: a PCAT scheme covering domestic energy, road fuel and air travel would be on average quite progressive; it would make real the carbon rationing required and could bring about behavioural change more directly and quickly. It could be implemented using personal carbon cards and smart metering, though the administrative difficulties should not be underestimated. In effect it would constitute a carbon form of the Basic Income idea, and could have similar benefits by redistributing income while not harming disincentives to work; indeed it would likely have more legitimacy than a basic cash income.

PCAT would be inherently progressive, so overcomes the distributional dilemma inherent in mandated markets and carbon taxation. However, alongside the daunting political challenges, it raises similar issues of fairness to carbon taxation, concerning those living in inefficient or underutilised housing, or dependent on car travel, or with special needs. Too many exceptions to the standard allowance could undermine the scheme, but too few would result in 'rough justice', which could undermine public support. For these and other reasons the UK government abandoned its plans for testing the idea in 2009.

Conclusion

Yet it is a paradox that all except the first policy option share a common denominator: they are directed towards direct carbon emissions, not to the much broader swathe of indirect emissions from all personal consumption (even PCAT schemes usually target domestic energy and transport, and it is difficult to see how they could be extended to include the carbon content of supermarket goods and the myriads of services). If we wish to target all embodied greenhouse gases, there are two alternatives: broader carbon taxes and a broad-based upstream cap and trade system. Various proposals for carbon taxation could yield more equitable outcomes, but this will depend on how the revenue is spent and how wide is the carbon tax net – the inclusion of aviation, in particular, improves its progressivity (Green Fiscal Commission 2009). However, revenues from 'green' taxes are low and falling as a share of GDP in the UK and most other countries, a side-effect perhaps of dominant neoliberal thinking. If we want to move seriously to tracking and curbing total carbon *consumption* within the country, and not simply carbon production, this will require charging or taxing the carbon content of imports (presumably from outside the EU). Some system of 'border levelling' would be necessary, to track and tax embodied carbon crossing borders. This is difficult and would require some rewriting of WTO rules.

This leaves the EU ETS cap and trade system which has many defects but targets about half of all industry and will thus in time raise the embodied carbon costs over a wider range of goods and services (Gough 2011). Our research here suggests the effect of this would be somewhat less regressive than the current system. Combined with a Universal Credit linked to a low income price index, and in combination with social tariffs and eco-social investment, this could provide the most effective means of combining carbon mitigation and social equity.

Postscript: Carbon and the welfare state

The public services of the welfare state also emit carbon and greenhouse gases. This report has focused on private consumption and emissions, but as Table 3 shows, the state sector emits 1.8 tonnes CO2e per head per year, a 13% addition to private household emissions. About one third of this is emitted by the NHS and another sixth by education and social work services. However, the distributional pattern of welfare services is directly the opposite: because of its redistributive nature, the emissions apportioned to lower income groups are higher (and higher still as a share of income). Tackling public sector emissions will entail developing green public procurement and altering modes of service delivery (SDC 2008) – but that is another story!

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Appendix

Table A1.1 : The EFS split by equivalised income decile and household composition

	Equivalised Income Deciles										
Household category	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	***All***
Households, with only one person,aged 60+	76	256	188	151	95	72	52	45	26	23	*984*
Households with two or more people aged 60+	54	141	179	145	123	88	62	53	46	44	*935*
Households with only one person under 60	147	44	47	41	51	87	77	91	127	122	*834*
Households with two adults (including one under 60), no children	75	57	78	66	95	125	171	193	199	247	*1,306*
Households with three+ adults no children	28	21	36	40	70	59	76	59	65	26	*480*
Households with two+ adults and children	132	103	128	199	222	202	192	190	144	137	*1,649*
Single parent households	177	58	53	47	39	28	17	16	14	8	*457*
All	**689**	**680**	**709**	**689**	**695**	**661**	**647**	**647**	**621**	**607**	**6,645**

Table A1.2 : Employment status and income decile

Employment Status	Equivalised Income Deciles										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	***All***
Full Time	17	22	90	189	308	373	433	450	484	445	281
Part Time	48	60	86	92	82	64	40	44	33	28	577
Self Employed	43	38	47	52	65	62	58	60	44	84	553
Unemployed	83	14	7	3	6	2	2	1	2	3	123
Retired, unoccupied over minimum NI pension age	124	398	372	276	206	123	93	68	42	35	1,737
Unoccupied, under minimum NI pension age	374	148	107	77	28	37	21	24	16	12	844
All	**689**	**680**	**709**	**689**	**695**	**661**	**647**	**647**	**621**	**607**	**6,645**

Table A1.3 : Usual hours worked and income decile

Usual Hours Worked	Equivalised Income Deciles										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average**
0 hours worked	577	558	486	356	240	162	117	93	59	50	2,698
1 to 30 hours worked	54	62	83	81	79	64	39	46	33	41	582
30 to 40 hours worked	19	24	61	126	199	250	269	301	325	277	1,851
40+ hours worked	39	36	79	126	177	185	222	207	204	239	1,514
All	**689**	**680**	**709**	**689**	**695**	**661**	**647**	**647**	**621**	**607**	**6,645**

Table A1.4 : Household size

Household Size	Equivalised Income Deciles										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average**
1 person household	223	300	235	192	146	159	129	136	153	145	1,818
2 person household	210	224	279	237	235	224	245	259	251	296	2,460
3 person household	120	58	68	98	120	113	128	115	120	87	1,027
4 person household	64	49	76	92	134	122	108	105	79	62	891
5 or more person household	72	49	51	70	60	43	37	32	18	17	449
All	**689**	**680**	**709**	**689**	**695**	**661**	**647**	**647**	**621**	**607**	**6,645**

Table A1.5 : Tenure

Household Tenure	Equivalised Income Deciles										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average**
Social Housing	126	126	130	122	120	95	103	113	111	83	1,129
Private Housing	82	75	79	73	78	71	70	66	69	66	729
Owner Occupied Housing	481	479	500	494	497	495	474	468	441	458	4,787
All	**689**	**680**	**709**	**689**	**695**	**661**	**647**	**647**	**621**	**607**	**6,645**

Table A1.6 : Total emissions: correlations with income and household size

Correlation Coefficients:	Equivalised Income	Household Size
Direct Emissions	0.3427	-0.3057
Indirect Emissions	0.5038	-0.2559
Sectors:		
Transport	0.4591	0.0619
Food	0.1824	-0.1697
Consumables	0.3305	0.0117
Private Services	0.5466	-0.1333
Domestic Energy	0.1286	-0.4767
Other Housing	0.2344	-0.1189
Total Emissions	0.5016	-0.2749

Table A1.7 : T-Test (2-tailed significance) for equality of means

Household Composition	hh1	hh2	hh3	hh4	hh5	hh6
hh2	1.1*					
hh3	3.5***	2.4**				
hh4	-6.8***	-7.9***	-10.3***			
hh5	14.1***	12.9***	10.6***	20.9***		
hh6	-13.1***	-14.3***	-16.7***	-6.3***	-27.4***	
hh7	13.3***	12.2***	9.9***	20.1***	-0.8*	26.7***

HRP Employment Status	Full Time	Part Time	Self Employed	Unemployed	Retired
Part Time	43.5***				
Self Employed	44.3***	0.7*			
Unemployed	62.5***	17.6***	16.9***		
Retired	16.2***	-25.2***	-25.9***	-42.1***	
Unoccupied	35.5***	-7.1***	-7.8	-24.2***	17.9***

Housing Tenure	Owner Occupied	Private Housing
Private Housing	73.8***	
Social Housing	58.7***	-9.4***

Household Employment status	Adult 1 & 2 employed	Adult 1& 2 without work	Employed & Unemployed	Single hh employed
Adult 1& 2 without work	18.9***			
Employed & Unemployed	20.8***	1.8*		
Single hh employed	22.9***	3.8***	2.1*	
Single hh without work	14.9***	-3.9***	-5.6***	-7.7***

Note: * Statistically significant at p=<0.5, ** Statistically significant at p=<0.01, *** Statistically significant at p=<0.001

Regressions of Logged Total Emissions, Logged Emissions per £ of Income & Logged Equivalised Emissions on:

1 Variable -

- Equivalised Income
- Household Size
- Household Type
- Employment Status
- Housing Tenure
- Usual Hours Worked
- Other Employment Status

2 Variables -

- Equivalised Income & Household Type
- Equivalised Income & Household Size
- Equivalised Income & Employment Status
- Equivalised Income & Household Tenure
- Equivalised Income & Usual Hours Worked
- Equivalised Income & Other Employment Status

3 Variables -

- Equivalised Income, Household Type & Employment Status
- Equivalised Income, Household Type & Household Tenure
- Equivalised Income, Household Type & Usual Hours Worked
- Equivalised Income, Household Size & Employment Status
- Equivalised Income, Household Size & Household Tenure
- Equivalised Income, Household Size & Usual Hours Worked
- Equivalised Income, Household Tenure & Employment Status
- Equivalised Income, Household Tenure & Usual Hours Worked
- Equivalised Income, Usual Hours Worked & Employment Status
- Equivalised Income, Household Type & Other Employment Status
- Equivalised Income, Household Size & Other Employment Status
- Equivalised Income, Household Tenure & Other Employment Status
- Equivalised Income, Usual Hours Worked & Other Employment Status

4 Variables -

- Equivalised Income, Household Type, Employment Status & Household Tenure
- Equivalised Income, Household Size, Employment Status & Household Tenure
- Equivalised Income, Household Type, Other Employment Status & Household Tenure
- Equivalised Income, Household Size, Other Employment Status & Household Tenure

Regressions of Logged Direct Emissions on:

- Equivalised Income, Household Type, Employment Status & Household Tenure
- Equivalised Income, Household Type, Other Employment Status & Household Tenure

Regressions of Logged Indirect Emissions on:

- Equivalised Income, Household Type, Employment Status & Household Tenure
- Equivalised Income, Household Type, Other Employment Status & Household Tenure

Regressions of Logged Transport Sector Emissions on:

- Equivalised Income, Household Type, Employment Status & Household Tenure
- Equivalised Income, Household Type, Other Employment Status & Household Tenure

Regressions of Logged Food Sector Emissions on:

- Equivalised Income, Household Size, Employment Status & Household Tenure
- Equivalised Income, Household Size, Other Employment Status & Household Tenure

Regressions of Logged Commercial Sector Emissions on:

- Equivalised Income, Household Size, Employment Status & Household Tenure
- Equivalised Income, Household Size, Other Employment Status & Household Tenure

Regressions of Logged Private Services Sector Emissions on:

- Equivalised Income, Household Type, Employment Status & Household Tenure
- Equivalised Income, Household Type, Other Employment Status & Household Tenure

Regressions of Logged Domestic Energy and Other Housing Sector Emissions on:

- Equivalised Income, Household Type, Employment Status & Household Tenure
- Equivalised Income, Household Type, Other Employment Status & Household Tenure

Further regression results

Table A2.1: The effect of equivalised income, household composition and HRP employment status on logged direct per capita emissions

Log Per Capita GHG Emissions	Coefficients	Standard Error	T-Statistic
Intercept	0.8145	0.043	19.10
Equivalised income	0.0006	0.000	22.98
Households with two or more people aged 60+	-0.1745	0.030	-5.79
Households with only one person under 60	-0.0327	0.043	-0.77
Households with two adults, no children	-0.2957	0.039	-7.64
Single parent households	-0.6615	0.048	-13.86
Households with two+ adults, and children	-0.6535	0.039	-16.75
Households with three+ adults, no children	-0.3535	0.044	-8.08
Part time employed	-0.0282	0.032	-0.88
Retired	-0.1177	0.036	-3.24
Self employed	0.0672	0.031	2.19
Unemployed	-0.2451	0.068	-3.59
Unoccupied	-0.1468	0.030	-4.87
Adj R^2 =0.221			

Table A2.2: The effect of equivalised income, household composition and HRP employment status on logged indirect per capita emissions

Log Per Capita GHG Emissions	Coefficients	Standard Error	T-Statistic
Intercept	1.971	0.028	70.11
Equivalised income	0.001	0.000	39.74
Households with two or more people aged 60+	-0.067	0.020	-3.37
Households with only one person under 60	-0.040	0.028	-1.44
Households with two adults, no children	-0.119	0.025	-4.67
Single parent households	-0.419	0.031	-13.60
Households with two+ adults, and children	-0.388	0.026	-15.09
Households with three+ adults, no children	-0.191	0.029	-6.64
Part time employed	0.055	0.021	2.62
Retired	-0.021	0.024	-0.87
Self employed	0.089	0.020	4.37
Unemployed	-0.182	0.041	-4.41
Unoccupied	-0.032	0.019	-1.63
Adj R^2 =0.337			

Table A2.3: The effect of equivalised income, household composition and household employment status on logged per capita emissions in the transport sector

Log Per Capita GHG Emissions	Coefficients	Standard Error	T-Statistic
Intercept	1.0064	0.882	1.14
Equivalised Income	0.0010	0.000	27.93
Households with two or more people aged 60+	-0.5913	0.882	-0.67
Households with only one person under 60	0.1367	0.051	2.70
Households with two adults, no children	-0.6735	0.882	-0.76
Single parent households	-0.1335	0.055	-2.45
Households with two+ adults, and children	-0.8402	0.882	-0.95
Households with three+ adults, no children	-0.4900	0.881	-0.56
2 Adult households			
Neither in paid employment	-0.2429	0.045	-5.37
One in employment, one not	0.0005	0.035	0.02
1 Adult households			
In work	-0.8884	0.882	-1.01
Out of work	-1.3210	0.881	-1.50
Adj R^2 =0.259			

Table A2.4: The effect of equivalised income, household composition and HRP employment status on logged per capita emissions in the food sector

Log Per Capita GHG Emissions	Coefficients	Standard Error	T-Statistic
Intercept	0.36179	0.042	8.56
Equivalised income	0.00035	0.000	13.37
Households with two or more people aged 60+	0.16096	0.030	5.38
Households with only one person under 60	-0.08954	0.042	-2.14
Households with two adults, no children	0.01964	0.038	0.51
Single parent households	-0.35997	0.046	-7.77
Households with two+ adults, and children	-0.26157	0.039	-6.76
Households with three+ adults, no children	-0.06447	0.043	-1.49
Part time employed	0.02385	0.032	0.75
Retired	0.08570	0.036	2.38
Self employed	0.07081	0.031	2.31
Unemployed	-0.18351	0.062	-2.95
Unoccupied	0.03133	0.029	1.07
Adj R^2 =0.101			

Table A.25: The effect of equivalised income, household composition, HRP employment status and housing tenure on logged per capita emissions in the consumables sector

Log Per Capita GHG Emissions	Coefficients	Standard Error	T-Statistic
Intercept	-0.43429	0.076	-5.68
Equivalised income	0.00087	0.000	19.96
Households with two or more people aged 60+	0.30006	0.050	5.94
Households with only one person under 60	0.02703	0.071	0.38
Households with two adults, no children	0.23923	0.065	3.70
Single parent households	-0.12320	0.078	-1.58
Households with two+ adults, and children	0.02251	0.065	0.34
Households with three+ adults, no children	0.16603	0.073	2.27
Part time employed	0.09856	0.054	1.84
Retired	-0.22254	0.061	-3.66
Self employed	-0.02278	0.052	-0.44
Unemployed	-0.30184	0.105	-2.88
Unoccupied	-0.09964	0.049	-2.02
Private housing	-0.08007	0.036	-2.20
Social housing	-0.02212	0.052	-0.42
Adj R^2 =0.124			

Table A2.6: The effect of equivalised income, household composition and HRP employment status on logged per capita emissions in the private services sector

Log Per Capita GHG Emissions	Coefficients	Standard Error	T-Statistic
Intercept	-0.074	0.035	-2.10
Equivalised income	0.001	0.000	39.83
Households with two or more people aged 60+	-0.089	0.025	-3.56
Households with only one person under 60	0.130	0.035	3.74
Households with two adults, no children	-0.063	0.032	-1.98
Single parent households	-0.275	0.039	-7.12
Households with two+ adults, and children	-0.248	0.032	-7.69
Households with three+ adults, no children	-0.049	0.036	-1.37
Part time employed	0.011	0.026	0.41
Retired	-0.126	0.030	-4.19
Self employed	0.069	0.026	2.71
Unemployed	-0.182	0.052	-3.51
Unoccupied	-0.110	0.024	-4.52
Adj R^2 =0.333			

Table A2.7: The effect of equivalised income, household composition and HRP employment status on logged per capita emissions in the domestic energy and housing sector

Log Per Capita GHG Emissions	Coefficients	Standard Error	T-Statistic
Intercept	1.366	0.038	35.63
Equivalised income	0.000	0.000	18.43
Households with two or more people aged 60+	-0.347	0.027	-12.79
Households with only one person under 60	-0.283	0.038	-7.46
Households with two adults, no children	-0.465	0.035	-13.37
Single parent households	-0.674	0.042	-16.04
Households with two+ adults, and children	-0.725	0.035	-20.67
Households with three+ adults, no children	-0.651	0.039	-16.57
Part time employed	0.020	0.029	0.70
Retired	0.070	0.033	2.13
Self employed	0.107	0.028	3.85
Unemployed	-0.239	0.057	-4.22
Unoccupied	-0.079	0.027	-2.99
Adj R^2 =0.208			