MAPPING OUR CARBON RESPONSIBILITIES: MORE KEY RESULTS FROM THE SURREY ENVIRONMENTAL LIFESTYLE MAPPING (SELMA) FRAMEWORK

by

Angela Druckman and Tim Jackson

RESOLVE Working Paper 02-09

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Abstract

If we are to successfully design policies to move towards lower carbon lifestyles, we need to understand who should take responsibility for the carbon emissions that arise in the production and distribution of goods and services. In this paper we argue that, in contrast to conventional accounting practices, consumers should take responsibility. By taking this stance, we show that the commonly cited reports that the UK is making good progress in reducing its greenhouse gas (GHG) emissions are misleading. This is because the conventional production perspective accounts mask the effect of off-shoring GHG-intensive industries. In this paper we show that, using the consumption perspective, the UK's emissions were 7% higher (60mtCO2e) in 2004 than they were in 1990 and that they were rising by around 3% per annum between 2000-04.

Households are responsible for over three quarters of UK GHG emissions when measured this way. Our paper therefore proceeds to explore what household activities give rise to the highest and lowest quantities of GHGs. We also look at the relative quantities of GHGs that are produced per unit of monetary expenditure. Not surprisingly the categories of direct energy expenditure (gas, electricity and transport fuels) have the highest values of GHG intensity (GHG/£). Food and other transport also have relatively high GHG intensities. This information is useful as a basis for devising policy measures to shift to lower carbon consumption patterns.

Keywords: Carbon footprint; Environmental Input-Output; household consumption; carbon intensity of household expenditure.

1 Introduction

The UK has passed into law the Climate Change Act which sets a legally binding target for the UK to reduce greenhouse gas emissions by at least 80% below 1990 levels by 2050 (HM Government 2008). The Act also established the Committee on Climate Change, which is an independent, expert body whose role is to advise Government on setting and meeting carbon budgets. The Committee has recommended that the UK should reduce emissions of all greenhouse gases by at least 34% in 2020 relative to 1990 levels, and that this should be increased to 42% relative to 1990 once a global deal to reduce emissions is achieved (CCC 2008). These targets apply to UK emissions on a territorial production basis, and include all emissions that occur in the UK regardless of the destination of final goods and services in the production of which they arise. Accounting for emissions in this way is known as accounting from the 'production perspective', and is the perspective that is used in assessing emissions for the purposes of the Kyoto Treaty (UN 2004).

Alongside the Climate Change Act and its related targets, the UK's sustainable development strategy "Securing the Future" (HM Government 2005) has a "One Planet Economy" as one of its principles. This document states "*There would be little value in reducing environmental impacts within the UK if the result were merely to displace those impacts overseas*" (HM Government 2005: page 43). This means that the UK recognises that achieving the Climate Change Act targets through off-shoring its heavy, GHG intensive industries to other countries is not an acceptable way forward. However, no targets have been set to guide the extent to which the UK exports its heavy industries in future, and methods of measuring the GHGs required to support UK consumption have not been formalised.

The way to fill this gap is to account for GHG emissions from a perspective known as the 'consumption perspective'. According to this perspective emissions that arise in the production and distribution of goods and services are attributed to final consumers, regardless of the location where the emissions arise. Thus in the consumption perspective we take account of emissions embedded in imports but exclude those embedded in exports, whereas in the production perspective we take account of emissions embedded in exports and exclude those embedded in imports. The difference between the two is known as the 'carbon trade balance' and is a measure of the extent to which the UK has "off-shored" its GHG intensive industries. In the first part of this paper we compare trends of emissions for the UK 1990-2004 from these two perspectives and examine the trend in the carbon trade balance.

Conventional GHG reporting and climate policies follow the production perspective. However the consumption perspective is widely considered to be a more appropriate method for assessing the emissions for which each nation must take responsibility (Bastianoni et al. 2004; Druckman et al. 2008; Jackson et al. 2007; Munksgaard and Pedersen 2001; Peters and Hertwich 2006). Hence in the second part of the paper we use the consumption perspective.

Using this perspective the highest final demand category is households: in fact results shown later in this paper estimate that over three quarters of consumption-based GHGs are attributed to households, the remainder being attributed to Government and capital investment. It is therefore imperative that we start to understand the drivers of the emissions of GHGs attributed to households if we are to make true reductions in the UK's GHG emissions. In pursuit of this goal, in the second part of this paper we investigate which categories of household expenditures give rise to the highest and lowest quantities of GHGs. We also look at the relative quantities of GHGs that are produced per unit of monetary expenditure in various categories of expenditure. This gives us an insight into which activities are most carbon intensive, and is useful as a basis for discussions concerning potential shifts to less GHG-intensive lifestyles.

The results reported in this paper are calculated using the Surrey Environmental Lifestyle MApping (SELMA) framework. SELMA is a framework that accounts for resource use (such as energy use) and associated emissions (such as greenhouse gases (GHGs)) from the consumption perspective. SELMA is the subject of on-going work in the ESRC Research Group on Lifestyles, Values and Environment (RESOLVE) at the University of Surrey. In this paper we report results obtained by applying SELMA to GHG emissions, whereas previous publications based on findings from SELMA have focused on carbon dioxide emissions and wastes (Bradley et al. 2006; Bradley et al. 2007; Druckman et al. 2008; Druckman and Jackson 2007; Druckman and Jackson 2008; Druckman and Jackson 2009; Jackson et al. 2006; Jackson et al. 2007).

The organisation of this paper is as follows. The Methodology section (Section 2) first describes the quasi-multi-regional environmentally extended input-output (QMRIO) model that is incorporated in SELMA in order to account for national GHG emissions from the consumption perspective (Section 2.1). Section 2.2 focuses on household consumption. The categories of expenditure that are used as a basis for analysis of GHG emissions attributed to households from the consumption perspective are described. Two categorisation systems are used: the first is based on the United Nations COICOP classification (UN 2005); the second allocates emissions to high level functional uses. The methods used for allocating emissions to these categories are explained. Following this we explain how quantities of GHGs that are produced per unit of monetary expenditure are estimated. The findings are presented in Section 3, starting with a comparison of the trends in UK GHG emissions estimated using the production and consumption perspectives (Section 3.1). Estimates of GHG emissions due to each of the various types of household expenditure are presented in Section 3.2. A discussion of the policy implications of this work are discussed in Section 4.

2 Methodology

2.1 Accounting from the production and consumption perspectives

In Section 1 the concept of accounting from the production and consumption perspectives was introduced. Accounting from the production perspective is relatively straightforward for the purposes of this work, as UK GHG emissions[1] are taken from the Environmental Accounts (ONS 2008). Accounting from the consumption perspective is based on Environmental Input-Output (EIO) analysis. Equation 1 is the fundamental EIO equation.

$$\mathbf{c} = \mathbf{u}'(\mathbf{I} - \mathbf{A})^{-1}\hat{\mathbf{y}} \tag{1}$$

where

c is the vector GHG emissions attributable to final demand expenditure;
u is the vector of GHG emissions intensity; **u′** is the transpose;
I is an identity matrix;
A is the matrix of technology coefficients. (**I**-**A**)$^{-1}$ is known as the 'Leontief Inverse';
$\hat{\mathbf{y}}$ is a diagonilised vector of final demand expenditure (households; Not for Profit Institutions Serving Households (NPISH); government; fixed capital).

Equation 1 applies to a closed economy (in other words, an economy that has no imports or exports). The UK is, however, a relatively open economy and therefore it is important, when accounting from the consumption perspective, to take trade into account. This is done by extending equation (1) to enable imports to be accounted for (exports are excluded as explained in the Background section). In this paper we apply a Quasi-Multi-Regional Input-Output (QMRIO) model which groups all the countries from which the UK receives imports into 12 world regions (see Appendix 1). In this model, while the UK Leontief inverse matrix is used to model the industry structure of each region, each region is characterised by a vector of GHG emissions intensities that reflects the industry of that region. The QMRIO model is defined by equations (2) to (4).

$$\mathbf{c}^{\mathbf{P}} = \mathbf{u}^{\mathbf{1}'}(\mathbf{I} - \mathbf{A})^{-1}\hat{\mathbf{y}}^{\mathbf{11}} \tag{2}$$

$$\mathbf{c}^{\mathbf{Q}} = \sum_{n=2}^{n=13}\left(\hat{\mathbf{u}}^{\mathbf{n1}}\mathbf{u}^{\mathbf{1}}\right)'(\mathbf{I} - \mathbf{A})^{-1}\left(\mathbf{P}^{\mathbf{n1}}.\mathbf{B}^{\mathbf{imp}}\right)(\mathbf{I} - \mathbf{A})^{-1}\hat{\mathbf{y}}^{\mathbf{11}} \tag{3}$$

$$\mathbf{c}^{\mathbf{R}} = \sum_{n=2}^{n=13}\left(\hat{\mathbf{u}}^{\mathbf{n1}}\mathbf{u}^{\mathbf{1}}\right)'(\mathbf{I} - \mathbf{A})^{-1}\hat{\mathbf{y}}^{\mathbf{imp}}\hat{\mathbf{p}}^{\mathbf{n1}} \tag{4}$$

where

[1] In this paper "GHG emissions" refers to a basket of six GHGs: Carbon dioxide, methane, nitrous oxide, hydro-fluorocarbons, perfluorocarbons and sulphur hexafluoride.

$\mathbf{c}^{\mathbf{P}}$ are the GHGs associated with the flow of goods produced in the UK to meet final demand in the UK;

$\mathbf{c}^{\mathbf{Q}}$ are the GHGs associated with the flow of goods produced in the 12 non-UK world regions to meet intermediate demand in the UK for goods destined for final demand in the UK;[2]

$\mathbf{c}^{\mathbf{R}}$ are the GHGs associated with the flow of goods produced in the 12 non-UK world regions to meet UK final demand;

$\mathbf{u}^{\mathbf{n1}}$ is the vector of the relative intensity of GHG coefficients for region n compared to region 1;

$\mathbf{y}^{\mathbf{11}}$ is the vector of final demand for commodities produced and consumed in region 1 (the UK);

$\mathbf{y}^{\mathbf{imp}}$ is the vector of final demand for commodities produced in the 12 non-UK world regions and consumed in the UK;

$\mathbf{p}^{\mathbf{n1}}$ is the vector of the proportion of imports from region n to region 1;

$\mathbf{P}^{\mathbf{n1}}$ is a square matrix formed by replicating vector $\mathbf{p}^{\mathbf{n1}}$;

$\mathbf{B}^{\mathbf{imp}}$ is the Imports Use Matrix for imports to the UK from the 12 non-UK world regions.

These equations give us the emissions embedded in goods and services purchased by UK final demand, to which we need to add direct emissions from fuel used directly by households such as gas for heating and cooking and personal transport fuels. These are obtained from the Environmental Accounts (ONS 2008).

Further details of the methodology and data sources are described in Druckman and Jackson (2008) and (2009). The assumptions and limitations are covered in detail elsewhere (Druckman et al. 2008; Druckman and Jackson 2008; Druckman and Jackson 2009) and are therefore not repeated. It is, however, important to point out here that the major limitation in this study is use of the 1995 A-matrix of technology coefficients. This is because the most recent set of UK Input-Output Analytical Tables (from which the A-matrix is taken) are for the year 1995 (ONS 2009). A detailed discussion of the uncertainties that this causes is given in Druckman et al (2008). Nevertheless, although our study suffers limitations, comparison of the SELMA's results with those from other studies (which suffer from similar data deficiencies) is favourable (see Results section).

2.2 *Estimating emissions attributed to UK households*

In the second part of this paper we use the consumption perspective to consider emissions attributable to UK households only, excluding those attributed to Not for Profit Institutions Serving Households (NPISHs), government and fixed capital[3].

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[2] Note that for accounting purposes this flow must exclude the goods required to produce the demand for exports back to the Rest of the World.

[3] For re-attribution of emissions due to fixed capital expenditure, see Appendix 4.

To estimate embedded emissions we run the QMRIO as given in equations 2-4 with household final demand only. In our analysis of household consumption we are interested in exploring the uses for which households emit GHGs. For this purpose the format of the results from the QMRIO model are not ideal, being in Standard Industrial Classification (SIC). We therefore convert them to Classification of Individual Consumption According to Purpose (COICOP) (UN 2005) which gives uses in twelve functional use categories. As our focus is on GHG emissions we separate out four categories of direct energy use (gas[4], electricity[5], other fuels[4] and personal transportation fuels), making altogether 16 categories of GHG emissions as shown in Table 1.

Table 1: Extended COICOP categories used in this study

COICOP Category	Description
1	Food & non-alcoholic beverages
2	Alcoholic beverages, tobacco, narcotics
3	Clothing & footwear
4.4.1	Electricity
4.4.2	Gas
4.4.3	Other fuels
4.1 - 4.3	Housing
5	Furnishings, household equipment & routine household maintenance
6	Health
7.2.2.1-2	Personal transport fuels
Remainder of 7	Other transport
8	Communication
9	Recreation & culture
10	Education
11	Restaurants & hotels
12	Miscellaneous goods & services

The conversion from SIC to COICOP classifications is carried out based on information given in Table 4 "Households final consumption expenditure by COICOP heading" of the Supply and Use Tables (ONS 2006). Categories are aggregated and disaggregated as necessary to comply with the extended COICOP categories shown in Table 1.

Table 2: High level functional needs categories

High Level Functional Needs Categories
Space heating
Household
Food & catering
Clothing & footwear
Health & Hygiene
Recreation & Leisure
Education
Communications
Commuting

[4] These categories include small amounts of upstream emissions.
[5] In fact electricity is not strictly a direct energy, as energy is generated at power stations while electricity is itself just an energy carrier. It is, however, included in this category as this is how it is commonly perceived by consumers, and it is subject to household decisions concerning its use and savings in a similar manner to gas.

As stated in Druckman and Jackson (2008) one of the aims of SELMA is to attribute GHG emissions to 'high level functional uses' to give us information on the activities that the GHGs are used to support. As can be seen from Table 1, the extended COICOP categories do not give this information: for example gas can be used for space heating, or for cooking, or to heat water for uses such as bathing or washing clothes. We therefore take our analysis one step further and attribute GHG emissions to the high level functional used previously by Druckman and Jackson (2008; 2009), Carbon Trust (2006), Jackson and Papathanasopoulou (2008) and Jackson et al (2006; 2007). These are shown in Table 2. As explained in these publications, the rationale for these categories is in part to reflect the range of material, social and psychological needs that are associated with modern lifestyles (Jackson 2005; Jackson and Marks 1999). Some of these are basic functional needs for material subsistence, protection and health. Others are associated more with social needs such as communication and education. Others cover a range of social and psychological motivations for leisure, relaxation, and interacting with friends and family. Attribution to the high level functional needs categories is based on the Allocation Chart shown in Appendix 2, and further details of the methodology and data sources are given in Druckman and Jackson (2008; 2009).

In this paper we also explore the relative quantities of GHGs that are produced per unit of monetary expenditure in various categories of expenditure. This is known as the GHG intensity of household expenditure. It is estimated by dividing GHG emissions in each extended COICOP category by household expenditure from Table 4 "Households final consumption expenditure by COICOP heading" of the Supply and Use Tables (ONS 2006). It should be noted that this table gives expenditure as recorded in the National Accounts and which is used in running the QMRIO model. This is not the same as household expenditure published in the Expenditure and Food Survey (ONS various years-a). This is because the National Accounts augment information from the Expenditure and Food Survey with data from additional sources such as the International Passenger Survey, Her Majesty's Revenue and Customs and the National Health Survey (for more details see Appendix B in ONS (2007)).

3 Findings

3.1 Comparison of UK GHG emissions from contrasting perspectives

In this section we compare UK GHG emissions viewed from the two perspectives defined in Section 1.1: the production and the consumption perspective. In Figure 1 the lower line shows UK emissions from the production perspective as reported to the UNFCCC[6] for the purposes of the Kyoto Treaty. Accounting in this way shows that UK GHG emissions were 15% lower in 2004 than they were in 1990. UNFCCC reporting excludes emissions due to international aviation and shipping. When these emissions are added to give us a more complete estimation of emissions from the

[6] United Nations Framework Convention on Climate Change.

production perspective, the picture is less good, with emissions being just 9% lower in 2004 than they were in 1990, as shown by the line marked "Production perspective (according to Environmental Accounts)".

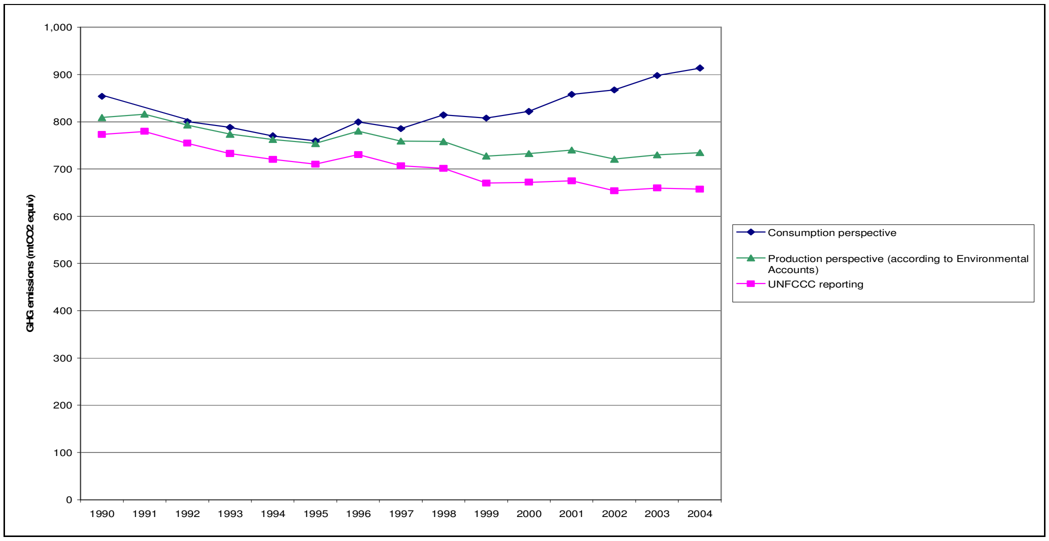

Figure 1: UK GHG emissions according to different accounting perspectives

A marked difference is visible when we compare emissions from the consumption perspective with those from the production perspective. Figure 1 shows that consumption perspective emissions were 854mtCO_2e in 1990 and 914mtCO_2e in 2004, which is a 7% increase. The line shows that although consumption perspective GHG emissions fell between 1990 and 2000, since 1995 they have been rising, and the rate of increase was around 3% p.a. between 2000-04. The graph shows that the GHG trade balance increased from 6% (45mtCO_2e) in 1990 to 24% (179mtCO_2e) in 2004. This indicates that the UK is increasingly "off-shoring" its GHG intensive industries.

When we consider GHG emissions from the consumption perspective, over three quarters of emissions are attributed to households[7] (76% on average 1990-2004) whereas on average 13% is attributed to fixed capital expenditure and 11% to government expenditure. The average GHG intensity is highest for households[8] (0.69kgCO_2e/£) and fixed capital expenditure (0.63kgCO_2e/£) and lower for government expenditure (0.41kgCO_2e/£). For completeness the GHG intensities of expenditures according to Standard Industrial Classification categories is given in Appendix 3.

The results shown in this section are similar to those found in other studies. For example, a study of the UK by Francis (2004) estimated emissions in 2001 to be 612mtCO_2e, which is 6% lower than the 653mtCO_2e estimated in this study. Francis's

[7] Including NPISHs.
[8] Excluding direct fuel use (gas, petrol, diesel and other fuels).

lower estimate is as expected, due to his use of the domestic technology assumption[9]. In a previous study our QMRIO model was used to estimate CO_2 emissions due to energy use (excluding other GHGs) and the trend shown was very similar to that found by Wiedmann et al (2008). Our model gave slightly lower estimates than those by Wiedmann et al (2008) and Peters and Hertwich (2008). This was expected and is due to use of multi-regional input-output (MRIO) models[10] compared to our QMRIO model. Our QMRIO model, however, gave a higher estimate than Ahmad and Wyckoff (2003). For a more detailed discussion concerning this comparison see Druckman and Jackson (2008).

3.2 Emissions attributed to UK households

We now turn our attention to the GHG emissions attributed to UK household expenditure when estimated according to the consumption perspective. The difference here is that the previous section examined emissions due to total UK final consumption which includes NPISHs, government, and capital investment in addition to households, whereas now we look at emissions that arise due to household consumption only.

Figure 2 shows estimates of GHG emissions attributed to household expenditure, classified using the extended COICOP categories. It shows that the direct energy use categories account on average for 38% of the total (Gas 13%; Electricity 11%; Other household fuels 3%; Personal transport fuels 10% [11]). Emissions embedded in products and services account for, on average, the remaining 62%.

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[9] In the domestic technology assumption imported goods are assumed to be produced using the same production recipe and energy use structure as those produced in the UK (Lenzen et al. 2004).

[10] The basic difference between an MRIO model and the QMRIO model is that in a MRIO each region is represented by its Leontief Inverse Matrix. Some MRIO models have bi-lateral trade only, whereas some have multi-lateral trade (Lenzen et al. 2004).

[11] Differences are due to rounding errors

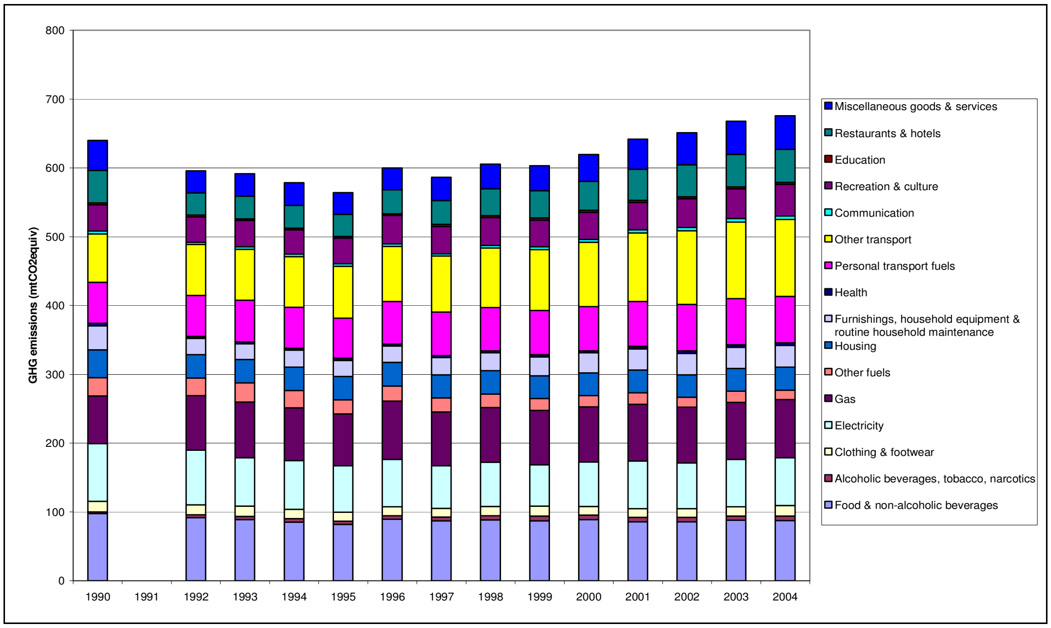

Figure 2: GHG emissions attributed to UK households 1990-2004: extended-COICOP categories

Figure 2 shows a similar trend in overall GHG emissions attributed to households as was apparent for total UK consumption perspective emissions (Figure 1), with again the level rising by around 3% p.a. since 2000. In 2004 the largest categories of GHGs attributed to households were Other transport (which includes aviation) (17%), Food and non-alcoholic beverages (13%) and the categories of direct fuel use, specifically, Gas (13%), Electricity (10%) and Personal transport fuels (10%). Emissions in some categories have reduced since 1990: for example Other fuels has decreased by 48% on 1990 levels but these emissions are only responsible for a very small proportion (mean 3%) of the total and so this has little effect overall. In other categories emissions have increased. The most significant increase is due to Other transport which rose from 11% of the total in 1990 to 17% in 2004, mainly due to increased aviation emissions.

Figure 3 shows the GHGs attributed to high level functional uses as described in Section 2.2 for 2004. The average household footprint is estimated to be 26tCO_2e. The chart shows that the highest quantity of GHG emissions are attributable to Recreation and Leisure, and that this category accounts for a quarter of total emissions. The next highest category is Food and catering (22%). Comparison with the similar pie-chart published in Druckman and Jackson (2009) illustrates the importance of including a range of GHGs rather than simply focusing on carbon dioxide. In Druckman and Jackson (2009) the pie-chart is given for carbon dioxide only, and Food and catering make up just 15% of total emissions. The difference of 7% is due to the generation of other GHGs (in particular methane and nitrous oxide) that arise in the production of food.

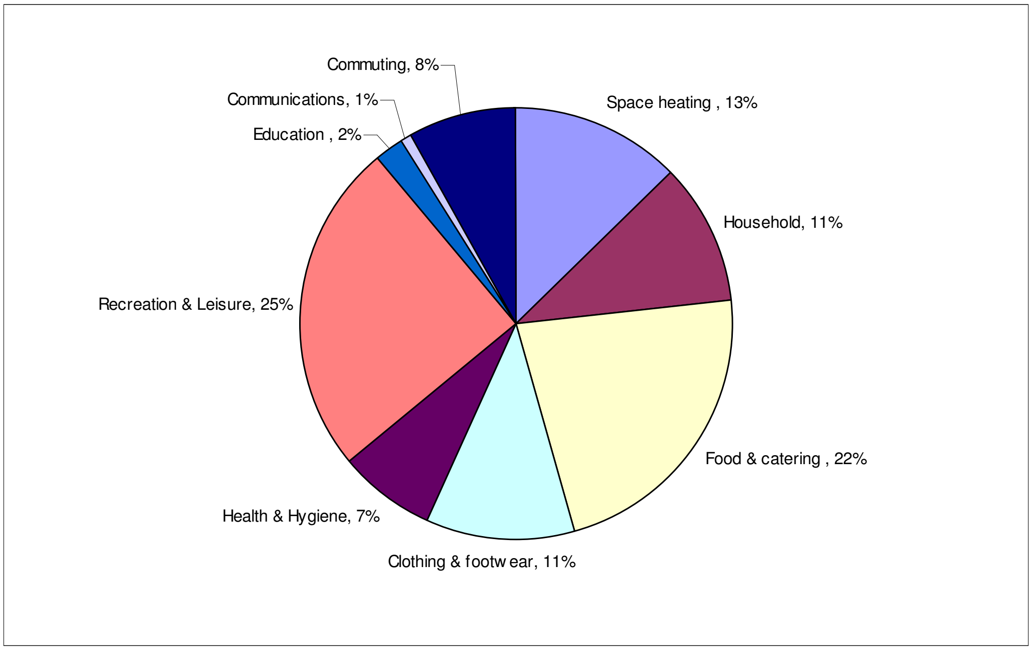

Figure 3: GHG emissions attributed to UK households 2004: high level functional uses

One aspect that we can address through consumption accounting is exploration of the relative GHG intensity of each of expenditure category. In this investigation we once again use the extended COICOP categories as listed in Table 1. The GHG-intensity of each category is shown in Table 3. Not surprisingly, the most GHG intensive categories are Gas; Other fuels; Electricity and Personal transport fuels, meaning that per pound sterling of expenditure these categories are responsible for the highest emissions. These categories are the direct fuel consumption categories that we separated out of the standard COICOP categories, as explained above. The emissions intensities of all other types of expenditures, which give rise to indirect emissions, are all relatively low in comparison.

Table 3: GHG intensity of expenditures (2004)

COICOP Category	Description	Intensity of expenditure (kgCO2-e/£)
4.4.2	Gas	11.3
4.4.3	Other fuels	10.0
4.4.1	Electricity	8.5
7.2.2.1-2	Personal transport fuels	2.6
1	Food & non-alcoholic drink	1.3
Remainder of 7	Other transport	1.3
5	Household goods & services	0.7
12	Miscellaneous goods & services	0.6
11	Restaurants & hotels	0.6
9	Recreation & culture	0.5
3	Clothing & footwear	0.3
8	Communication	0.3
10	Education	0.3
6	Health	0.3
4.1-4.3	Housing	0.3
2	Alcoholic drinks, tobacco, narcotics	0.2

These rankings agree well with those found by Kerkhof et al (2008) in a study of the Netherlands. They also agree well with those found by Symons et al (1994) in a study of the UK, although Symons et al focused on carbon dioxide emissions and therefore food has a lower ranking.

4 Discussion and policy implications

In this paper we have compared trends in UK GHG emissions when measured from two different perspectives: the production perspective (which takes a territorial approach) and the consumption perspective (which attributes all GHGs that support UK consumption to the UK regardless of the country in which the emissions actually arise). Our results show that whereas emissions from the production perspective have *decreased* by 9% between 1990 and 2004 they have *increased* by 7% when measured according to the consumption perspective. Furthermore the rate of increase was around 3% p.a. between 2000-04. Our results also show that the GHG trade balance increased from 6% in 1990 to 24% in 2004. This indicates that the UK has increasingly "off-shored" its GHG intensive industries.

As noted in the Introduction, the UK's sustainable development strategy includes the goal of a "One Planet Economy" but no official measure of its progress towards this is reported. Measurement of consumption perspective GHG emissions demonstrated in this paper fills this gap and although there are uncertainties in our results the trends are, we believe, robust and agree well with results from other studies. Our results show that from this perspective the trend is the reverse of what is required. This may be politically un-palatable. Indeed, the alarmingly high rate of increase in consumption-based emissions indicates that the UK Government is currently only paying lip-service to the One Planet Economy principle. We urge the Government to adopt consumption accounting as one of the key indicators in UK climate policy, to ensure that the UK does not continue to be lulled into a false sense of security by achieving its emissions reductions through off-shoring its GHG-intensive industries.

Our results show that from the consumption perspective households were responsible (on average for years 1990-2004) for over three-quarters (76%) of total UK GHG emissions, the remainder being due to government expenditure (11%) and capital investment (13%). Of the GHG emissions attributed to households, embedded emissions account for 62% and those due to direct energy use (gas, electricity, other fuels and personal transportation fuels) account for the remaining 38%. The highest categories for household GHG emissions, when classification is based on extended COICOP categories, are Food and non-alcoholic beverages (14%) and Other transport (which includes aviation) (14%), and categories of direct fuel use, specifically, Gas (13%), Electricity (11%) and Personal transport fuels (10%). When we allocate household GHG emissions to high level functional uses we find that in 2004 a quarter were due to the pursuit of recreation and leisure, and a significant quantity were also tied up in food and catering (22%). This shows that while a good deal of GHGs are tied up in our pursuit of leisure activities, considerable amounts are used in more mundane activities such as keeping ourselves and our families clean, warm and fed. This has policy implications with respect to changes that are needed in the institutional infrastructure within which UK citizens operate, and underlines the importance of tackling the high level of GHG emissions associated with food production[12]. Further discussion is beyond the scope of this paper, but the implications of these findings will form the basis of future work by the ESRC Research Group on Lifestyles, Values and Environment (RESOLVE).

The results found in this study on the GHG-intensity of expenditure can be of use in policies aimed at shifting expenditure patterns from high to low GHG intensity categories. Our analysis shows that, amongst the categories used here, direct energy uses have the highest GHG intensities. Therefore policies that reduce direct energy use can generally be expected to lead to a reduction in overall GHGs. Suppose, for example, dwellings were better insulated, resulting in a decrease in expenditure on gas. Gas is, according to our results, the most GHG intensive category of expenditure. Therefore the money saved will be spent in a category that is less GHG intensive, and a reduction in GHG emissions should, in theory, be achieved. Of course, a caveat is needed here, as the classifications we have used are fairly broad. Aviation is, in this categorisation, included in Other transport, and if savings were spent on flights for a holiday abroad, this is likely to increase emissions.

Food and non-alcoholic beverages is an important consumption category, being the category with the highest GHG emissions in the extended COICOP categorisation and also being ranked fifth highest in the GHG-intensity of expenditures table after direct fuels. Although food and drink are, of course, necessary for subsistence, it has

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[12] See the Food Climate Research Network for work in this field associated with RESOLVE. In particular the reader is referred to Garnett (2008).

been show that UK households throw away approximately one third of the food they purchase (WRAP 2008). The question arises: if these wasteful habits were discontinued, and the money saved spent on other items, what impact may this have on overall GHG emissions? Our ranking of the GHG intensity of expenditures shows that as long as the saved money is spent in any of the categories below Food and non-alcoholic beverages in the list, then an overall reduction in GHG emissions may be achieved. For example, if the savings were spent on clothing and footwear, which has a GHG intensity of around a quarter that of Food and non-alcoholic beverages, emissions would be reduced proportionately. Again, caution must be taken when interpreting this, due to the broad categories used and, in particular, with regards to aviation, as discussed above.

Ranking of the GHG intensities of expenditure categories is vital to government in designing strategies to move to a lower carbon economy[13]. It is becoming increasingly acknowledged that, due to the rebound effect, it is important to take an economy-wide approach to ensure that expenditure saved in one area is not spent in a more GHG intensive area. The work shown here gives guidance on the broad categories of expenditure which are more or less GHG intensive, and shows which categories should be considered for policy measures such as taxation, subsidies or information campaigns. In particular, if carbon trading were to be successful, a high price of carbon[14] would, in theory, achieve a shift in expenditures from the higher to lower intensity categories.

Additional Acknowledgements

We are grateful to Dr Glen Peters for his kind provision of amendments to the GTAP GHG emissions data for selected countries.

[13] In this case ‘carbon’ refers to GHG emissions measured as carbon equivalent.

[14] Food has higher non-CO_2 GHG emissions than other categories of expenditure. Therefore, depending on the details of any scheme, carbon trading effects food differently. A similar argument holds for the effects of a carbon tax in contrast to a GHG tax. See Kerkhof et al (2008).

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Appendix 1. QMRIO Regions (adapted from Wilting (2008)).

World region		GTAP Region	
Number	Name	GTAP 6 code	Description
1	UK	43	UK
2	North America	21	Canada
		22	United States
		23	Rest of N. America
3	Central and South America	23	Mexico
		25	Colombia
		26	Peru
		27	Venezuela
		28	Rest of Andean Pact
		29	Argentina
		30	Brazil
		31	Chile
		32	Uruguay
		33	Rest of South America
		43	Central America
		35	Rest of FTAA
		36	Rest of the Caribbean
4	Oceania	1	Australia
		2	New Zealand
		3	Rest of Oceania
5	Japan and New Industrializing Economies	5	Hong Kong
		6	Japan
		7	Korea
		8	Taiwan
		13	Singapore
6	South East Asia	10	Indonesia
		11	Malaysia
		12	Philippines
		14	Thailand
		15	Vietnam
		16	Rest of South East Asia
7	China and East Asia	4	China
		9	Rest of East Asia
8	South Asia	17	Bangladesh
		18	India
		19	Sri Lanka
		20	Rest of South Asia
9	Middle East	71	Turkey
		72	Rest of Middle East
10	Former Soviet Union	69	Russian Federation
		70	Rest of Former Soviet Union
11	Eastern Europe	54	Rest of Europe
		55	Albania
		56	Bulgaria
		57	Croatia
		58	Cyprus
		59	Czech Republic
		60	Hungary
		61	Malta
		62	Poland
		63	Romania
		64	Slovakia
		65	Slovenia
		66	Estonia
		67	Latvia
		68	Lithuania
12	OECD Europe	37	Austria
		38	Belgium
		39	Denmark
		40	Finland
		41	France
		42	Germany
		44	Greece
		45	Ireland
		46	Italy
		47	Luxembourg
		48	Netherlands
		49	Portugal
		50	Spain
		51	Sweden
		52	Switzerland
		53	Rest of EFTA
13	Africa	73	Morocco
		74	Tunisia
		75	Rest of North Africa
		76	Botswana
		77	South Africa
		78	Rest of South African CU
		79	Malawi
		80	Mozambique
		81	Tanzania
		82	Zambia
		83	Zimbabwe
		84	Rest of SADC
		85	Madagascar
		86	Uganda
		87	Rest of Sub-Saharan Africa

Appendix 2. Allocation table for high level functional uses.

COICOP categories plus direct use of domestic fuels	CIOCOP category	High level functional uses: Household	Recreation & Leisure	Space Heating	Food & Catering	Commut-ing	Health & Hygiene	Clothing & Footwear	Education	Commun-ications	Total[1]
Food & Non-alcoholic drink	1.1, 1.2, 11.1				100%						100%
Alcohol & Tobacco	2.1, 2.2		100%								100%
Clothing & Footwear	3.1, 3.2							100%			100%
Housing	4.1, 4.2, 4.3, 5.5, 5.6,	100%									100%
Water Supply & Other Misc Services	4.4						75%	25%			100%
Furnishings & Other Household	5.1, 5.2, 5.4	100%									100%
Household Appliances	5.3	25%	25%		25%		13%	13%			100%
Health & Hygiene	6.1, 6.2, 6.3, 12.1						100%				100%
Transport Services (indirect)	7.1, 7.2, 7.3	1%	40%		5%	37%	7%	6%	4%		100%
Post & Communication	8.1, 8.2, 8.3									100%	100%
Recreation & Entertainment	9.1 – 9.4		100%								100%
Books & Newspaper	9.5								100%		100%
Other Personal Effects	12.3							100%			100%
Holidays excl dir personal aviation and vehicle use	9.6, 11.2		100%								100%
Education	10								100%		100%
Financial & Other Services	12.4, 12.5, 12.6, 12.7	100%									100%
Delivered Fuels (indirect)	4.5 (part)[2]	11%	6%	48%	9%		13%	13%		1%	100%
Space Heating				100%							100%
Water Heating							50%	50%			100%
Cooking					100%						100%
Electricity (lighting)		100%									100%
Electricity (cold appliances)					100%						100%
Electricity (brown goods)			90%							10%	100%
Electricity (wet appliances)							50%	50%			100%
Electricity (misc)		100%									100%
Personal vehicle use		1%	40%		5%	37%	7%	6%	4%		100%
Personal aviation			100%								100%

[1] Discrepancies in totals are due to rounding errors.

[2] COICOP category 4.5 includes emissions from electricity production, which are excluded from this domestic functional category as they included directly elsewhere.

Appendix 3. GHG Intensity of final demand 2004

		GHG Intensity of final demand 2004		
	Sector	Households (inc NPISH)	Government	Investment
		kgCO2e/£ purchasers' prices	kgCO2e/£ purchasers' prices	kgCO2e/£ purchasers' prices
1	Agriculture	2.96	NA	4.05
2	Forestry	0.43	NA	0.42
3	Fishing	0.68	NA	2.74
4	Coal extraction	3.35	NA	-43.64
5	Oil & gas extraction	NA	NA	1.93
6	Metal ores extraction	NA	NA	-5.11
7	Other mining & quarrying	0.84	NA	1.22
8	Meat processing	1.29	NA	3.20
9	Fish & fruit processing	0.93	NA	1.96
10	Oils & fats	1.13	NA	3.06
11	Dairy products	1.29	NA	2.79
12	Grain milling & starch	1.11	NA	-0.35
13	Animal feed	0.92	NA	2.12
14	Bread, biscuits etc.	1.02	NA	1.21
15	Sugar	0.81	NA	3.01
16	Confectionery	0.51	NA	1.43
17	Other food products	1.11	NA	1.56
18	Alcoholic beverages	0.32	NA	1.19
19	Soft drinks & mineral waters	0.71	NA	1.79
20	Tobacco products	0.12	NA	1.35
21	Textile fibres	0.12	NA	-1.92
22	Textile weaving	0.26	NA	1.89
23	Textile finishing	23.08	NA	0.00
24	Made-up textiles	0.35	NA	1.05
25	Carpets & rugs	0.20	NA	1.24
26	Other textiles	0.23	NA	1.58
27	Knitted goods	0.84	NA	1.57
28	Wearing apparel & fur products	0.20	NA	0.73
29	Leather goods	0.36	NA	-3.65
30	Footwear	0.30	NA	2.47
31	Wood & wood products	0.78	NA	1.03
32	Pulp, paper & paperboard	NA	NA	-4.78
33	Paper & paperboard products	0.06	NA	1.92
34	Printing & publishing	0.52	NA	0.98
35	Coke ovens, refined petroleum & nuclear fuel	0.76	NA	17.87
36	Industrial gases & dyes	1.14	NA	0.00
37	Inorganic chemicals	NA	NA	-0.81
38	Organic chemicals	NA	NA	-1.01
39	Fertilisers	0.72	NA	-0.25
40	Plastics & synthetic resins etc.	NA	NA	-0.45
41	Pesticides	0.31	NA	-1.09
42	Paints, varnishes, printing ink etc.	0.09	NA	0.94
43	Pharmaceuticals	0.19	NA	-0.17
44	Soap & toilet preparations	0.14	NA	0.84
45	Other chemical products	0.37	NA	2.42
46	Man-made fibres	NA	NA	15.63
47	Rubber products	0.73	NA	1.33
48	Plastic products	0.58	NA	1.00
49	Glass & glass products	0.50	NA	2.22
50	Ceramic goods	0.60	NA	-4.81

		GHG Intensity of final demand 2004		
	Sector	**Households (inc NPISH)**	**Government**	**Investment**
		kgCO2e/£ purchasers' prices	kgCO2e/£ purchasers' prices	kgCO2e/£ purchasers' prices
51	Structural clay products	0.16	NA	1.42
52	Cement, lime & plaster	3.60	NA	11.68
53	Articles of concrete, stone etc.	2.38	NA	2.39
54	Iron & steel	NA	NA	87.38
55	Non-ferrous metals	0.31	NA	3.16
56	Metal castings	0.89	NA	1.72
57	Structural metal products	0.11	NA	1.37
58	Metal boilers & radiators	0.16	NA	0.93
59	Metal forging, pressing etc.	0.57	NA	1.29
60	Cutlery, tools etc.	0.18	NA	0.85
61	Other metal products	0.28	NA	1.25
62	Mechanical power equipment	0.43	NA	0.79
63	General purpose machinery	0.69	NA	0.86
64	Agricultural machinery	0.17	NA	0.68
65	Machine tools	0.30	NA	0.76
66	Special purpose machinery	NA	NA	0.79
67	Weapons & ammunition	0.65	NA	0.00
68	Domestic appliances nec	0.37	NA	0.81
69	Office machinery & computers	0.21	NA	0.35
70	Electric motors & generators etc.	0.28	NA	0.63
71	Insulated wire & cable	0.12	NA	0.89
72	Electrical equipment nec	0.31	NA	0.54
73	Electronic components	NA	NA	0.65
74	Transmitters for TV, radio & phone	0.37	NA	0.59
75	Receivers for TV & radio	0.10	NA	0.42
76	Medical & precision instruments	0.18	NA	0.75
77	Motor vehicles	0.46	NA	0.42
78	Shipbuilding & repair	0.64	NA	1.01
79	Other transport equipment	0.35	NA	0.87
80	Aircraft & spacecraft	0.64	NA	0.54
81	Furniture	0.49	NA	0.93
82	Jewellery & related products	0.33	NA	5.99
83	Sports goods & toys	0.10	NA	0.86
84	Miscellaneous manufacturing nec & recycling	0.35	NA	1.37
85	Electricity production & distribution	8.08	NA	NA
86	Gas distribution	1.22	NA	0.00
87	Water supply	1.06	NA	1.06
88	Construction	0.62	NA	0.63
89	Motor vehicle distribution & repair, automotive fuel retail	0.86	NA	NA
90	Wholesale distribution	NA	NA	NA
91	Retail distribution	27.96	NA	0.52
92	Hotels, catering, pubs etc.	0.55	NA	NA
93	Railway transport	1.37	NA	NA
94	Other land transport	1.36	NA	2.12
95	Water transport	3.67	NA	3.19
96	Air transport	2.83	NA	NA
97	Ancillary transport services	0.45	NA	NA
98	Postal & courier services	0.38	NA	NA
99	Telecommunications	0.32	NA	0.36
100	Banking & finance	0.29	NA	NA
101	Insurance & pension funds	0.33	NA	NA
102	Auxiliary financial services	0.31	NA	0.31

		GHG Intensity of final demand 2004		
	Sector	**Households (inc NPISH)**	**Government**	**Investment**
		kgCO2e/£ purchasers' prices	kgCO2e/£ purchasers' prices	kgCO2e/£ purchasers' prices
103	Owning & dealing in real estate	0.25	NA	NA
104	Letting of dwellings	0.12	NA	NA
105	Estate agent activities	0.14	NA	0.16
106	Renting of machinery etc.	0.37	NA	NA
107	Computer services	0.34	NA	0.32
108	Research & development	0.41	NA	0.00
109	Legal activities	0.18	NA	0.19
110	Accountancy services	0.18	NA	0.21
111	Market research, management consultancy	NA	NA	0.24
112	Architectural activities & technical consultancy	0.20	NA	0.27
113	Advertising	0.55	NA	0.72
114	Other business services	0.32	NA	0.33
115	Public administration & defence	0.41	0.41	0.41
116	Education	0.31	0.31	0.31
117	Health & veterinary services	0.39	0.39	0.39
118	Social work activities	0.31	0.31	0.31
119	Sewage & sanitary services	2.18	2.18	NA
120	Membership organisations	0.32	NA	NA
121	Recreational services	0.43	0.51	0.50
122	Other service activities	0.40	NA	0.00
	All sectors	**0.69**	**0.41**	**0.63**

NA=Not Applicable. This has been put where there is zero expenditure in the sector.

Appendix 4. Re-attribution of GHG emissions allocated to investment

In the work described in this document so far, consumption perspective GHG emissions have been attributed to the three major categories of final demand: households, government and capital investment (called simply 'investment' henceforth). Strictly speaking, investment supports present and future consumption activities in a wide variety of different sectors. So, for example, most of final demand in the construction sector is classified as investment. But construction – building and refurbishment – is carried out in support of a variety of different industrial sectors: retail, manufacturing, hospitals, schools, offices, distribution and so on. In one sense these investments – and the GHG emissions associated with them – are still intermediate inputs to the other commodity sectors.

To pursue our aim of attributing GHG emissions to final demand, we should ideally re-distribute the carbon associated with these investments as an input to the sectors supported by the investment (Carbon Trust 2006; Jackson et al. 2006; Lenzen 2001; Nansai et al. 2008). Lenzen and Treloar (2005) argue that this represents a transition from the short-term to the long term perspective

In this section we describe how we re-allocate the GHG emissions due to investment expenditure to households and government. In doing this we assume that that the economy is in a steady state: in other words we assume that it is legitimate to take investment carbon in the current economic cycle as a proxy for the investments required to support consumption in the current cycle (Carbon Trust 2006; Jackson et al. 2006; Nansai et al. 2008). This represents a crude proxy for a much more complicated allocation which ought ideally to involve the stream of past investments supporting current activities and exclude the components of current investment that support future activities.

There are three possible methodologies for achieving the re-attribution. One possible methodology involves endogenising investment expenditure into the A-Matrix by forming an extra row and column, or, in other words, making a new industry sector for investment (Lenzen and Treloar 2005). This is called the Augmentation Method. The drawback of this methodology is that it does not take into account the sector in which the investment expenditure is made and can lead to systematic errors (Lenzen and Treloar 2005).

An alternative but similar methodology, known as the Flow Matrix Method, overcomes this shortcoming by disaggregating investment expenditure across the sectors in which it is spent. The resulting matrix is then added to the A-Matrix for use in the input-output equations (Lenzen and Treloar 2005; Nansai et al. 2008). The drawback of this method is that it is highly data-intensive. This is particularly true for the UK, for which data on investment expenditure are provided in purchaser prices only, and therefore require converting to basic prices in order to be combined with the A-Matrix.

In this work we use the Re-allocation Method. In this method the GHG emissions attributed to investment final demand are re-allocated according to the industry sector that carried out the expenditure (Carbon Trust 2006; Jackson et al. 2006). This is done by running the input-output model with intensity coefficients that are formed from the emissions originally attributed to investment. These are known as 're-allocation investment intensity coefficients'.

The first step in calculating the re-allocation investment intensity coefficients is to allocate the GHG emissions to the industrial sectors that made the investment (the buying sectors). This is done according to expenditure data from the Blue Book and the Supply and Use Tables[15]. Re-allocation investment intensity coefficients are then calculated for each sector by dividing the investment carbon attributed to each sector by the output from that sector. The input-output model is then re-run with the re-allocation investment intensity coefficients. Two adjustments are then made. The first adjustment is because when the model is re-run a residue of emissions are again attributed to investment. The model is therefore run for successive iterations until this is negligible. The second adjustment is required because, as the model does not close, the re-allocated emissions do not equal the original investment GHG emissions. This is adjusted for by a scaling factor. The result gives the GHG emissions due to investment attributed to household and government final demand expenditure. This is added to the original GHG emissions, estimated as described in the main body of this Working Paper, to estimate total GHG emissions with investment emissions re-allocated.

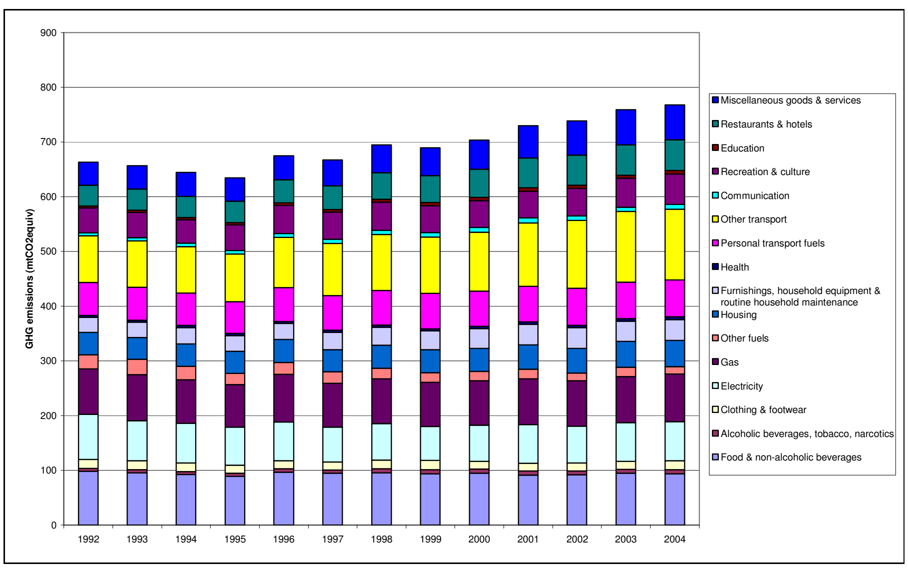

Figure A4.1. GHG emissions attributed to UK households 1990-2004: extended COICOP categories

[15] Table 6 in the Supply and Use Tables provides information on investment expenditure in 57-sector disaggregation, excluding Changes in Inventories (ONS 2006). This is augmented by information from Table 2.2 in the Blue Book which includes Changes in Inventories, but is only provided in a high level (11-sector) disaggregation (ONS Various years-b). These expenditures are disaggregated to 122 sectors using proportionality based on the output of each sector, and transformed from purchasers' prices to basic prices as described in Druckman et al (2008).

In 2004, without investment re-allocated, households were estimated to be responsible for 75% of UK GHG emissions from the consumption perspective, with government and investment being responsible for 11% and 14% respectively. With investment reallocated, households are estimated to be responsible for 85% of GHG emissions, and government for the remaining 15%. Figure A4.1 shows UK household GHG emissions attributed to extended COICOP categories with emissions due to investment re-allocated.