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The carbon footprint of UK households 1990-2004: a socio-economically disaggregated, quasi-multi-regional input-output model

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Abstract

This paper presents a socio-economically disaggregated framework for attributing carbon emissions from energy used in the production of goods and services to people's high level functional needs. Based around a quasi-multi-regional input-output (QMRIO) model, the study, in theory, takes into account all energy consumption and associated carbon emissions due to the production of goods and services required to satisfy UK household demand, whether the energy use and emissions occur in the UK or abroad. Results show that carbon emissions attributable to households were 17% above 1990 levels in 2004, and are estimated to have been increasing by about 3% per annum between 1997 and 2004. Absolute decoupling occurred between household expenditure and carbon emissions during the UK's switch from coal to gas in the early 1990s but since then only very slight relative decoupling is evident. Embedded (upstream) carbon accounts for over half the total carbon footprint of an average UK household, and this proportion is rising. Incorporated in this are emissions due to production outside the UK and reducing these emissions is particularly problematic in a global trading system. Investigation into the footprint of 'typical' UK households segmented according to the National Output Area Classification shows that footprints vary widely: the Supergroup with the highest footprint emits 67% more carbon than the Supergroup with the lowest footprint. Footprints are shown to depend to a large extent, but not solely, on incomes, with other factors, such as type of dwelling and lifestyle choices also being of importance. We find that recreation and leisure are responsible for over one quarter of carbon emissions in a typical UK household in 2004, with food and catering, space heating, household, and clothing and footwear also being significant. The most affluent Supergroup uses the greatest quantity of carbon and also the highest proportion of their total carbon footprint for recreation and leisure. We conclude that expanding lifestyle aspirations are very significant factors in driving household carbon emissions, but the study also emphasizes that attention must be paid to the infrastructures and institutions that result in considerable amounts of carbon being locked up in the basic household activities through which ordinary people meet their everyday needs for subsistence, protection, and communication with family and friends. The findings highlight the sheer scale of the challenge facing UK policy-makers, and also indicate that policies should be targeted at the segments in society responsible for the highest carbon footprints.

Keywords: carbon footprint; households; trends; socio-economic disaggregation; segmentation.

1. Introduction

The premise of this study is that the responsibility for carbon emissions from economic activity lies with people's attempts to satisfy certain functional needs and desires. In simple economic terms, our needs and desires are expressed in the consumer demand for commodities, and it is this demand for goods and services which drives the production processes that consume resources – including energy resources – and emit pollutants – including carbon dioxide and other greenhouse gases (Daly 1996; Daly and Cobb 1989; HM Government 2005; UN 2002; UNCED 1992). To help us understand the link between the attempted satisfaction of human needs and desires and carbon emissions, and to understand the scale of carbon reductions that are required, we ask the following questions. How much carbon is attributable to which kinds of needs and desires? Is the highest amount attributable to subsistence needs such as food and clothing? Or protection (housing and security)? Or our leisure demands? Or to the need to communicate with our family and friends? Do some segments of UK society have a higher carbon footprint than others? If so, what is the disparity? What are the current trends, and to what extent is decoupling occurring between household expenditure and carbon emissions?

In order to be able to start to answer some of these questions we present a framework that estimates the energy use and the associated carbon dioxide emissions of UK households from the consumption perspective. We apply this framework for three investigations: we examine trends from 1990 to 2004; we look at carbon emissions by different segments of society; and we explore the amounts of carbon that are used to support the various different activities that make up modern lifestyles, or, in other words, we attribute carbon emissions to functional uses.

In accounting from the consumption perspective we include energy used directly in homes (for space heating, lighting, hot water and so on), for personal transportation (including personal vehicle use and personal aviation), and also energy and emissions that occur upstream in the production of goods and services purchased by UK households (Bastianoni et al. 2004; Druckman et al. 2007; Jackson and Papathanasopoulou 2008; Jackson et al. 2006; Munksgaard and Pedersen 2001; Peters 2008). The upstream energy and emissions are referred to as "embedded". An important aspect of the consumption perspective is that it takes account of all emissions incurred in support of household consumption within the UK, whether or not they occur in the UK or abroad. This contrasts with the production perspective, which accounts for emissions produced within UK territorial boundaries, regardless of where consumption of final goods and services occurs. The difference between the two approaches is the carbon embodied in trade.

One of the reasons that consumption accounting is not used more widely is that accounting for upstream energy and carbon missions embedded in consumption uses Environmental Input-Output (EIO) modelling. This is a highly data-intensive technique for which there are significant difficulties in compiling robust datasets (Peters et al. 2007), and this is particularly the case for the UK[1]. Furthermore, in order to take account of the energy embedded in goods and services produced abroad to support UK consumption, a Multi-Regional Input-Output model (MRIO) is ideally required. MRIO models present even greater data challenges than conventional EIO models, and are often limited in the number of sectors (Huppes et al. 2006; Tukker et al. 2006; Turner et al. 2007). To overcome this difficulty we have developed a quasi-multi-regional input-output (QMRIO) model which attempts to estimate carbon emissions due to imported goods and services with maximum accuracy while retaining the greatest possible number of sectors.

The paper is organised as follows. In the Background section (Section 2) we give an overview of relevant conditions specific to the UK, and augment the rationale for the study. In particular, we introduce the reader to the segmentation system used to study different "types" of UK households (we look at seven types, known as "Supergroups"). We also introduce the reader to the Local Area Resource Analysis (LARA) model that is used to achieve socio-economic disaggregation of carbon emissions. In Section 3 we describe the methodologies used in the paper. We start with an overview of consumption accounting (Section 3.1), followed by the methodology of the QMRIO model (Section 3.1.1). The way in which LARA is applied to estimate the average household footprint for each Supergroup is described in Section 3.2, followed by the methodology for mapping carbon emissions to high level functional uses (Section 3.3). In the Results section we first look at trends in energy use and carbon emissions (Section 4.1). We then compare the carbon footprints of the Supergroups, and look at how carbon is used in support of high level functional uses (Section 4.2). The Assumptions and Limitations section comes next (Section 5). In the Discussion section we synthesize the salient findings and comment on their relevance for policy-makers.

[1] The latest dataset available as a basis for EIO for the UK is for 1995 (Druckman et al. 2007; ONS 2008a).

2. Background

As alluded to above, a good starting point for investigating carbon emissions due to consumption is to look at expenditures. UK household expenditure has risen by 49% since 1990 and, as illustrated in Figure 1, the highest increases have been in Communications, and Recreation and culture (237% and 195% respectively). In this paper one of the questions we ask is: to what extent has this increased expenditure resulted in rising energy use and associated carbon emissions? In other words, has decoupling taken place[2]? Decoupling can occur due to technical progress, and one of the drivers that is considered in this paper is the "dash for gas" that occurred in the 1990s in the UK. During this period, due largely to cheap availability of natural gas from the North Sea, the UK electricity industry shifted much of its fuel supply from coal to natural gas, as shown in Figure 2. Other drivers of decoupling can be changes in consumer choices, for example, shifts in household expenditure from highly resource intensive commodities (such as package holidays abroad) to lower intensity commodities (such as works of art).

Figures 1 and 2

Another aim in this paper is to explore the variation in footprints across different segments of society. There is a wealth of segmentation systems available, many of which are used for commercial marketing purposes and have elements of "lifestyles" encoded within them. These systems are undoubtedly successful for the purposes for which they are designed, but, being commercial, full details are generally not disclosed. Therefore in this study we base our segmentation on the UK National Output Area Classification (OAC) (Office for National Statistics 2005b; Vickers and Rees 2007; Vickers et al. 2005), which is chosen for its transparency and robustness. We limit our examination to the carbon emissions of the top seven OAC Supergroups (henceforth called simply 'Supergroups')[3], although the methodology is applicable to more detailed levels of segmentation, such as 21 OAC Groups or 52 Sub-Groups. A more detailed segmentation level would, of course, give more extreme results and may be a subject for further work. Additionally the methodology can be applied to examine the carbon emissions of individual small local areas (known as Output Areas, based on Census 2001 boundaries (Office for National Statistics 2006a) and through this we could focus on households of extreme affluence and deprivation, and assess measures of inequality (Druckman and Jackson 2008a; Papathanasopoulou and Jackson 2008).

The methodology underlying the analysis of the carbon footprint of Supergroups in this study is the Local Area Resource Analysis (LARA) model. LARA

[2] Decoupling is defined as '*breaking the link between "environmental bads" and "economic goods"*', and it can be relative (when the growth rate of the environmentally relevant variable is positive, but less than the growth rate of the economic variable) or absolute (when the environmentally relevant variable is stable or decreasing while the economic driving force is growing) (OECD 2002).

[3] A summary of the salient characteristics of the Supergroups is given in Appendix 4.

estimates expenditure, resource use and emissions for households in socio-economically homogenous local areas based on their socio-economic characteristics. In previous work LARA has been applied to estimate the direct household energy use and associated carbon emissions for Supergroups (Druckman and Jackson 2008b) It was found that household energy use and associated carbon emissions are both strongly, but not solely, related to income levels. Other factors, such as the type of dwelling, tenure, household composition and rural/urban location are also extremely important. In this study we apply LARA to estimate entire carbon footprints, including embedded emissions, for the first time. Footprints are estimated based on household expenditures as recorded in the Family Expenditure Survey (Office for National Statistics various years). It is important to take account of total expenditure on all goods and services, as expenditure saved in one area, ostensibly aimed at reducing carbon emissions (such as savings on fuel bills due to installation of loft insulation), may be spent in another which might have a negative effect on overall carbon savings. For example, respondents in a survey were asked how they would spend any savings accrued from lower energy bills: the most common single answer was 'an overseas holiday involving air travel' (NHBC 2008). This phenomenon is known as the rebound effect (Allan et al. 2006; Berkhout et al. 2000; Dimitropoulos 2007; Herring 1998; Hertwich 2005; Sorrell and Dimitropoulos 2008) and is one of the reasons why it is imperative to take account of consumption of the entire range of goods and services available for purchase in carbon reduction strategies.

3. Methodology

3.1 Consumption accounting

As introduced earlier, when accounting from the consumption perspective, we take account of energy use and associated carbon emissions induced by purchases of goods and services within the UK, whether the energy use takes place in the UK or abroad. In this paper we account for four broad categories:

a) Energy and emissions embedded in goods and services purchased by households
b) Energy and emissions due to direct fuel use by households
c) Energy and emissions due to personal vehicle use
d) Energy and emissions due to personal aviation

We are concerned here only with household consumption as shown by household expenditure. Household expenditure is just one component of final demand in the System of National Accounts (United Nations 1993), the other components being government, fixed capital and exports[4]. There is an argument that all government and fixed capital expenditure is made in support of households (Carbon Trust 2006; Jackson et al. 2006; Jackson et al. 2007; Peters and Hertwich 2004) and therefore analyses sometimes allocate these expenditures to households. However, in order to draw direct

[4] Not for Profit Institutions Serving Households (NPISH) is a further final demand category. This accounts for under 2% of final demand in 2004, and is often combined with households. In the analysis of trends in this study we follow this convention.

policy implications with regard to households this allocation has not been carried out in the current study.

The choice of the categories above reflects the end uses that we are interested in from a policy perspective. In the category of direct fuel use by households, we include electricity use. Electricity is not, in itself, a fuel: it is an energy carrier, and emissions from its production arise upstream, for example, at the power plants where coal, gas or nuclear fuel are burnt. Energy use and emissions from the electricity used by households are, technically, embedded energy and emissions. However, it is separated from the category of embedded emissions and included as a direct household fuel because this is how it is commonly perceived by consumers, and it is subject to direct household decisions concerning use and savings.

Personal transportation is an important contributor to energy use and associated emissions, and in the following analysis we choose two categories, as defined above, again, selected with a view to policy relevance. Energy and emissions due to personal vehicle use are those directly due to petrol and diesel consumption, whereas those due to personal aviation occur upstream: they have been separated from the general category of embedded emissions due to their significance for emissions reduction policy. [5]

Estimating energy and emissions due to direct household fuel use, personal vehicle use and personal aviation is relatively straightforward, and data sources can be found in Appendix 1. Estimation of embedded energy use and carbon is the subject of the next section.

3.1.1 Embedded energy and emissions

In this study accounting for emissions embedded in expenditure by households is carried out using a Quasi-Multi-Regional Input-Output (QMRIO) model. Input-output is a well established technique (Leontief 1986; Miller and Blair 1985) and therefore only a brief description of the basic model is given here. Our model is based on the two-region model developed by Proops et al (1993) and Jackson et al (2007), and is described by the following equations:

$$C_P = \mathbf{u}^{a'}(\mathbf{I} - \mathbf{A}^{a})^{-1}\mathbf{y}^{aa} \quad (1)$$

$$C_Q = \mathbf{u}^{b'}(\mathbf{I} - \mathbf{A}^{b})^{-1}\mathbf{B}^{ba}(\mathbf{I} - \mathbf{A}^{a_1})^{-1}\mathbf{y}^{aa} \quad (2)$$

$$C_R = \mathbf{u}^{b'}(\mathbf{I} - \mathbf{A}^{b})^{-1}\mathbf{y}^{ba} \quad (3)$$

where

C_P is the carbon associated with the flow P of goods produced in the UK to meet final demand in the UK;

[5] Energy use and emissions due to personal travel by trains and ferries is not separated into a category of its own because the per capita levels from these modes of transport are generally lower, and these modes are not so relevant for carbon reduction strategies.

C_Q is the carbon associated with the flow Q of goods produced in the Rest of the World to meet intermediate demand in the UK for goods destined for final demand in the UK;[6]

C_R is the carbon associated with the flow R of goods produced in the Rest of the World to meet UK final demand;

$\mathbf{u}^{\alpha}$ is the vector of carbon coefficients for region α;

$\mathbf{y}^{\beta\alpha}$ is the vector of final demand for commodities produced in region β and consumed in region α;

I is an identity matrix

$\mathbf{A}^{\alpha}$ is the matrix of intra-regional technical coefficients for region α. $(\mathbf{I}\text{-}\mathbf{A})^{-1}$ is known as the 'Leontief Inverse';

$\mathbf{B}^{\alpha\beta}$ is the imports use coefficients matrix for imports from region α to region β. This is often referred to as the Imports Use Matrix.

An important shortcoming of most two-region models is the assumption that imported goods have the same footprint as those produced in the UK. This assumption, known as the 'domestic technology assumption', is described by the following equation:

$$\mathbf{u}^{b'}(\mathbf{I}-\mathbf{A}^{b})^{-1} = \mathbf{u}^{a'}(\mathbf{I}-\mathbf{A}^{a})^{-1} \quad (4)$$

In this paper we modify this assumption so that the intensity coefficient of imported goods more accurately represents the intensity of our importing partners[7]. According to this modification, equation (4) now becomes

$$\mathbf{u}^{b'}(\mathbf{I}-\mathbf{A}^{b})^{-1} = \mathbf{u}^{b'}(\mathbf{I}-\mathbf{A}^{a})^{-1} \quad (5)$$

where $\mathbf{u}^{b}$ represents the intensity of our importing partners.

Thus equations (2) and (3) become

$$C_Q = \mathbf{u}^{b'}(\mathbf{I}-\mathbf{A}^{a})^{-1}\mathbf{B}^{ba}(\mathbf{I}-\mathbf{A}^{a})^{-1}\mathbf{y}^{aa} \quad (6)$$

$$C_R = \mathbf{u}^{b'}(\mathbf{I}-\mathbf{A}^{a})^{-1}\mathbf{y}^{ba} \quad (7)$$

To estimate $\mathbf{u}^{b}$ we use data from the GTAP database version 6. The GTAP dataset has 87 regions covering the world (see Appendix 2) classified into 57 sectors (Dimaranan 2006). The EIO model represented by equations 1, 6 and 7 is in terms of 122 sectors based on Standard Industrial Sector (SIC) classification (ONS 1998). The 57 GTAP sectors do not directly translate onto the 122 SIC sectors, as the GTAP dataset has higher disaggregation than SIC in agricultural sectors and lower disaggregation in other sectors, such as manufacturing. We therefore define a 41-sector economy onto which we map the 57 GTAP sectors and 122 SIC sectors. We call this the RESOLVE economy. Then, as an intermediate step to estimating $\mathbf{u}^{b}$ for the 122-sector economy (which we denote by ${}_{122}\mathbf{u}^{b}$) we calculate the intensity of imports using 41-sector

[6] 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.

[7] Note that the industry structure of region 2 is still represented by the UK Leontief.

RESOLVE economy (denoted by ${}_{41}\mathbf{u}^{\mathrm{b}}$). This process is shown diagrammatically in Figure 3 and explained in more detail below.

Figure 3.

The first step is to aggregate the GTAP dataset from 57 sectors to 41 sectors. Then, working in the RESOLVE 41 sector economy, we define ${}_{41}p_{rs}$ as the proportion of imports to the UK for any industrial sector *s* from region *r* such that

$$\sum_r {}_{41}p_{rs} = 1 \quad (8)$$

The intensity of imports to the UK from each region *r* for sector *s* is written as ${}_{41}u_{rs}$. For each sector, the overall intensity of imports from all regions is found by summing the intensity of production in each region multiplied by the proportion of imports to the UK from that region. In other words

$${}_{41}u_s^b = \sum_r {}_{41}p_{rs}\ {}_{41}u_{rs} \quad (9)$$

We denote UK to be region 1, so ${}_{41}u_{r=1,s}$ is the intensity of UK domestic production for each sector in the RESOLVE economy. Using UK specific datasets we know the intensity of UK domestic production in each of the 122 SIC sectors (${}_{122}u_s^a$). Assuming a simple proportionality to estimate the intensity of imports to each sector in the 122 SIC economy (${}_{122}u_s^b$), we arrive at:

$${}_{122}u_s^b = \left(\frac{{}_{41}u_s^b}{{}_{41}u_{r=1,s}} \right) {}_{122}u_s^a \quad (10)$$

Equation 10 enables us to obtain the vector ${}_{122}\mathbf{u}^{\mathrm{b}}$ to be used in equations 6 and 7. The EIO model given by equations 1, 6 and 7 is then applied for an annual time-series 1990-2004 to estimate energy use and associated carbon dioxide emissions.

The data requirements for EIO are substantial. Economic datasets are obtained from the Supply and Use Tables (ONS 2008a). Data for 1990 is in SIC80, and data for all other years was in SIC92. The most recent versions of the Leontief Inverse and Imports Use Matrices for the UK are for 1990 (in SIC80) and for 1995 (in SIC92). For the early years of the study (1990-1992/3) we would ideally like to use the 1990 Leontief Inverse. However, Supply and Use Tables for 1991 are not available, and the 1992 Supply and Use Table is only available in SIC92. Therefore 1990 is modelled in SIC80 using the 1990 Leontief and years 1992-2004 are modelled in SIC92 using the 1995 Leontief Inverse and Imports Use Matrices. Annual energy use data are obtained from the UK Environmental Accounts in 93 sector format, which were mapped onto the SIC80 and SIC92 classification. Carbon emissions factors are obtained from IPCC (2006). Other details are as explained in Druckman et al (2007).

3.2 Socio-economic disaggregation using LARA

The result of the procedures explained above is a time-series of total energy use and carbon emissions attributable to UK households from 1990 to 2004. We now show how LARA is used to achieve socio-economic disaggregation in order to estimate the carbon attributable to each Supergroup.

The Local Area Resource Analysis (LARA) model is used to estimate mean household expenditure, direct resource use and associated emissions for small local areas of 124 households on average from a consumption perspective. A brief description of LARA's methodology is included in Appendix 3 and further details given elsewhere (Druckman and Jackson 2007; Druckman and Jackson 2008b; Druckman et al. 2008).

In this study LARA is applied to each of the 175,434 Output Areas in England and Wales. These areas are then grouped into seven segments (known as Supergroups) of typical types of households, using the UK National Output Area Classification (Office for National Statistics 2005b; Vickers and Rees 2007; Vickers et al. 2005). The main characteristics of each of these seven Supergroups, which have names such as 'Prospering Suburbs' and 'Constrained by Circumstances', are given in Appendix 4.

A schematic diagram showing the use of LARA in this study is shown in Figure 4[8]. On the left-hand side data inputs to LARA are shown. Outputs from LARA used in this study are in terms of carbon emissions (namely mean carbon emissions due to direct fuel use by households and vehicle use for each Supergroup) and expenditures. Estimation by LARA of carbon emissions due to direct household fuel use by households in Supergroups has been carried out previously (see Druckman and Jackson (2008b)), and results from that study are used here[9]. This methodology has been repeated to estimate mean carbon due to personal vehicle use for each Supergroup. Carbon from personal aviation is estimated using expenditure information on aviation by each Supergroup from LARA, and assuming that energy use and emissions (as calculated from the Environmental Accounts, see Appendix 1) are proportional to expenditure.

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[8] In the diagram we only refer to carbon, but energy use is also calculated in all cases.

[9] Adjustments were required due to use of different data sources in the two studies. First, different estimates of the number of households in UK are used: Druckman and Jackson (2008b) used an estimate based on Expenditure and Food Survey whereas this study uses figures from DCLG (2008). The DCLG estimate is believed to be more accurate although the actual number of households, is, in fact, unknown. Second, figures for total energy use by UK households for Druckman and Jackson (2008b) were obtained from Energy Trends (DTI various years) whereas this study uses figures from DUKES (2006) Table 5.2.

Figure 4.

Embedded emissions for each Supergroup are calculated using expenditure data from LARA, and this has not been carried out before and is therefore described here. In essence the methodology is simple: embedded energy and emissions for typical household types are estimated by running the QMRIO model, as given in equations 1, 6 and 7, with household demand for the seven different Supergroups estimated using LARA. However, the results from LARA cannot be directly used in the QMRIO model, as they are in terms of 247 COICOP[10] categories in Purchasers' prices estimated based on the UK Family Expenditure Survey (Office for National Statistics various years), whereas the QMRIO model requires household final demand in terms of 122 SIC categories in Basic prices. Another difficulty is that UK household expenditure based on the Expenditure and Food Survey differs from that published in the Supply and Use Tables for a number of reasons: different sources of data are used (ONS 2007); the Supply and Use Tables include imputed rents[11]; and the time periods covered are different[12]. Details of the procedure used to estimate mean household expenditure for each Supergroup for use in the QMRIO model is explained in Appendix 5.

Figure 4 also shows how carbon emissions are allocated to high level functional uses, and this is the subject of the next section, which commences with an explanation of the reasoning underlying the choice of high functional categories.

3.3 Mapping carbon emissions to high level functional uses

As discussed above, in this paper we aim to estimate the amount of energy and associated carbon emissions for each Supergroup attributed to high level functional uses. Figure 1 shows expenditures allocated to 12 COICOP categories (United Nations 2005). These categories are designed to identify the 'functional uses' on which people spend their money, such as Education, Health and Transport. When considering the energy use and associated carbon emissions involved in supporting UK lifestyles these COICOP categories are not ideal, and therefore we select different high level functional use categories for the purposes of this study, as used previously by Jackson et al (2006; 2007), and Carbon Trust (2006). The rationale for this selection 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

[10] COICOP stands for Classification of Individual Consumption According to Purpose (United Nations 2005).

[11] People living in dwellings they own are considered to be selling housing services to themselves. The rents recorded in the national accounts therefore include both the actual rents paid by tenants and imputed rents in the case of owner-occupiers. In most countries, this is the largest imputed item in households' consumption. The amount of the imputed rent is measured by the rents paid for comparable housing in a similar part of the country. http://caliban.sourceoecd.org/vl=5879620/cl=31/nw=1/rpsv/una/Chapter5.htm. Imputed rent accounts for approximately 10% of household expenditure in 2004 according to Table 4.

[12] The national accounts use a calendar year whereas the Family Spending is based on the Expenditure & Food Survey is carried out annually covering April to March.

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. We therefore use the following categories:

- Space heating
- Household
- Food & catering
- Clothing & footwear
- Health & Hygiene
- Recreation & Leisure
- Education
- Communications
- Commuting

The procedures used for mapping carbon emissions to these high level functional uses are shown diagrammatically in Figure 4. The Allocation Chart referred to in the diagram is given in Table 1. We first consider how embedded emissions are allocated to these categories. As shown in Figure 4 the results from the QMRIO model are in SIC categories, and therefore the first task is to convert these industrial classifications to COICOP. This conversion is carried out using Table 4 ('Households final consumption expenditure by COICOP heading') of the Supply and Use Tables (ONS 2008a). We then use the Allocation Chart shown in Table 1 as a basis for mapping the COICOP classification onto high level functional uses.

Results from LARA for direct household energy use by each Supergroup are simply in terms of energy use (gas, electricity and other fuels), but give us no information about the *uses* for which these fuels are purchased. For this purpose we use information from DTI concerning the amount of each type of fuel used for 'Space heating', 'Water heating', 'Cooking' and 'Lighting and appliances'[13]. Electricity use for 'Lighting and appliances' is further disaggregated into use for Lighting, Cold appliances (refrigerators and freezers), Cookers, Brown appliances (such as televisions and computers), Wet appliances (such as dishwashers) and Miscellaneous[14]. Information on these allocations is, to the knowledge of the authors, not available for different types of households based on their socio-economic characteristics, and therefore mean estimates for the UK are applied to all Supergroups. These categories are then allocated to high level functional uses as shown in Table 1.

Energy and emissions due to personal vehicle use are mapped onto high level functional uses based on information published by the DfT on personal travel by purpose as shown in the Allocation Chart (Table 1) [15]. Again, UK mean figures are

[13] Source: http://www.dti.gov.uk/energy/statistics/publications/energy-consumption/domestic-tables/page18071.html Accessed Oct 06.
[14] Source http://www.dti.gov.uk/energy/statistics/publications/energy-consumption/domestic-tables/page18071.html Accessed Oct 06.
[15] Sources: Trips and distance per person per year by trip purpose (http://www.dft.gov.uk/stellent/groups/dft_transstats/documents/page/dft_transstats_612468.hcsp Accessed Oct06); Allocation of shopping trips to purpose is based on DfT (2007).

applied for each Supergroup due to lack of socio-economically disaggregated data. Personal aviation is allocated to recreation and leisure, assuming that the number of people who privately purchase flights for the purposes of commuting is negligible.

4. Results

4.1 UK national trends 1990-2004

The first question we address is what are the current trends in UK household carbon emissions from the consumption perspective? The graph in Figure 5 shows that emissions decreased slightly on average between 1990 and 1997[16]. However, since 1997 carbon emissions have been steadily rising, with levels in 2004 (172mtC) being 17% higher than those in 1990 (147mtC). In order to explore this in more detail, Figure 6 illustrates trends in total household energy use and carbon emissions indexed to 1990=100, alongside household expenditure in constant prices (2003) [17], also indexed to 1990=100. From this we see that energy use dropped below 1990 levels from 1991 to 1995, but has been steadily rising since 1997. Due to the "dash for gas", carbon emissions decreased at a faster rate than energy use in the early 1990s, and remained below 1990 levels until 1999. However, since then, carbon emissions have risen at the same rate as energy use. Household expenditure has risen every year since 1991, with the year on year increase being slightly higher than the increases in energy use and carbon emissions. From this we can conclude that absolute decoupling occurred between carbon emissions and expenditure between 1992-1995, but since 1997 only very slight relative decoupling is evident, and the current trend is that carbon emissions from the consumption perspective are rising by around 3% per year.

Figures 5 and 6.

Figure 5 shows carbon emissions in four categories: energy embedded in goods and services, direct household energy, and energy due to personal vehicle use and aviation. The largest category is embedded carbon[18]. Its percentage of the total has increased overall with time, commencing at 56% in 1990, it reached its lowest proportion (54%) between 1992-1996, before steadily rising to 60% in 2004. Figure 7 shows the percentage of imported goods and services into the UK economy in monetary terms, and also the percentage of household embedded carbon that is due to imports[19]. This shows that the proportion of embedded carbon that is emitted outside UK borders has increased, rising from around 37% in 1990 to 48% in 2004.

[16] As explained in Section 3.1.1, data for 1991 are not available.
[17] The household expenditure time-series is based on data from Consumer Trends in constant 2003 prices. See http://www.statistics.gov.uk/statbase/product.asp?vlnk=242 downloaded 29.04.08.
[18] This figure is lower than figures that are often quoted because this study does not include energy use and carbon emissions due to government and fixed capital expenditures (see Section 3.1).
[19] Imported carbon includes carbon emitted abroad in producing goods and services directly consumed by households, and carbon emitted abroad in producing goods and services to meet intermediate demand by industry for production of goods and services destined for UK household consumption.

Figure 7.

Figure 5 shows that carbon from direct household energy use is the next largest category of total emissions after embedded carbon. The proportion due to direct household energy use has decreased over time from 30% in 1990 to 24% in 2004, although in absolute terms it estimated to have been the same in 2004 as it was in 1990 (44mtC). The largest percentage change over the time period is carbon from personal aviation, which, although being a low proportion of total carbon, has risen from under 4mtC in 1990 to over 7mtC in 2004, an increase of 86%. Increases in carbon from personal vehicle use are significant but more modest, at 8% over the time period.

4.2 Carbon emissions for different types of UK households (2004)

Figure 8 shows the mean household carbon emissions for each Supergroup, categorised as energy embedded in goods and services, direct household energy, and energy due to personal vehicle use and aviation. The Supergroup with the highest total emissions is Prospering Suburbs. Emissions from this segment are 67% higher than those from Constrained by Circumstances, which has the lowest emissions. The graph also shows the mean emissions level for all UK households, and when we compare against this, we find that Prospering Suburbs' emissions are 24% above the mean and Constrained by Circumstances' are 26% below mean.

Figure 8.

When we look at the relationship between affluence and carbon emissions, we find that, at either end of the income scale, carbon emissions increase with increasing disposable income levels: for example, the most affluent Supergroup (Prospering Suburbs) has higher emissions than the next most affluent (Countryside), and similarly, the least affluent (Constrained by Circumstances) has lower emissions than the second least affluent (Multicultural). In particular, Constrained by Circumstances has the lowest emissions from personal aviation, perhaps reflecting that lifestyles entail less foreign travel due to financial constraints. Conversely, Prospering Suburbs and Countryside have the highest proportion of emissions from personal aviation, reflecting their relative affluence. Constrained by Circumstances stands out as the Supergroup that has the highest proportion of carbon due to direct household energy use. These households are expected to be at most risk of being in fuel poverty, which is defined as household that has to spend more than 10% of its income on energy to heat its home to an adequate standard (DTI 2006). Therefore it is no surprise that a high proportion of the carbon emissions of these households is, on average, due to direct household energy consumption (BERR 2007; Druckman and Jackson 2008b; Moore 2005; Thumin et al. 2007).

In the middle income groups carbon emissions are shown to depend on other factors in addition to relative affluence. For example, the normal weekly disposable income of an average City Living household is about 5% above that in Blue Collar Communities, but their mean carbon emissions are lower in all categories (4% lower overall). With regard to direct household energy use this is assumed to reflect the relative thermal efficiency of flats (which predominate City Living) over terraced housing (which predominate in Blue Collar Communities) (see Appendix 4 and Druckman and Jackson (2008b)). If we look at carbon emissions embedded in goods and services we find that City Living has the highest proportion of its total in this category, reflecting the relative efficiency of direct energy consumption in urban living.

Figure 9 shows the proportions of carbon emissions allocated to high level functional uses for an average UK household. The highest proportion is attributed to Recreation and leisure (26%). Food and catering is next highest at 16%, Space heating is ranked next at 13%, followed by Household (12%) and Clothing and footwear (11%).

Figure 9.

When we look at how typical carbon use by each Supergroup is allocated to high level functional uses (see Figure 10), we find that the proportions do not vary a great deal from the pattern of the average UK household, although the absolute values of carbon vary widely. This is to a certain extent due to data limitations in the model (see Assumptions and Limitations section). However, if we look at Recreation and Leisure, we see that the most affluent Supergroup uses the most carbon for this purpose in both absolute terms (2.3tC which is 0.5tC above UK mean), and also uses the highest proportion of its overall footprint in leisure pursuits (28% of its footprint). Conversely, the least affluent Supergroup, Constrained by Circumstances, uses the least carbon in absolute terms (1.3tC, which is 0.5tC below mean), and devotes just one quarter of its overall footprint to recreation and leisure. With regards to Space heating, City Living and Constrained by Circumstances emit the lowest amounts (22% and 19% below UK mean, respectively), reflecting the superior thermal efficiency of flats.

Figures 10 and 11.

Figure 11 shows the same information as Figure 10 but in this case on a per capita basis rather than per household. The mean number of people per household varies from 2.2 in City Living and Constrained by Circumstances to 2.5 in Prospering Suburbs, with the UK mean being 2.4. These varying household sizes make the differentials between per capita emissions for Supergroups lower than on a household basis, with, for example, Prospering Suburbs only emitting 41% more than Constrained by Circumstances (compared to 67% on a per household basis). When carbon emissions were estimated on a household basis, we saw that although emissions were generally higher for households with higher disposable incomes, the situation was reversed in the middle income ranges. The situation changes when we consider carbon emissions on a per capita basis: on this basis the carbon ranking is in line with disposable income for all Supergroups. However, if we include only adults over the age of 18 in the count per household, the rankings once again deviate from that dictated purely by disposable incomes. The difference that this accounting basis makes is important when, for example, considering Personal Carbon Allowances (Roberts and Thumin 2006; Starkey and Anderson 2005), which can be on a household basis, per capita basis, per adult basis, or they even possibly on an equivalised basis, with graded weightings assigned to children of different ages (Lunn 2005; McClements 1977; Office for National Statistics 2005a).

5. Assumptions and limitations

Accounting from the consumption perspective is challenging with regard to both the methodological assumptions and data limitations. A basic premise of environmental input-output (EIO) modelling is the assumption of linearity: it is assumed that all industrial sectors exhibit constant returns to scale, and that carbon emissions produced by each industry sector are linearly related to the sector output. Hence, by extension, carbon emissions are assumed to be directly related to sector input (Miller and Blair 1985:11; Office for National Statistics 1973). A second important assumption in EIO is that every sector is assumed to be homogeneous with regard to its input requirements, the commodity it produces, and the emissions from the firms within the sector. Therefore the fewer the sectors, the more errors occur (Francis 2004; Nielsen and Weidema 2000) and this is one of the reasons behind the development of a QMRIO model instead of a multi-region model at this stage, as an MRIO model would almost certainly have fewer sectors.

As mentioned in the Introduction, the UK lacks up-to-date datasets for EIO and hence, as stated in the Methodology, 1992-2004 are modelled using the 1995 Leontief Inverse and Imports Use Matrices, and therefore changes in industry structure are not captured in the model. Furthermore, final demand is not available in Basic Prices. The implications of these data shortcomings are covered in detail in Druckman et al (2007), and suffice to say here that they are considerable. In our estimation of the energy and carbon intensity of imports we have used data from GTAP for 2001, and by so doing we assume that the relative intensity of UK's trading partners and proportion of imports from each of the UK's trading partners is constant for all years at 2001 levels. This may result in under-estimates of increases in embedded emissions. The inaccuracies that arise in the input-output model affect only estimates of embedded emissions, which average 57% of total emissions over the study period (emissions due to direct household energy use and personal transportation are unaffected as they are not estimated using the QMRIO model). Despite our model's limitations, our results for 2004 are in broad agreement with those estimated for the UK by Helm (2007), and the nature of the limitations in the accuracy of our estimates of embedded emissions mean that we can have a fair amount of confidence in the general trends shown. Furthermore, our results show that most carbon emissions are due to the broad areas of recreation, housing (including heating) and food, which is in agreement with other studies (for example, Nijdam et al (2005), Tukker et al (2006) and WWF-UK (2006)).

A summary of the major assumptions and limitations incurred in the use of LARA is included here, and for more detailed discussions the reader is referred to Druckman and Jackson (2008b) and Druckman et al (2008). LARA estimates local expenditure, resource use and emissions based on two datasets: the Expenditure and Food Survey (Office for National Statistics various years) and Census 2001 (National Statistics 2005). The small annual sample in the EFS of just 7,000 households limits LARA's accuracy concerning infrequently purchased items such cars and household appliances. Use of Census 2001 assumes that the socio-economic characteristics of local neighbourhoods have not changed between 2001 and 2004. In this study LARA has been applied for England and Wales only, which represents 88% of all UK households, and we assume that the Supergroups represent all UK households. This assumption is most problematic with respect to direct household energy use in Northern Ireland, where households are much more likely to use solid fuel or oil than gas for space heating (DSDNI 2004). Furthermore, although through LARA we can identify the functional uses to which embedded carbon emissions should be allocated for each Supergroup[20], information is not, at this stage, available to identify the functional uses to which direct energy use and personal transportation emissions should be allocated specifically for each Supergroup, as discussed in Section 3.3. This limits the extent to which we can elicit differences between Supergroups in the amounts of carbon attributable to high level functional uses.

Compiling the Allocation Chart shown in Table 1 is an interesting exercise in itself and some of the values are open to debate. For example, should all carbon emissions due to COICOP category 'Catering services' be allocated to high level functional uses 'Food and catering', or should a proportion be allocated to 'Recreation and leisure'? Arguably some attribution to 'Recreation and leisure' may be appropriate, but in this study we have allocated 100% to 'Food and catering'. Our final estimation of emissions attributed to 'Recreation and leisure' may therefore be under-estimated. Assessment of carbon emissions due to aviation are particularly problematic. First, due to the international nature of air travel, many UK citizens book tickets on airlines that are not UK registered companies. The national datasets used in this study include UK registered companies only: we assume that the number of overseas citizens purchasing flights from UK registered airlines balances the number of UK citizens purchasing flights from non-UK registered airlines. Furthermore the boundary between personal flights for recreational purposes and business flights is blurred. This is because many people combine holiday and business trips together, and also some flights are booked personally and then claimed on expenses. In this study we assume that all flights booked by individuals are for personal leisure, and all flights purchased by businesses are used for business purposes only.

6. Discussion

In this study we have used a quasi-multi-regional input-output model (QMRIO) to show that, from the consumption perspective, carbon emissions due to energy use attributable

[20] A caveat to this is that national average values were used for actual and imputed rentals for all Supergroups, as explained in Section 3.2. This is particularly problematic for some Supergroups.

to UK households are estimated to be currently rising by approximately 3% per annum. This is in stark contrast to the proposed statutory goal in the UK's Climate Change Bill of at least 60% reduction in carbon dioxide emissions by 2050 (HM Government 2007)[21], and at even higher odds with the suggestion that the UK must cut emissions by around 6% per annum[22] (Bows et al. 2006). During the study period (1990-2004) household expenditure increased by 49%, and we have shown that absolute decoupling between carbon emissions and household expenditure has not been evident since the early days of the UK's "dash for gas" in the 1990s, although there is currently a small level of relative decoupling. This suggests that technological developments and any of the (sparse) attempts to encourage households to curb their carbon emissions have been, overall, negated by the rebound effect or by "off-shoring" of carbon-intensive industry.

Embedded carbon accounts for over half of the average UK household's carbon footprint, and this proportion is rising. Furthermore, we estimate that, in 2004, approximately 48% of embedded carbon was due to imports from outside the UK, a proportion that has risen by over 10 percentage points since 1990. This presents a particular problem for UK policy as the extent to which an importing country can control the carbon intensity of its exports under current World Trade Organisation rules is limited (Pauwelyn and Sindico 2008).

In the study UK households are segmented into 7 Supergroups based on their socio-economic characteristics using the UK National Output Area Classification. The carbon emissions of the Supergroups vary widely, and are strongly related to affluence. For example, the most affluent Supergroup (Prospering Suburbs) is responsible for 67% more carbon than the least affluent Supergroup (Constrained by Circumstances) on a household basis. Other socio-economic characteristics are also important determinants of carbon emissions. An example of this is that households in City Living have relatively low carbon emissions due to direct household energy use, reflecting the greater thermal efficiency of flats over other types of dwellings. A further example is that households in this is the Supergroup have the highest proportion of carbon emissions embedded in goods and services. The results illustrate the extreme differences between Supergroups and are indicative of the high levels of inequality that currently exist with respect to carbon emissions.

Our study is currently limited in its ability to explore in detail the differences between how carbon emissions due to direct energy use are attributable to high level functional uses for each Supergroup. This is because at the moment we do not have information for each Supergroup concerning, for example, the purpose of their personal vehicle use or the relative quantities of electricity that is used for powering, say, household appliances, lighting and brown goods such as computers and televisions. This is a subject for further investigation, and will be important in targeting specific carbon reduction schemes at different sectors of society. Not withstanding this limitation, a

[21] The target of 60% is currently being challenged with calls for it to be increased to 80%. See, for example, Blundell et al (2008)

[22] Bowes et al (2006) estimate that to constrain global temperature rise to 2 degrees Centigrade the UK budget is around 4.8 billion tones carbon in 2050. Emissions must be stabilized as soon as possible, following which year on year reductions of around 6% are required beginning 2012-14.

striking result is that the average UK household emits over a quarter of its carbon emissions in the pursuit of recreation and leisure activities (including personal aviation), and the most affluent Supergroup uses the highest amount of carbon (in real quantities) and also the highest proportion of their total carbon footprint for these activities. Our study makes it clear the rising aspirations of the UK population for recreational activities (including leisure travel) are making the task of reaching the UK's challenging carbon reduction targets increasingly hard to achieve. However, at the same time, a considerable amount of carbon is locked up in basic household activities such as heating and maintaining the home, feeding ourselves and our families, getting to and from work, and maintaining our health and hygiene (Jackson and Papathanasopoulou 2008). In other words, it is probably wrong to place the blame for climate change entirely on rising consumer aspirations. At least some of the responsibility has to rest with the infrastructures and institutions through which ordinary people meet their everyday needs for subsistence, protection, and communication with family and friends.

These remarks are by no means the final word in unravelling the complex mixture of factors that drive modern consumption patterns. However, they serve to illustrate that reducing carbon emissions attributable to UK households will require a dedicated and sophisticated effort. In particular, we must strive to increase the use of renewable (non-fossil) energy in homes, offices and factories and develop technologies that decouple carbon emissions from expenditure; to work towards international agreements that will reduce emissions embedded in imports; to reduce the need for everyday car travel; to improve the 'systems of provision' used to deliver functional services; to address the elements of consumer 'lock-in' that leave people powerless to change their lives and reduce their carbon impact; and to find new and innovative ways of meeting consumers' aspirations for recreation and leisure. Without concerted efforts in these areas, it is likely that carbon emissions attributable to UK households will continue to rise.

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Table 1. Allocation table for high level functional uses.

COICOP Categories plus Direct Use of Domestic Fuels	CIOCOP category	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.

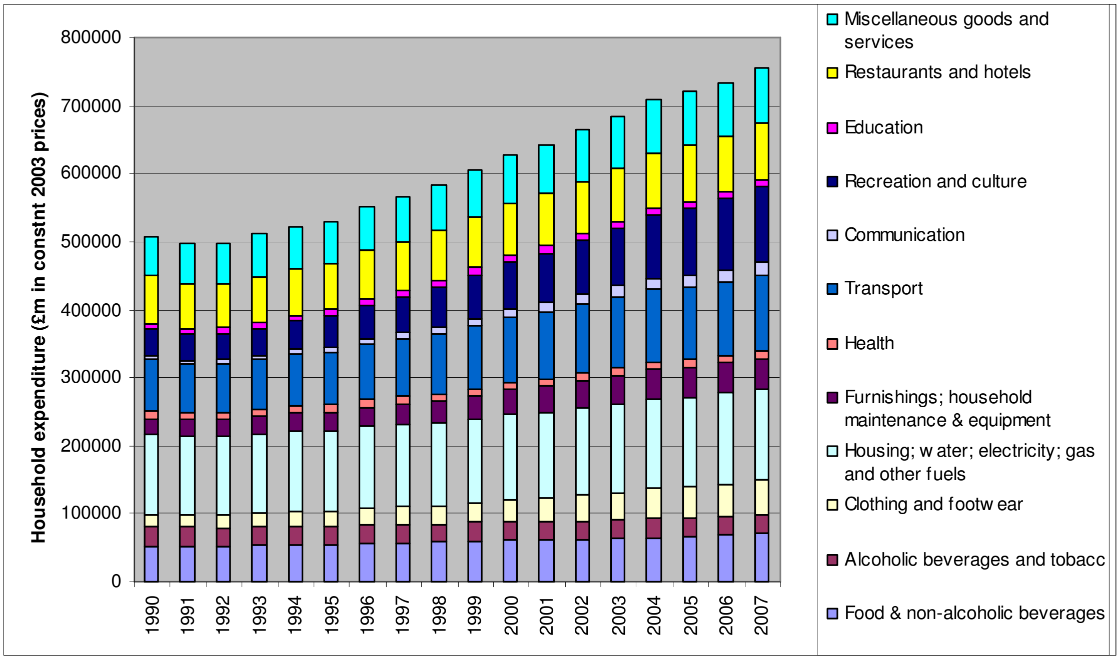

Figure 1. UK household expenditure 1990-2007.

Source: ONS (2008b)

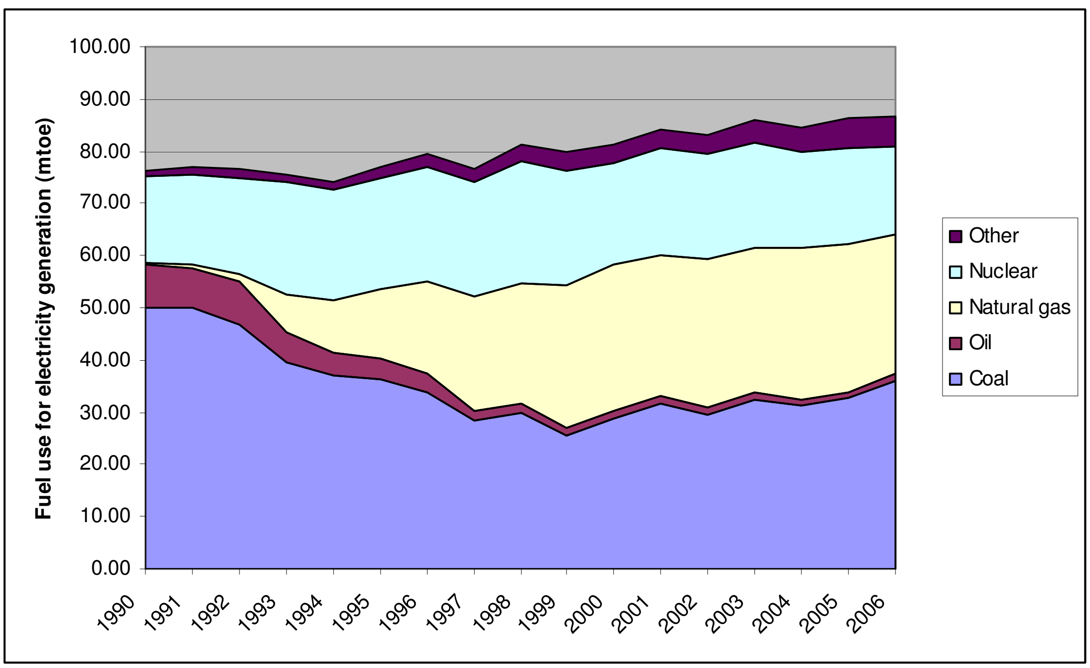

Figure 2. Fuel use for electricity generation 1990-2006.

Source: DUKES (2008)

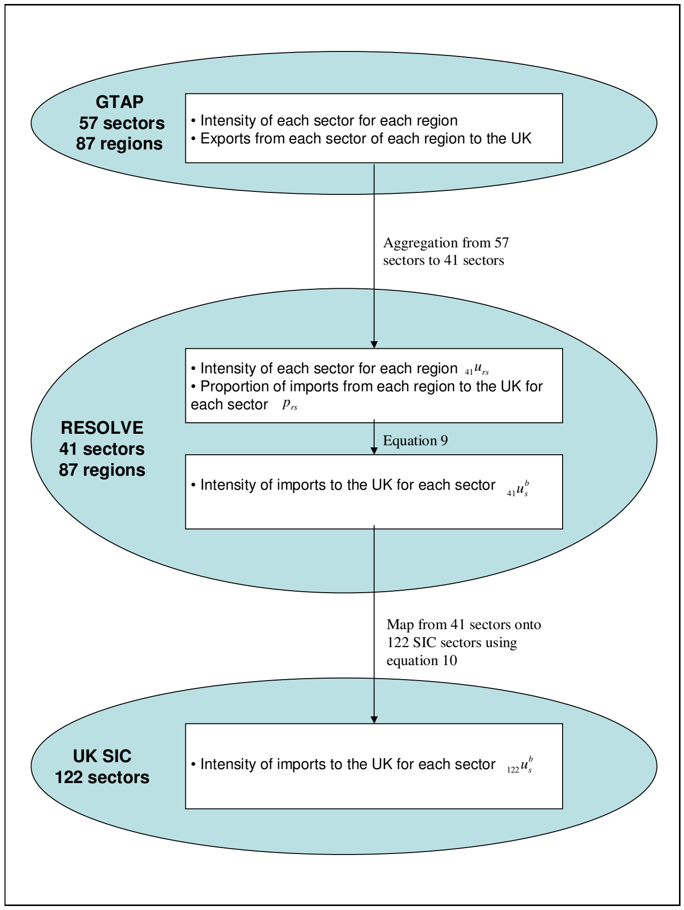

Figure 3. Estimation of intensity of imports using GTAP data

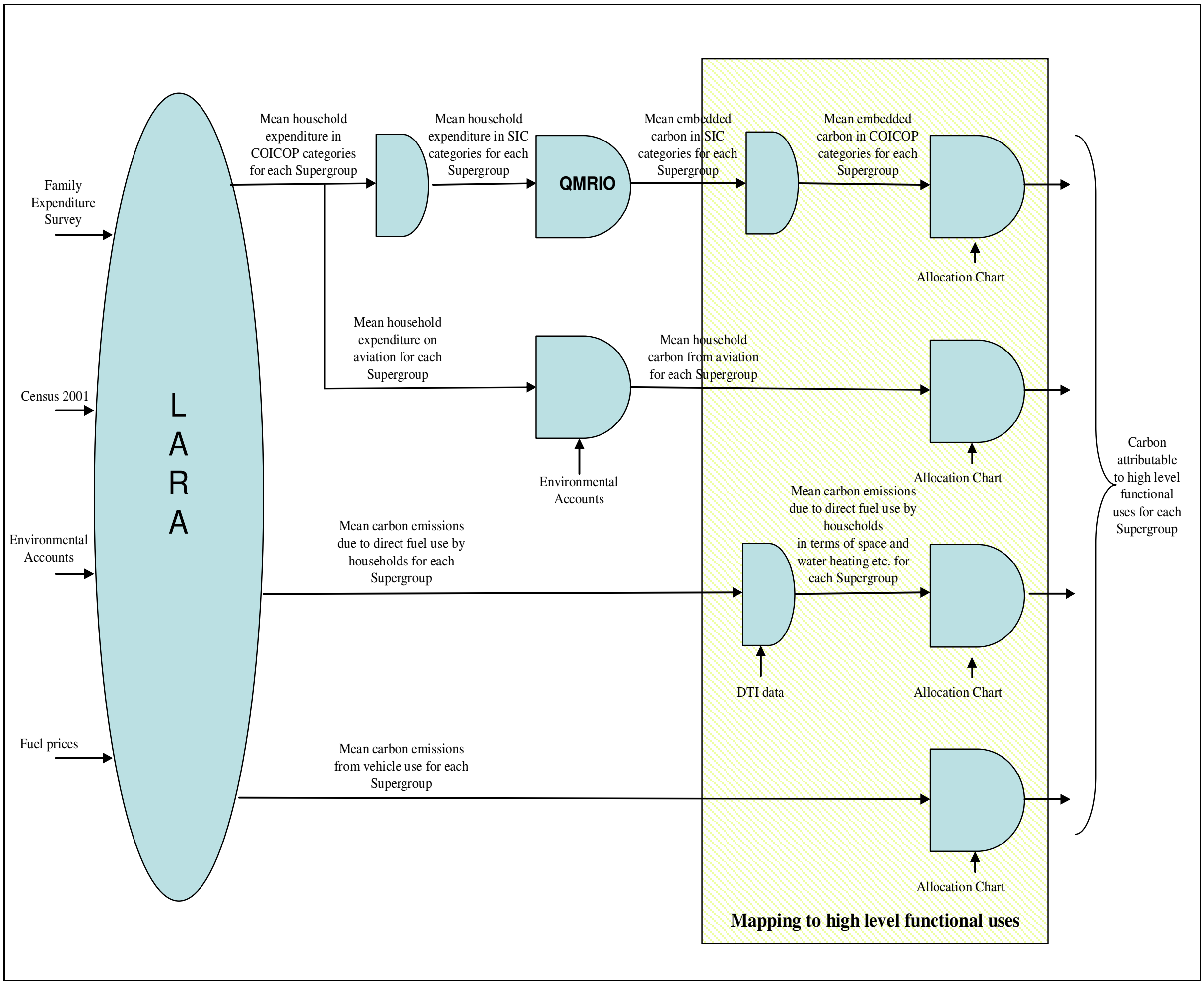

Figure 4. A flow diagram to show estimation of carbon emissions attributable to Supergroups using LARA, and allocation to high level functional uses

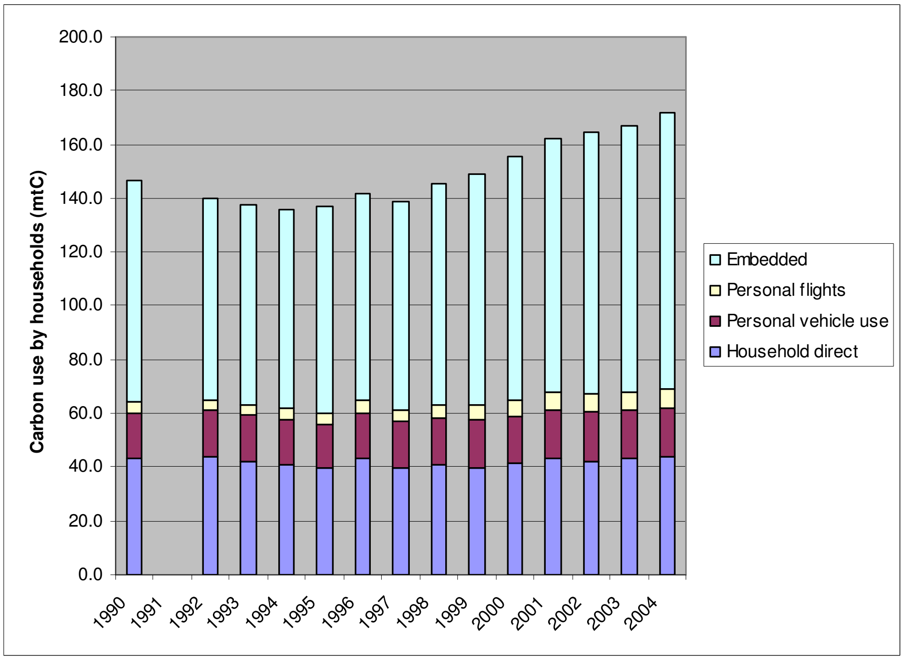

Figure 5. Trends in carbon emissions attributable to UK households 1990-2004.

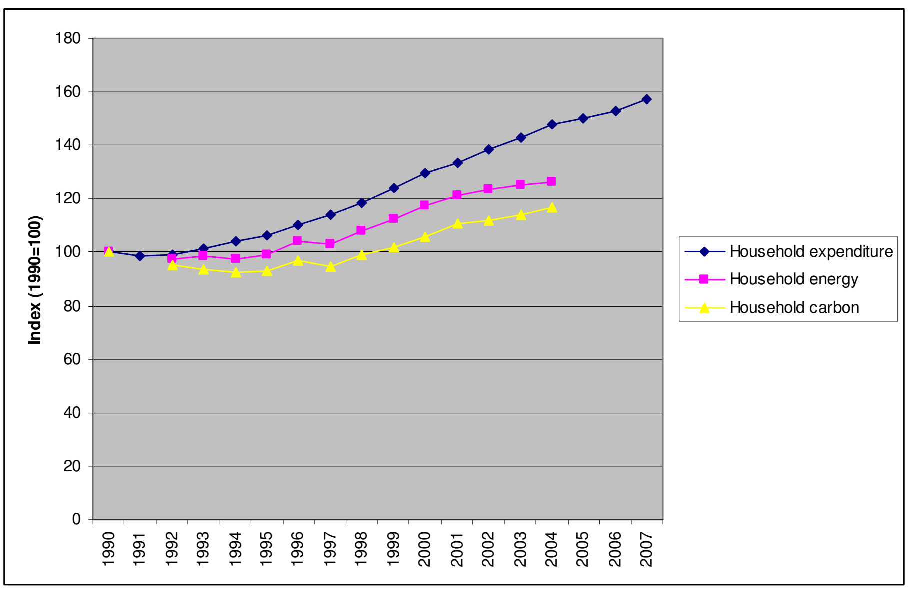

Figure 6. Trends UK household expenditure, energy use and carbon indexed to 1990=100.

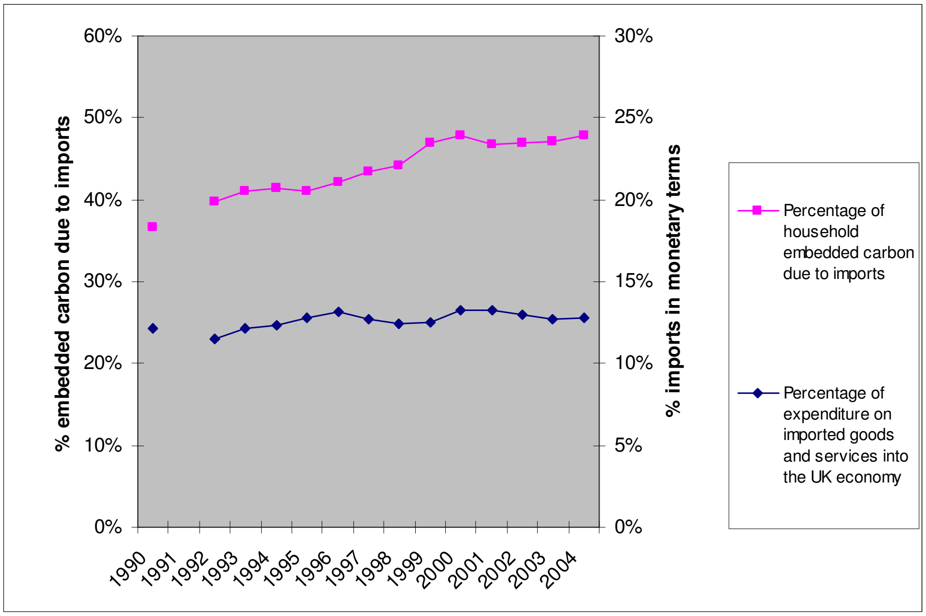

Figure 7. Import trends

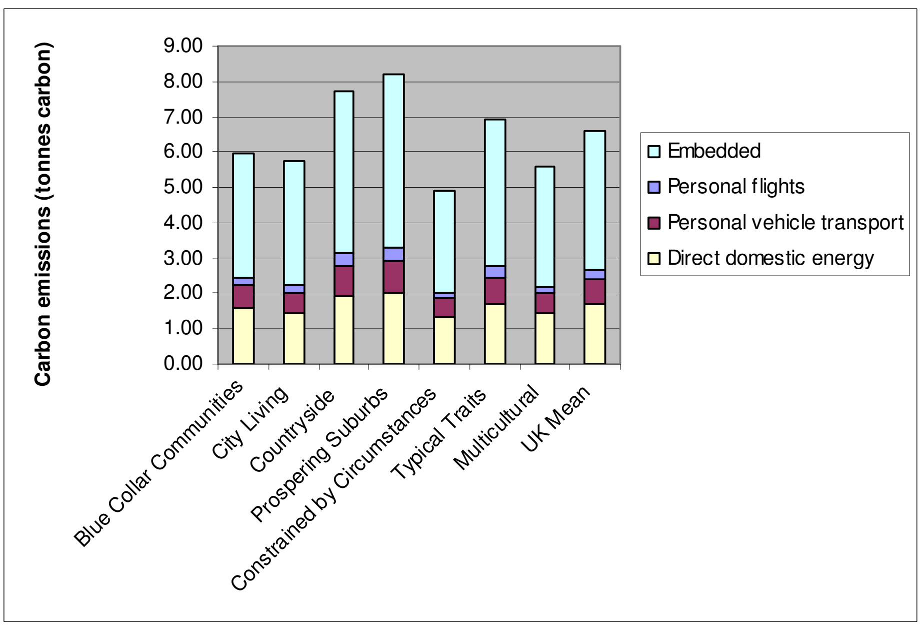

Figure 8. Carbon emissions attributable to Supergroups in 2004.

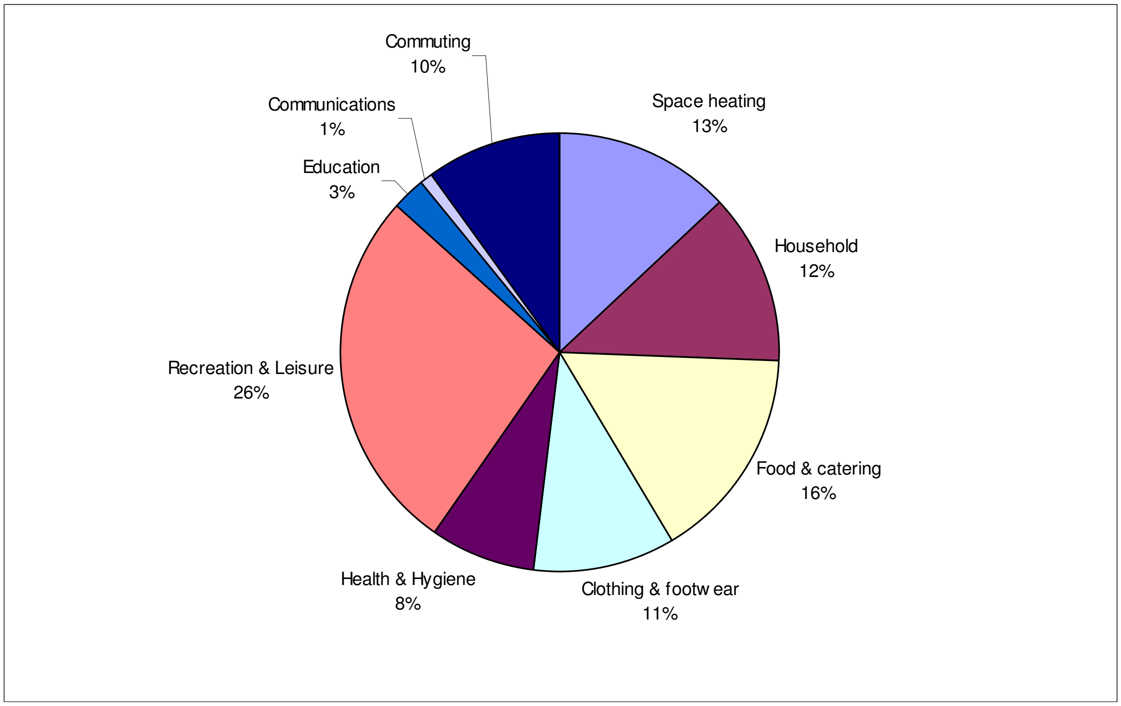

Figure 9. Proportions of carbon emissions allocated to high level functional uses for an average UK household (2004)

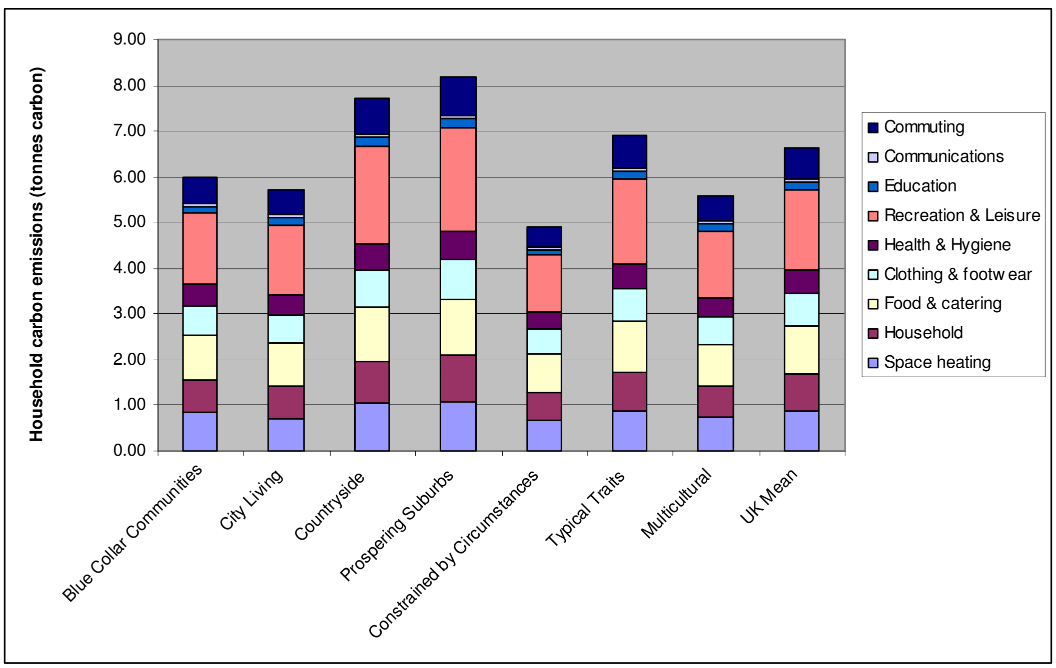

Figure 10. Carbon emissions attributable to Supergroups allocated to high level functional uses (household basis) (2004)

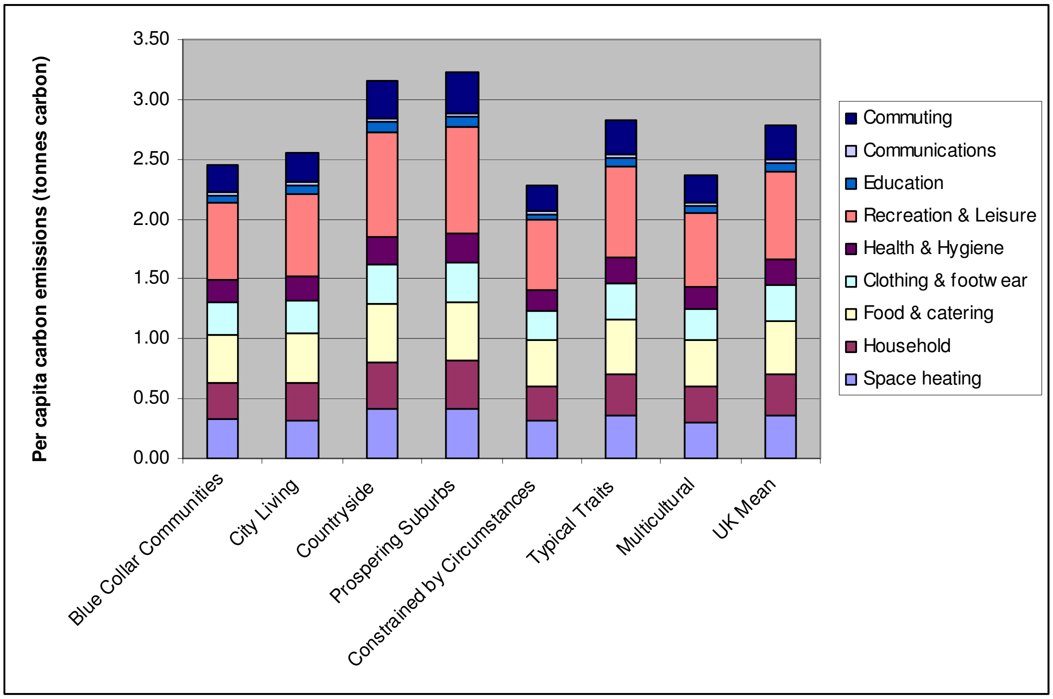

Figure 11. Carbon emissions attributable to Supergroups allocated to high level functional uses (per capita basis) (2004)

Appendix 1. Direct household fuel use, personal vehicle use and personal aviation

Data concerning direct household use of gas, oil coal and other fuels are obtained from the Environmental Accounts Sector 92 (Office for National Statistics 2006b) for each year. Energy and carbon emissions due to domestic electricity use is estimated using data supplied by AEA Energy & Environment from the UK Greenhouse Gas Inventory 2007 NAEI and the Digest of UK Energy Statistics 2006 (DUKES) (Department of Trade and Industry 2006). Data on personal vehicle use are obtained from the Environmental Accounts Sector 93. The data on aviation, which is obtained from Environmental Accounts Sector 70, includes energy use due to business travel (as intermediate demand) and by households (as final demand). We assume that the mix of short- and long-haul flights, and price paid, is the same for these two types of demand, and hence we take a simple proportion using the monetary value of flights purchased from the Supply and Use Tables (ONS 2008a).

Appendix 2. GTAP 6 Regions

Number	Code	Name	Number	Code	Name
1	AUS	Australia	47	LUX	Luxembourg
2	NZL	New Zealand	48	NLD	Netherlands
3	XOC	Rest of Oceania	49	PRT	Portugal
4	CHN	China	50	ESP	Spain
5	HKG	Hong Kong	51	SWE	Sweden
6	JPN	Japan	52	CHE	Switzerland
7	KOR	Korea	53	XEF	Rest of EFTA
8	TWN	Taiwan	54	XER	Rest of Europe
9	XEA	Rest of East Asia	55	ALB	Albania
10	IDN	Indonesia	56	BGR	Bulgaria
11	MYS	Malaysia	57	HRV	Croatia
12	PHL	Philippines	58	CYP	Cyprus
13	SGP	Singapore	59	CZE	Czech Republic
14	THA	Thailand	60	HUN	Hungary
15	VNM	Viet Nam	61	MLT	Malta
16	XSE	Rest of Southeast Asia	62	POL	Poland
17	BGD	Bangladesh	63	ROM	Romania
18	IND	India	64	SVK	Slovakia
19	LKA	Sri Lanka	65	SVN	Slovenia
20	XSA	Rest of South Asia	66	EST	Estonia
21	CAN	Canada	67	LVA	Latvia
22	USA	United States of America	68	LTU	Lithuania
23	MEX	Mexico	69	RUS	Russian Federation
24	XNA	Rest of North America	70	XSU	Rest of Former Soviet Union
25	COL	Colombia	71	TUR	Turkey
26	PER	Peru	72	XME	Rest of Middle East
27	VEN	Venezuela	73	MAR	Morocco
28	XAP	Rest of Andean Pact	74	TUN	Tunisia
29	ARG	Argentina	75	XNF	Rest of North Africa
30	BRA	Brazil	76	BWA	Botswana
31	CHL	Chile	77	ZAF	South Africa
32	URY	Uruguay	78	XSC	Rest of South African Customs Union
33	XSM	Rest of South America	79	MWI	Malawi
34	XCA	Central America	80	MOZ	Mozambique
35	XFA	Rest of Free Trade Area of the Americas	81	TZA	Tanzania
36	XCB	Rest of the Caribbean	82	ZMB	Zambia
37	AUT	Austria	83	ZWE	Zimbabwe
38	BEL	Belgium	84	XSD	Rest of Southern African Development Community
39	DNK	Denmark	85	MDG	Madagascar
40	FIN	Finland	86	UGA	Uganda
41	FRA	France	87	XSS	Rest of Sub-Saharan Africa
42	DEU	Germany			
43	GBR	United Kingdom			
44	GRC	Greece			
45	IRL	Ireland			
46	ITA	Italy			

Source: Dimaranan (2006)

Appendix 3. LARA Methodology

As explained in the main text, LARA estimates expenditure, resource use and emissions for households in small local areas based on their socio-economic characteristics. This is achieved by combining two national level datasets: the UK Family Expenditure Survey (Office for National Statistics various years) and the 2001 Census (National Statistics 2005). The geographical basis of LARA is Output Areas (OAs) as defined by the UK Census 2001. These are areas of approximately 124 households, on average, that are as socio-economically homogenous as possible. The socio-economic characteristics of households in each OA are found from the Census and typical household expenditure by people with matching characteristics is found from the Family Expenditure Survey. Households are categorised into Household Categories (HoCs), which are defined in terms of type of dwelling, tenure, age and economic status of the household representative[23]. The mean household expenditure is estimated using the equation

$$E^{kl} = \sum_{i=1}^{i=N} p_i^l e_i^k \quad (11)$$

where

E^{kl} = average annual household expenditure in local area *l*, on commodity *k*

p_i^l = proportion of households in local area *l,* that are members of HoC *i*

e_i^k = average annual household expenditure commodity on *k,* of households in HoC *i*

i = HoC number, such that *i*=1 to N, where N= total number of HoCs (N=45)

Equation 11 shows LARA in terms of expenditure, and this is used as a basis for final demand in the QMRIO model in order to estimate embedded energy and emissions attributable to household expenditure in local neighbourhoods.

In this paper, particular attention is paid to direct household energy use and personal vehicle use. For these commodities there are wide price variations across different areas of the UK and also prices vary during the sample period of one year. In order to take these variations into account, appropriate price information (according to the time in the year the sample was taken and the household's regional location) is allocated to each sample household in the Expenditure Survey in order to estimate quantity of fuel purchased, or associated carbon emissions[24]. Therefore, for these categories LARA is run in terms of physical quantities, and E^{kl} and e_i^k in Equation 11 represent the consumption of fuel or carbon emissions instead of expenditures.

[23] Each household has a designated Household Reference Person (HRP) who, for a person living alone is that person, or for more than one person, is chosen on the basis of their economic activity, followed by age (Office for National Statistics 2001).

[24] Matrices of price information were kindly supplied by the Centre for Alternative Energy http://www.cse.org.uk/ .

Appendix 4. Selected characteristics of OAC Supergroups

	Blue Collar Communities	City Living	Countryside	Prospering Suburbs	Constrained by Circumstances	Typical Traits	Multicultural
Variables distinctively above national average	• Age 5-14 • Rent (public) • Terraced housing • Lone parent households	• Age 25-44 • Population density • Rent (private) • Flats • No central heating	• Age 45+ • Detached housing • Rooms per household • 2+ car households	• Age 45-64 • Detached housing • Rooms per household • 2+ car households • Two adults no children • Households with non-dependant children	• Age 65+ • Single pensioner households • Rent (Public) • Flats • People room • Unemployment	*Typical traits is characterised by its 'averageness'. This Supergroup has few values which are high or low in comparison to the other groups.*	• Age 0-15 • Born outside UK • Population density • No central heating • People per room • Flats • Unemployment • Rent (public and private)
Variables distinctively below national average	• Rent (private) • Flats	• Ages 0-14 • Rooms per household	• Population density • Flats • People per room • Single person household	• No central heating • Terraced housing • Flats • Single person household • Rent (private and public)	• Two adults no children • Rent (private) • Detached housing • Rooms per household • 2+ car household		• Age 45+ • Single pensioner households • Detached housing

Source: Vickers et al (2005), Office for National Statistics (2005b) and Druckman and Jackson (2008b)

Appendix 5. Preparation of expenditure data from LARA for use in QMRIO model

As explained in Section 3.2 embedded carbon for each Supergroup is estimated by running the QMRIO model as given in equations 1, 6 and 7, with household demand for each Supergroup estimated using LARA. However, the results from LARA cannot be directly used in the QMRIO model, as they are in terms of 247 COICOP categories in Purchasers' prices, whereas the QMRIO model requires household final demand in terms of 122 SIC categories in Basic prices. Furthermore UK household expenditure based on the Expenditure and Food Survey differs from that published in the Supply and Use Tables. Therefore the following procedure is required to prepare the expenditure data from LARA for use in the QMRIO model.

Our first step is to find the ratio of expenditure in each SIC category above UK mean household expenditure for each Supergroup in Purchasers' prices. The basis of the conversion from COICOP to SIC is Table 4 ('Households final consumption expenditure by COICOP heading') in the Supply and Use Tables (ONS 2008a). Table 4 is given in only 41 COICOP categories so for the most important sectors in terms of energy use and carbon emissions (for example, food and transport), the conversion is carried out at a more disaggregated COICOP level by manually matching sectors. Information is needed for both 'Actual rentals for housing' and 'Imputed rentals for housing' for use in Table 4. Naturally, the Family Expenditure Survey does not, being a survey, give information on imputed rentals, although it does give information on actual rentals. Therefore imputed rental information cannot be estimated using LARA, and hence national average values for both these categories are used.

The next step is to estimate mean household expenditure in Purchasers' prices in SIC according to the Supply and Use Tables. This is done by dividing national household expenditure[25] as given in the Supply and Use Tables by the estimated number of households in the UK[26]. This is then converted to Basic prices using the methodology explained in Druckman et al (2007). We then assume that the ratio of expenditure on each SIC category above UK mean household expenditure for each Supergroup in Basic prices is the same as that in Purchaser' prices, and hence estimate final demand for each Supergroup for use in the QMRIO equations.

[25] For this exercise final demand due to Not For Profit Institutions Serving Households (NPISH) is not included in household demand. In the estimates of national trends, NPISH final demand has been included in order to achieve compatibility with other work that analyses emissions due to three major types of final demand: households (including NPISH), Government and fixed capital.

[26] This estimation is based on data from DCLG (2008).