Attributing Carbon Emissions to Functional Household Needs: a pilot framework for the UK

Jackson, T., Papathanasopoulou, E., Bradley, P., and A Druckman
Centre for Environmental Strategy, University of Surrey

Abstract

This study presents a framework for attributing carbon emissions to the underlying demand for goods and services to meet people's functional needs. Using a two-region, input-output model, the study re-allocates all direct and indirect carbon emissions associated with UK consumption to high-level functional consumer needs. The study confirms that, from a traditional production perspective, the sectors with the highest carbon emissions are those associated with energy generation and transport (air, water and land). After re-attribution to functional needs, the most important categories in terms of carbon emissions are Recreation and Leisure (31.6 MtC), Space Heating (24 MtC) and Food and Catering (22.4 MtC). Carbon attributable to maintaining the household (22.2 MtC) is also significant, as is the carbon attributable to health and hygiene (21.7 MtC). The paper also indicates that UK consumption is responsible for more carbon emissions than UK production, supporting the oft-cited 'pollution haven' hypothesis. The UK's 'carbon trade balance' amounts to at least 7% of the UK national carbon inventory.

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1. Introduction

The premise of this study is that the responsibility for carbon emissions from economic activity lies, ultimately, with people's attempts to satisfy certain functional needs and desires. It is not a particularly radical hypothesis. At one level, this understanding is inherent in both classical and neoclassical economics (Begg et al 2003, Anderton 2001). Our needs and desires are expressed, in economic terms, 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 and Cobb 1989, Daly 1996, UNCED 1992, UN 2002, DEFRA 2003).

There is, of course, a considerable question mark over the extent to which these commodities do or do not satisfy our needs and desires (Jackson et al 2004). The assumption from economics is that they do – or else we would not buy them. But this assumption has also been the object of considerable criticism for some time from those who argue that there is a kind of mismatch between the proliferation of economic goods and services and the satisfaction of human needs (Fromm 1976, Scitovsky 1976, Illich 1978). Not all of the things we buy contribute equally to our well-being, according to this argument (Jackson and Marks 1999, Max Neef 1992, Røpke 1999). This argument gains some support from the observation that life satisfaction has not changed very much in developed economies during the last thirty years in spite of a doubling of consumer expenditure (Jackson 2004, 2006) and that those with highly materialistic attitudes score less well in subjective well-being than those with less materialist ones (Kasser and Ryan 1993, Kasser 2002).

Though important, indeed crucial, in understanding how we might achieve sustainable consumption (SDC/NCC 2006, Jackson 2006) – these insights lie slightly beyond the scope of this paper to discuss in detail. But once we recognise a causal link between the attempted satisfaction of human needs and the emission of greenhouse gases, there are some equally important questions to be asked of this relationship. In particular, of course, it would be pretty useful to be know how many greenhouse gas emissions are attributable to which kinds of needs and desires. Does the impact come mainly from subsistence needs (food and clothing)? Or from protection (housing and security)? Or from our leisure demands? Or from the need to communicate with our family and friends? How much carbon is attributable to these different sectors of demand? In the broadest terms, these questions demand that we develop a framework for 'mapping' the relationship between our needs and desires and their impact on the environment.

This framework is useful for a number of reasons. In the first place, it would allow us to identify hot-spots: the product service systems which are most significant in terms of carbon impact. This identification can aid us in designing change and in particular in understanding which technical, behavioural and attitudinal characteristics are most important in achieving change. It can also allow us to explore the underlying societal drivers of our carbon impact. One of the key debates surrounding sustainable consumption is concerned with how much of the environmental impact of modern society is associated with the expansion of consumer aspirations, and how much is rather the result of the way in which our product service systems have developed, in technical and institutional terms (Sanne 2002, Jackson 2005a&b, Røpke 1999, Shove 2003). How much of the growing impact on the climate, in other words, is about the pursuit of luxury? And how much is a function of the familiar institutional architecture within which people attempt to live quite ordinary lives?

Again, these discussions lie beyond the scope of this particular paper to address in detail, although we shall return to them briefly in the final section. However, they serve to illustrate the importance of being able to identify both the direct and the indirect (upstream) carbon emissions associated with different categories of consumer activity and household behaviour.

The principal aim of this paper is develop a framework for mapping carbon emissions onto clearly defined functional needs. Or to put it another way, the aim is to identify the carbon emissions attributable to a specific set of high-level functional needs. In the next section we set out a broad methodology for approaching this question, drawing strongly on environmental input-output analysis and discuss the data sources used for the model. In the following section we present the results of applying this methodology to the UK and validate the overall findings against conventional carbon emission accounts. In the final section we discuss the implications of the model and sketch out some possible further work to improve the robustness of the analysis and extend its remit.

2. Methodology

The basis for developing a framework for allocating carbon emissions to underlying consumer needs was to assume that the level of carbon emissions attributable to each functional consumer need should be scaled according to the level of consumer activity in that sector and should include all the carbon 'induced' in the economy in the production of the 'product service systems' which are designed to meet that need. This includes in particular all the 'upstream' and 'downstream' carbon induced in the economy in the provision of particular products and services.

The broad strategy for achieving this aim was to use an environmental input-output (EIO) based methodology for 'mapping' carbon emissions first onto final demand commodity sectors, and then to extend that analysis and map commodity sectors onto higher level functional household needs. The use of EIO for mapping environmental impacts onto final demand sectors is now well-established in the literature. Tukker et al (2005) and Hertwich (2006) each review a wide variety of attempts to use EIO to allocate greenhouse gas emissions (and other environmental impacts) to commodity category at various levels of detail. Several papers have addressed in particular the question of carbon emissions from fossil fuels (Francis 2004, Moll et al 2005, Machado et al 2001, Munksgaard and Pedersen 2001).

This consumption-based approach for attributing carbon emissions to final demand categories differs from the conventional production-based methodology for accounting for emissions. Typically, national emission accounts tend to identify the carbon emissions associated directly with fuel consumption in specific production sectors. This is useful in quantifying the carbon emitted at the level of the economy as a whole by fuel consumption processes within the UK national boundary. It is also useful in comparing the relative carbon intensity of different production sectors. The upshot of such analyses tends to reveal, not surprisingly, that the carbon burden associated with primary sectors – such as electricity production or the manufacture of iron and steel – is higher than the carbon burden associated with secondary or service sectors - say grain milling or financial services.

Since the general tendency in developed economies has been to reduce the preponderance of primary (energy-intensive) sectors in the economy and to increase the so-called service sectors, it is not surprising to find that most industrialised nations have witnessed a steady decline in the energy and carbon intensity of economic output (Jackson 1996, Jänicke et al 1997, Papathanasopoulou 2005, Rothman 1998). Some absolute declines in energy consumption and carbon emissions have also been observed over certain periods of time in various countries. But this production-based perspective neglects two important underlying features of the consumption-production system.

In the first place, in allocating the highest burdens to primary sectors, it fails to identify the underlying drivers for production in those sectors and thence for emissions from those sectors. From a consumption perspective, primary commodities such as electricity and iron and steel are not particularly useful in their own right. Rather they provide functional inputs to a variety of other production processes whose purpose is to meet the 'final demand' for a wide range of other commodities: cars, appliances, buildings, grain milling, financial services and so on. These commodities, in their turn are desired by consumers, not generally for their own sake, but rather for the services they provide in meeting certain underlying functional needs.

Figure 1 illustrates this relationship between functional needs, product-service systems and production sectors using recreation and leisure as an example.

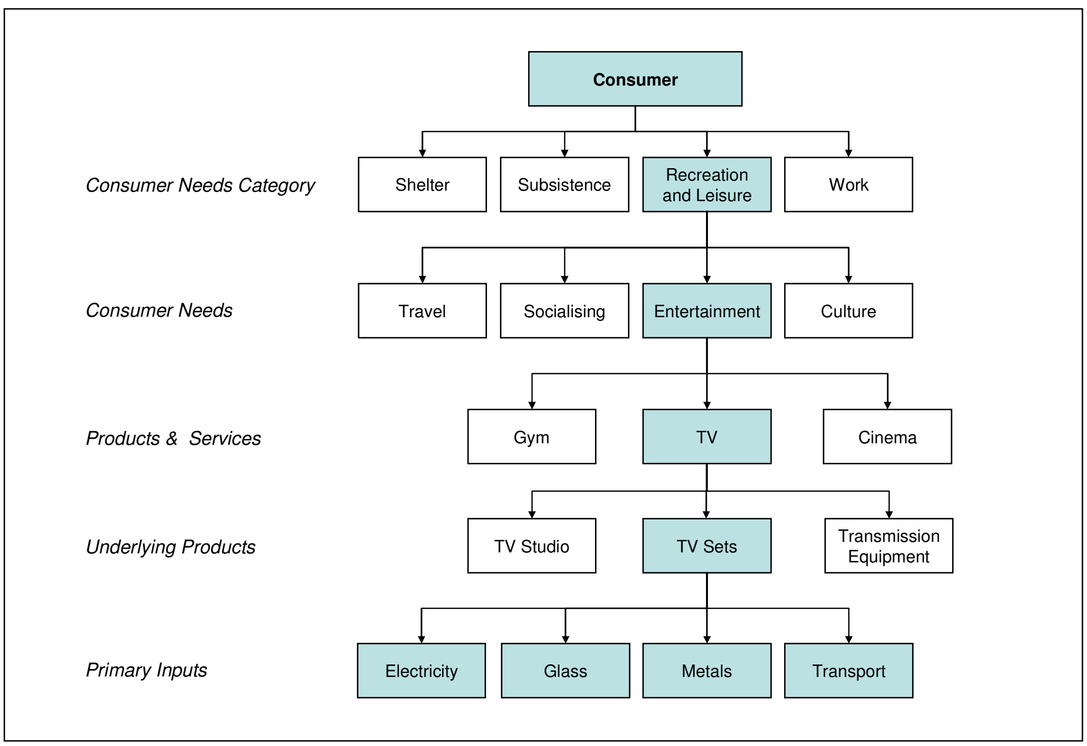

Figure 1: Mapping the Production Implications of Consumer Needs

Figure 1 shows how the satisfaction of the need for recreation and leisure drives a number of subsidiary needs, amongst them the desire for entertainment. This desire stimulates a demand for a specific set of product-service systems such as gyms, cinemas and TV systems. These systems generate in their turn a demand for specific consumer goods – such as TVs – and services – such as electricity. These goods and services have in their turn to be produced in the economy through a variety of different production processes, using a variety of different material and energy inputs, and generating a variety of different environmental impacts.

A second important question is left unanswered by the production perspective, namely: is the reduction in carbon intensity of economic output in the UK matched by a reduction in the carbon intensity of consumption? Or is it rather the case that the demand for consumer products is met by importing primary, semi-manufactured and manufactured goods from other countries? This issue of international trade (in goods and in emissions) is one of the key issues that the consumption perspective attempts to address. It depends critically on the difference between the carbon embodied in the UK's exports and the carbon embodied in the UK's imports and can only be fully answered by reference to a multi-region EIO model (Proops et al 1993, Machado et al 2001, Peters and Hertwich 2005).

In this study, we use a broad EIO framework to prepare six distinct sets of carbon accounts for the UK economy for the year 2002/3. Specifically, the six accounts are as follows:

- Account 1: Production-Based Account
- Account 2: Consumption-Based Account
- Account 3: Consumption Account with Fixed Capital Re-allocated
- Account 4: Consumption Account with Fixed Capital and Distribution Reallocated
- Account 5: Domestic Functional Use Account
- Account 6: High-Level Consumer Need Account

Each of these accounts is described in more detail in the following subsections.

Account 1: Production-Based Account

Carbon emission accounts are usually constructed at the national level by using carbon emission factors to estimate the emissions associated with the direct consumption of fossil fuels in different sectors: industry and commerce, the public sector and by households. This production perspective provides a pretty straightforward accounting framework and is usually reasonably successful in allocating emissions to specific industrial, commercial and domestic processes in an exhaustive and mutually exclusive way within a given geographical boundary.

Essentially, the carbon emissions c_i from each industrial sector i are assumed to be linearly related to sector output x_i and can be calculated by:

$$c_i = u_i\, x_i \tag{1}$$

where

u_i is the carbon intensity coefficient for each sector i calculated as shown below:

$$u_i = \frac{\sum_{n=1}^{n=m} f_n c_n}{x_i} \tag{2}$$

where:

f_n is the quantity of fuel type n used in sector i (n =1 to m)
c_n is the carbon emission factor for fuel type n
x_i is the output of sector i

In vector notation, the total carbon C associated with all production sectors across the economy (including the public sector) is given by:

$$\mathrm{C} = \sum_i c_i = \mathbf{u}'.\mathbf{x} \tag{3}$$

Data on fuel use by fuel type and industrial sector in the UK are collected in a number of places. For the purposes of this exercise we have used the 93-sector Environmental Accounts data prepared by the Office for National Statistics available on the National Statistics website.[1] The fuel consumption in these 93-sector accounts has then been mapped, using linear scaling assumptions, onto a 122-sector account to make them compatible with the UK input-output accounting framework (Office for National Statistics 2004). The Environmental Accounts report fuel consumption in several different fossil fuel categories including: coal, fuel oil, gas oil, petrol, DERV and aviation fuels. For the purposes of this study, carbon emission factors for these fuels have been taken from the revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, available on the IPCC website.[2]

To this production sector carbon, C, we must also add the carbon C_{dom} associated with the direct consumption of fossil fuels for heating, cooking and so on people's homes and also the carbon C_{trans} associated with the direct consumption of transport fuels by private households. These data are collected annually in the Digest of UK Energy Statistics (DUKES 2005 eg). They are also reported in summary form as sectors 91 to 93 of the Environmental Accounts data. Total carbon, C_{tot}^{prod}, reported in the production perspective is given by:

$$\mathrm{C}_{tot}^{prod} = \mathrm{C} + \mathrm{C}_{dom} + \mathrm{C}_{trans} \tag{4}$$

1 http://www.statistics.gov.uk/statbase/Expodata/Spreadsheets/D5688.xls.
2 http://www.ipcc-nggip.iges.or.jp/public/gl/guidelin/ch1wb1.pdf.

Account 2: Consumption Based Account

The first step in attributing carbon emissions to functional consumer needs is to map the production sector carbon C onto final demand sector commodities. This is the familiar use of the EIO framework following the pioneering work of Leontieff (1966). More extensive details of the underlying methodology can be found in a number of places including Miller and Blair (1985), Proops et al (1993), Francis (2004), Papathanasopoulou (2005). Broadly speaking, the vector of industry output, **x**, is related to the vector of final demand, **y**, using the conventional input-output equation:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \tag{5}$$

where:

I is the identity matrix;
A is the matrix of technology coefficients;
$(\mathbf{I} - \mathbf{A})^{-1}$ is the Leontieff inverse.

Substitution for **x** in equation (3) using equation (5) yields:

$$C = \mathbf{u}'.(\mathbf{I} - \mathbf{A})^{-1}.\mathbf{y} \tag{6}$$

By diagonalising **u'** and splitting **y** into separate final demand column vectors corresponding to the separate final demand components of household demand, government demand, investment (gross fixed domestic capital formation) and exports, it is possible to identify the carbon induced in the economy for each commodity sector and for each category of final demand. So for example, we can identify the carbon attributable to the final demand by households for textiles, say, and this will be equivalent to the carbon induced in all contributing sectors in the economy as a result of the demand for textiles by households.

Since the aim of this exercise is to identify the carbon attributable to UK consumers we will want to exclude from the calculation any carbon attributable to final consumer demand abroad, even if these were produced in the UK. On the other hand, we will want to include all the carbon associated with goods consumed in the UK even if these goods were produced abroad and delivered direct to final demand, or indeed if they rely on intermediate goods which were themselves produced abroad.

These boundaries around the accounting problem are illustrated in Figure 2. UK production is shown in the upper left hand rectangle in the Figure. Most of this production (shown by the flow P) is destined for UK consumption (the oval on the upper right of the picture. A small part of UK production, however, marked by the green (lighter shaded) area in the upper left rectangle, is destined for consumption overseas (Rest of World), either as intermediate demand (flow S) or as final consumption (flow T). Likewise a small part of the Rest of World production, shown by two red (darker shaded) areas in the large rectangle on the bottom left of the Figure is destined for the UK. Some of this (illustrated by flow Q) is destined for intermediate consumption by UK industries and some is destined for final consumption by UK consumers (flow R).

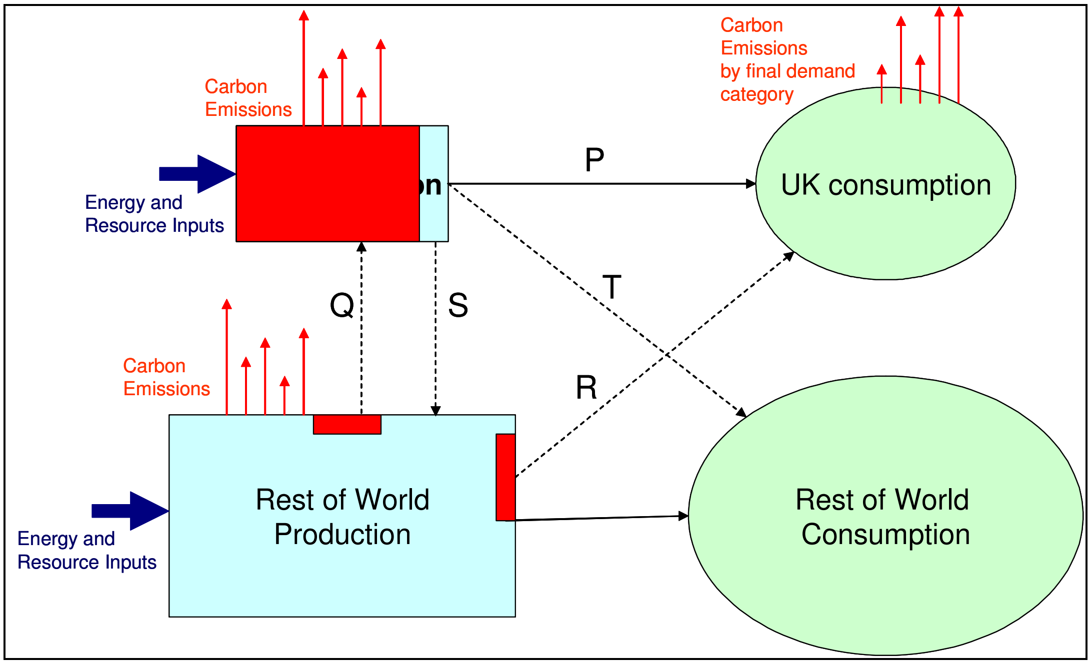

Figure 2: Two-Region Carbon Attribution Model

In summary therefore, we denote by:

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

C_Q – 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;[3]

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

C_S – the carbon associated with the flow S of goods produced in the UK to meet intermediate demand in the Rest of the World;[4] and by

C_T – the carbon associated with the flow T of goods produced in the UK to meet final demand in the Rest of the World;

Then we can express the carbon, C_{tot}^{prod}, associated with the UK from a production perspective as:

$$C_{tot}^{prod} = C_P + C_S + C_T + C_{dom} + C_{trans} \tag{7}$$

while the carbon C_{tot}^{cons} associated with the UK from a consumption perspective is given by:

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3 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.

4 Note that, in principle, some of the carbon C_S may support intermediate processes used in the Rest of the World to produce goods destined for intermediate or final demand in the UK. This carbon is usually ignored in the literature on the basis of the relative size of the UK by comparison with the Rest of the World – an assumption known as the small country assumption (Proops et al 1993).

$$C_{tot}^{cons} = C_P + C_Q + C_R + C_{dom} + C_{trans}. \quad (8)$$

Equation (7), denoting the carbon associated with the UK economy from the production perspective can be calculated easily from the identity:

$$C = C_P + C_S + C_T \quad (9)$$

where C is given by equation (3). For the consumption perspective, we need to derive explicit expressions for each of the components C_P, C_Q and C_R. This derivation is beyond the scope of the present paper. However, details can be found in Proops et al (1993), Papathanasopoulou (2005) and Jackson et al (2006). It turns out that, after making the small country assumption (footnote 4) the following identities hold:

$$C_P = \mathbf{u^{1'}(I - A_1)^{-1}y^{11}} \quad (10)$$
$$C_Q = \mathbf{u^{2'}(I - A_2)^{-1}B_{21}(I - A_1)^{-1}y^{11}} \quad (11)$$
$$C_R = \mathbf{u^{2'}(I - A_2)^{-1}y^{21}} \quad (12)$$

where:

$\mathbf{A}_\alpha$ is the matrix of intra-regional technical coefficients for region α;
$\mathbf{B}_{\beta\alpha}$ is the imports use coefficients matrix for imports from region β to region α;
$\mathbf{u}^{\alpha}$ is the vector of carbon coefficients for region α; and
$\mathbf{y}^{\beta\alpha}$ is the vector of final demand for commodites produced in region β and consumed in region α.

In order to simplify the data requirements, we also make the assumption that imported goods have the same carbon footprint as those produced domestically. In other words, we assume the following condition holds:

$$\mathbf{u^{1'}(I - A_1)^{-1} = u^{2'}(I - A_2)^{-1}} \quad (13)$$

Equation (13) then allows us to express equations (11) and (12) as:

$$C_Q = \mathbf{u^{1'}(I - A_1)^{-1}B_{21}(I - A_1)^{-1}y^{11}} \quad (14) \text{ and}$$
$$C_R = \mathbf{u^{1'}(I - A_1)^{-1}y^{21}} \quad (15)$$

and it is then possible to construct the carbon attribution model using available UK data sources.

Specifically, the calculations are based mainly on data for the year 2002 using 122 by 122 Input-Output classification sectors (HMSO 2004). This classification is based on the UK Standard Industrial Classification of Economic Activities (HMSO 2003). Data for industry sector output **x** are taken from National Statistics data published annually in the *Blue Book* and available on the web. Taken together with the Environmental Accounts data on energy emissions by industry and the IPCC carbon emission factors, output data can be used to calculate the vectors **u** of sectoral carbon emission coefficients. Final demand data **y** are also taken from National Statistics data available in the *Blue Book* and published on the web (Office for National Statistics 2003).

The Leontieff inverse $(\mathbf{I}-\mathbf{A}_1)^{-1}$, and the imports use coefficient matrix $\mathbf{B_{21}}$ are obtained from the most recent UK structural input-output table publication available (Office for National Statistics 2002b). This publication reports 1995 structural tables due to the unavailability of more up-to-date versions of the required tables. The imports use matrix is calculated from 'free on board' (f.o.b.) prices, which are converted to basic prices by accounting for insurance and payments on freight, customs uplift, taxes, subsidies and distribution margins (Papathanasopoulou 2005). The import final demand vector, $\mathbf{y^{21}}$, for 2002 is obtained from the Office of National Statistics data. This is also presented on a f.o.b basis and is converted to basic prices as described above.

As with Account 1, equation (8) also includes data on direct emissions due to fossil fuels consumed in residential homes and transport fuel demand by private consumers. These data are drawn directly from Digest of United Kingdom Energy Statistics (DUKES 2005).

Account 3: Consumption Based Account with Fixed Capital Reallocated

The aim of this study was to get as close as possible to attributing carbon to final consumer needs. Account 2 allows us to allocate carbon to final demand sectors on a commodity by commodity basis. One of the final demand sectors reported in the final demand vector **y** is gross domestic fixed capital formation (GDFCF) or 'investment'. 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 carbon associated with them – are still intermediate inputs to the other commodity sectors. To pursue our aim of attributing carbon to final demand, we should ideally re-distribute the carbon associated with these investments as an input to the sectors supported by the investment. This task is complicated by two factors. In the first place, data on capital investment in different sectors are reported – in the UK *Blue Book* – but only at relatively high levels of aggregation of industrial sector, whereas we need to be able to allocate investment carbon as an input to each of the 122 input-output sectors in the model. In the second place, allocating the carbon associated with this year's GDFCF, 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.

In order to make progress here, we make two simplifying assumptions about the allocation of investment carbon to final commodity sectors. The first is that the carbon associated with investment within each high-level SIC code is proportional to the output from the sub-sectors within that code. The second is that the economy is in a steady state – ie, 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.[5] Using these two assumptions it is possible to allocate the carbon associated with GDFCF in the following way:

- first, the total carbon from final demand in the category GDFCF is allocated to high-level industrial sectors according to the allocation of GDFCF to SIC sectors in the *Blue Book*;
- next, the carbon associated with high-level sectors is allocated to IO sectors within each high-level sector on the basis that investment carbon in each IO subsector is proportional to the output of the subsectors;
- an 'additional' carbon coefficient $u_{i,fcf}$ is calculated for each IO subsector i by dividing the investment carbon attributed to each subsector by the output from that subsector;
- the carbon attribution model described in Account 2 is re-run with a new vector $\mathbf{v}$ of carbon coefficients with components given by $v_i = u_i + u_{i,fcf}$ for each sector i.

Carbon from the domestic sector and from private transport is unaffected by the calculation.

Account 4: Consumption Based Account with Fixed Capital and Distribution Reallocated

From a functional use perspective, distribution is required to deliver final commodities to consumers. Once again, therefore, this 'final demand' category is really an intermediate demand required to support the distribution of other final demand commodities to consumers. Therefore the carbon associated with the sectors 'Retail Distribution', 'Wholesale Distribution' and 'Motor Vehicle Distribution and Repair' is re-allocated to the commodity sectors that are served by the distribution industries. Carbon associated with the sector 'Motor Vehicle Distribution and Repair' is allocated to the sector 'Motor Vehicles'. The carbon associated with wholesale and retail distribution is allocated to the other commodity sectors on a proportional basis, using data on distribution margins in each commodity sector reported in the UK final consumer expenditure accounts. Carbon from the domestic sector and from private transport is unaffected by the calculation.[6]

Account 5: Domestic Functional Use Account

Up to this point, we have allocated all the carbon associated with economic sectors on the basis of IO commodity categories such as iron and steel, textiles, meat processing, electricity production, financial services and so on. If the aim is to identify the carbon associated with high-level functional needs, we require some way of allocating these

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5 This assumption is also made by Lenzen (1998) for Australia and by Hertwich et al (2002) for Norway, the only other studies we have encountered which attempt to endogenise investment as an input to commodity sectors.

6 This account is used for illustrative purposes. The later Accounts are based in fact on Account 3, rather than on Account 4, as the COICOP classification makes its own allocation of the distribution sector outputs to consumer expenditure categories.

commodity sectors to the high-level needs. A useful way of proceeding here is to use the United Nations Classification Of Individual COnsumption by Purpose (COICOP) which allocates household final demand commodity purchases into around 40 functional use categories, divided into 12 high-level categories:[7]

1. Food and non-alcoholic beverages;
2. Alcohol and Tobacco;
3. Clothing and Footwear;
4. Housing, water, electricity, gas and other fuels;
5. Furnishings, household equipment and routine household maintenance;
6. Health;
7. Transport;
8. Communication;
9. Recreation and culture;
10. Education;
11. Restaurants and hotels; and
12. Miscellaneous goods and services.

For a variety of reasons, neither the 12 high-level categories nor the 40 or so lower-level categories quite work for our purposes. Keeping 40 separate categories does not help us in attributing carbon to high-level needs. On the other hand 12 categories is too few. For example, we need to keep separate the carbon associated with expenditures on gas, electricity and other fuels as these are accounted for separately using DUKES data; we need to separate out the carbon associated with expenditures on transport fuels (petrol and DERV); we want to be able to identify separately expenditures on different types of electrical appliances as these are associated with different high-level needs; and so on.

To overcome these difficulties we have aggregated the more detailed COICOP classification into a variety of domestic functional categories as set out in Table 1. This classification allows us to attribute all the carbon associated with commodity categories from household final demand calculated in Account 3 to the domestic functional use categories in Table 1.[8] In addition, Table 1 illustrates how we have addressed the issue of carbon emissions from the public sector.[9] Specifically, where public sector categories (such as spending on health, on education and on recreation) have a matching category in the COICOP classification, we have allocated the carbon emissions attributable to public sector final demand to these household categories. The assumption here is, once again, that it is the demand for health, education and recreation by households that ultimately must be regarded as the driver for public expenditures in these areas. The remaining (relatively small) carbon emissions from the public sector (mainly associated with administration and defence) have all been allocated to one functional category 'Other Government'.

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7 The data for the COICOP allocation are taken from Table 4 in the Supply and Use Tables published by the Office for National Statistics.

8 We have used the allocation of economic sector carbon from Account 3, rather than Account 4, because the COICOP matrix provides its own allocation of distribution sector outputs to functional use categories.

9 Where public sector allocations have been added to COICOP subcategories we have indicated this with the word public in Table 1.

Functional Use Category	COICOP Sectors
Food and non-alcoholic drink	1.1, 1.2
Alcohol and Tobacco	2.1, 2.2
Clothing and Footwear	3.1, 3.2
Housing	4.1, 4.2, 4.3, 5.5, 5.6, 11.2
Water Supply and other misc. services	4.4 (+ public)
Furnishings and other household (ex appliances)	5.1, 5.2, 5.4
Household Appliances	5.3
Health and Hygiene	6.1, 6.2, 6.3, 12.1 (+ public)
Transport Services (ex private transport fuels)	7.1, 7.2, 7.3
Post and Communications	8.1, 8.2, 8.3
Recreation and Entertainment	9.1 – 9.4 (+ public)
Books and Newspapers	9.5
Other Personal Effects	12.3
Holidays	9.6
Education	10 (+ public)
Financial and Other Services	12.4, 12.5, 12.6, 12.7
Other Government	(public)
Delivered Fuels (Indirect)	4.5 (part)[10]

Table 1: Mapping COICOP Sectors to Functional Use Categories

Finally, Account 5 breaks down the carbon associated with direct consumption of fossil fuels by households into a number of distinct enduse categories on the basis of data on household energy consumption by fuel type and enduse obtained from DUKES (2005) and from DTI statistical databases available on the website.[11] These enduse categories include:

- space heating
- water heating
- cooking
- lighting
- cold appliances
- wet appliances
- brown appliances (consumer electronics) and
- other miscellaneous electrical appliances.

Account 5 therefore provides a breakdown of carbon emissions in terms of a set of 27 domestic functional use categories. Some of these categories relate to the 'upstream' or indirect carbon emissions associated with the production of goods and services provided to households either on the market or via the public sector. Other categories relate to the direct consumption of delivered fuels (coal, oil, gas, electricity and transport fuels) by households.

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

[11] http://www.dti.gov.uk/energy/inform/energy_consumption/table.shtml

Account 6: High-level Consumer Needs Account

In the final account, an illustrative attribution has been made to high-level functional needs categories. We have selected 10 high-level needs to include:

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

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 and Marks 1999, Jackson et al 2004, Jackson 2005c). 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. A part of the aim of this paper is to be able to identify the importance of these different categories of need in terms of their carbon impact.

These high-level categories are derived essentially through an allocation (or re-allocation) of the 27 domestic functional use categories derived in Account 5. For example, emissions related to 'Clothing and Footwear' and to 'Other Personal Effects' have been aggregated into one high level category. Likewise emissions related to 'Financial Services' are assumed to be a necessary part of running the household and are allocated to the high level category 'Household'.

In addition to aggregating some emission categories, we have also made an attempt to re-allocate household appliance use and direct fuel consumption to individual high level needs. For example, the Food and Catering category includes carbon associated with purchases of food products, the purchase and use of cooking equipment, the use of catering facilities and the private and public travel required to meet these different requirements. A complete allocation of the 27 domestic functional use categories to the 10 high level consumer needs categories is shown in Table 2. Data for the re-allocation of transport related emissions to functional needs categories are based on data from the Department of Transport's Travel Use Survey and from data on transport use published on the DfT website.[12]

[12] Available at: http:www.dft.gov.uk/stellent/groups/dft_control/documents/contentservertemplate/dft_index.hcst?n=14133&l=4.

	Account 6: High-Level Functional Needs									
Account 5 Domestic Functional Use Categories	**Household**	**Recreation & Leisure**	**Space Heating**	**Food & Catering**	**Commut-ing**	**Health & Hygiene**	**Clothing & Footwear**	**Education**	**Communi-cation**	**Total**
Space Heating			100%							100%
Private Transport	3%	41%		5%	36%	7%	3%	4%		100%
Transport Services (indirect)	3%	41%		5%	36%	7%	3%	4%		100%
Food & Non-alcoholic drink				100%						100%
Health & Hygiene						100%				100%
Water Heating						50%	50%			100%
Recreation & Entertainment		100%								100%
Financial & Other Services	100%									100%
Other Personal Effects							100%			100%
Education								100%		100%
Housing	100%									100%
Public Admin & Defence									100%	100%
Household Appliances	25%	25%		25%		13%	13%			100%
Electricity (lighting)	100%									100%
Electricity (brown goods)		100%								100%
Electricity (cold appliances)				100%						100%
Holidays		100%								100%
Furnishings & Other Household	100%									100%
Clothing & Footwear							100%			100%
Electricity (wet appliances)						50%	50%			100%
Delivered Fuels (indirect)			75%			13%	13%			100%
Cooking				100%						100%
Alcohol & Tobacco		100%								100%
Electricity (misc)	100%									100%
Post & Communication									100%	100%
Water Supply & Other Misc Services						75%	25%			100%
Books & Newspaper								100%		100%

Table 2: Allocating Domestic Functional Use Categories to High-Level Consumer Needs

Assumptions and Limitations of the Model

The study is based on standard EIO which is subject to a number of fundamental assumptions and limitations. A basic premise of EIO is the assumption of linearity: it is assumed that all industrial sectors exhibit constant returns to scale (i.e. there is a direct relationship between inputs and outputs), 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; 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). An illustration of one of the ramifications of this assumption is that all consumer purchases from one commodity sector are assumed to have the same carbon intensity, whereas, for example, luxury purchases will generally have a lower carbon intensity than standard purchases (Vringer and Blok 1995).

Standard EIO assumes a steady state economy and hence a linear relationship between final deliveries and outputs is assumed; thus accumulating or depleting stocks are not accounted for (Duchin and Szyld 1985). This assumption is particularly important when considering fixed capital as, by treating fixed capital as a final demand category, it is assumed that the capital expenditure of each year is the capital required to produce infrastructure in the same year (Hertwich 2005).

A general drawback in EIO is the lack data availability. The use of the 1995 input-output structural table due to the absence of a more recent table assumes that the structure of economic production processes is the same in 2002 as it was in 1995. Shifts in economic structure between 1995 and 2002 – arising for example from changes in the efficiency of processes or input substitution effects – may not be accounted for. This may lead to some misallocation of carbon emissions between sectors. Work is ongoing to update the 1995 structural table to improve the applicability of the model.

It is assumed for the purposes of this study that imported goods have the same carbon footprint as those produced domestically. This condition is not particularly satisfactory as it assumes that the economic structure and energy mix in the Rest of the World can be approximated by those in the UK. This may be true for some importing regions but is likely to underestimate the carbon associated with imports from the developing countries where less energy efficient and more energy intensive processes may dominate the economic structure. This is most likely to cause an under-estimation of carbon emissions attributed to goods produced in countries with less carbon efficient technology than that of the UK (Lenzen et al. 2004; Peters and Hertwich 2005) On-going work aims to replace the need for this assumption by developing more sophisticated proxies for overseas production.

The study explicitly the informal economy, and therefore goods that are traded from consumers to consumers directly in the satisfaction of functional needs are excluded (Tukker et al. 2005:49). The study model survey-based data collected and published by national agencies. Errors arise due to sampling and reporting errors (Lenzen 2000; Miller and Blair 1985). Data are provided in various classification systems, and errors arise in mapping these onto one another; for example, data on fuel type and industry sector are available in the 93-sector Environmental Accounts, which was mapped onto a 122-sector account, as described in Section 2 above. Furthermore, some inaccuracies will arise due to converting price data, such as import data and consumption data, to basic prices and in allocating investment (GDCFC) carbon and distribution sector carbon to user sectors using linear proportionality assumptions.

Finally, this study only considers carbon dioxide emissions from fossil fuel consumption. Other sources of carbon dioxide emission from economic activity are excluded as they are assumed to be minor (Proops et al. 1993). These excluded sources include the production of carbon dioxide as a by-product in glass-making and in the manufacture of bricks and tiles from 'carbonaceous' clays, and carbon emissions produced by the incineration of waste materials containing plastics or other carbon based materials. On the other hand, greenhouse gas emissions – particularly from methane and nitrous oxide – are likely to change the results calculated here considerably and are the focus of on-going investigation.

3. Carbon Accounts for the UK

The model described in the previous section was used to attribute carbon emissions from fossil fuel consumption to production and consumption sectors and to high-level consumer needs in the year 2002. In this section, we describe the results achieved for each of the six different Accounts, and provide a top-level validation of the overall carbon burden based on existing national inventory data.

Account 1: Production Based Account

From a production perspective, the total carbon dioxide emitted by the UK economy in 2002 was 164.7 million tonnes of carbon (MtC)[13]. The largest proportion of these emissions (88 MtC or 57% of the total) came from 'indirect' emissions from the production of private and public sector goods and services in the economy (Figure 3).[14] Domestic electricity consumption accounted for an additional 22 MtC (13%), the direct consumption of fossil fuels in households accounted for 25.3 MtC (15%) and the direct consumption of transport fuels for private transport (cars) by households accounted for 18.3 MtC (11%). An additional 11.0 MtC (7%) is attributable to emissions from the consumption of aviation fuels by airlines registered in the UK.

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[13] Greenhouse gas emissions are measured throughout in this report as tonnes of carbon. For carbon dioxide emissions, this measure is calculated by taking the tonnes of carbon dioxide and multiplying this number by 12/44 – the ratio of molecular weights of carbon to carbon dioxide. This convention is in line with reporting in the UK national greenhouse gas emission inventory.

[14] Note that this total excludes the emissions associated with the production of electricity for use in domestic households which is counted as a 'direct' emissions and attributed separately to households.

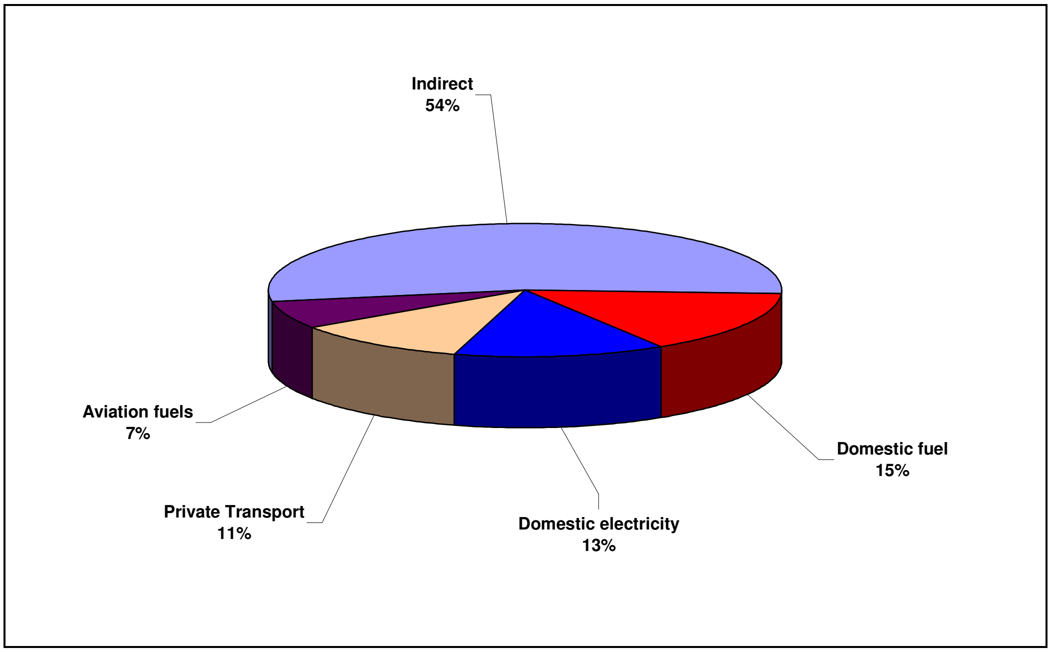

Figure 3: Production Based Carbon Account by Principal Sector

When looking in more detail at the production sectors responsible for indirect emissions, we find – not surprisingly – that the highest emitter is the electricity supply industry. The (upstream) electricity sector emissions attributable to the production of goods and services (excluding production of electricity for domestic consumption) amounted to around 24 MtC. Other significant commodity sectors included Other Land Transport, the Refining Industries, Water Transport, Oil and Gas Extraction and the Iron and Steel sector (Figure 4).

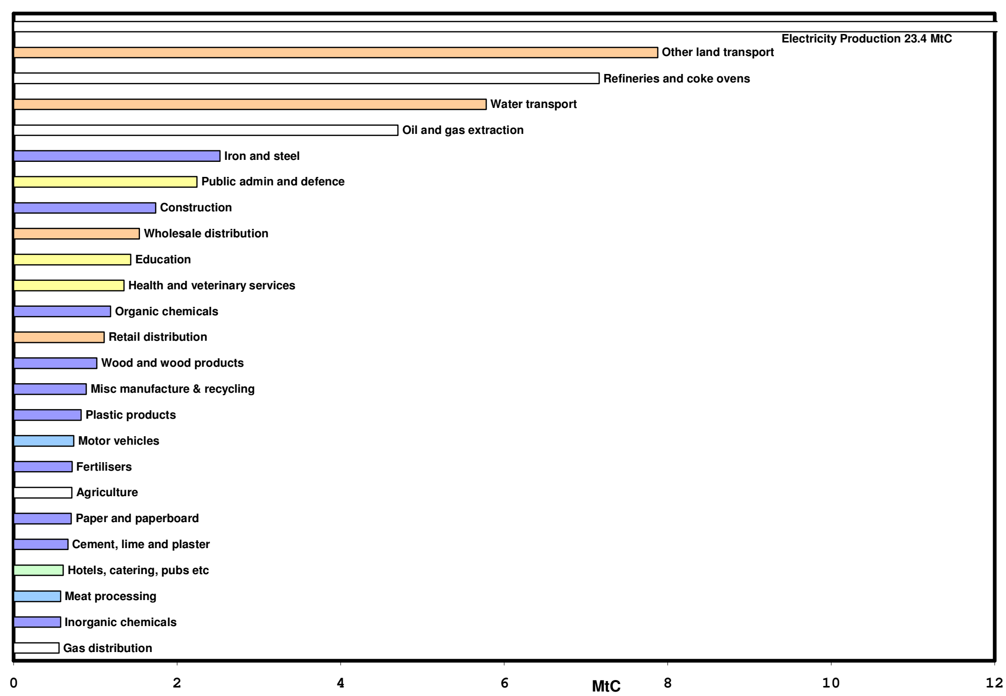

Figure 4: Indirect Carbon Emissions by Production Sector (Account 1)

The total carbon attributable to the UK economy in this account differs slightly from the carbon emissions identified in the national inventory reported in the e-Digest by the Department for the Environment, Food and Rural Affairs (DEFRA 2005). The DEFRA inventory for the year 2002 amounts to 149 MtC.[15] However, the e-Digest account excludes 11 MtC attributable to aviation fuels. In addition, its assessment of emissions from the water transport sectors differs from the Environmental Accounts data used in this study by approximately 4.8 MtC. Taken together, these two adjustments account for the quantitative difference between the published national inventory and the results of Account 1 in this study.

Account 2: Consumption Based Account

When considered from a consumption-based perspective, the total carbon emissions attributable to UK consumers in 2002 were 176.4 MtC, approximately 11.7 MtC higher than the emissions from a production-based account. This difference is a result of the different basis for the treatment of imported and exported goods and services on the consumption-based account. The difference (D) between the two accounts can be attributed to the mathematical difference between equation (7) and (8) above. Specifically, it is given mathematically by:

$$D = C_Q + C_R - C_S - C_T \qquad (16)$$

and numerically by the difference in 'indirect' emissions between Account 2 (99.8 MtC) and Account 1 (88.1 MtC). This difference is sometimes called the 'carbon trade balance' and the results of this study indicate that this carbon trade balance is positive and represents approximately 7% of the UK's national emissions. In other words, the study appears to confirm the hypothesis that UK consumption patterns is creating a pollution haven effect abroad – exporting dirty industries, whilst continuing to import the finished consumer products required to maintain and improve modern lifestyles.

The 'indirect' emissions associated with Account 2 are leads to a re-prioritisation of the 'indirect' carbon emissions associated with commodity sectors. At this point the model has allocated to each commodity sector all the carbon 'induced' directly or indirectly both in the UK economy and overseas as a result of the final demand (by households, government and investment) for that commodity in the UK. After this reallocation, it appears that largest carbon emissions are attributable to the demand for construction (Figure 5). This is explained by the energy-intensive nature of the demand for building materials required by the construction sector as well as by the fuel inputs to construction.

The next most important categories on the consumption perspective are the Distribution sectors, Hotels and Restaurants, and Health Services. The importance of these sectors can be explained in part by the infrastructure demands of these sectors and in part by the high level of fuel use for space heating, water heating and building

[15] Defra 2005 e-Digest Table 5: Estimated emissions of carbon dioxide (CO2) by UNECE source category, type of fuel and end user: 1970-2003 http://www.defra.gov.uk/environment/statistics/globatmos/download/xls/gatb05.xls

services in these sectors. Following these service sectors, we also find that Motor Vehicle Production becomes significant on the consumption-based perspective. This reflects the size of the industry and the carbon intensive nature of the materials and processes used in vehicle manufacturing.

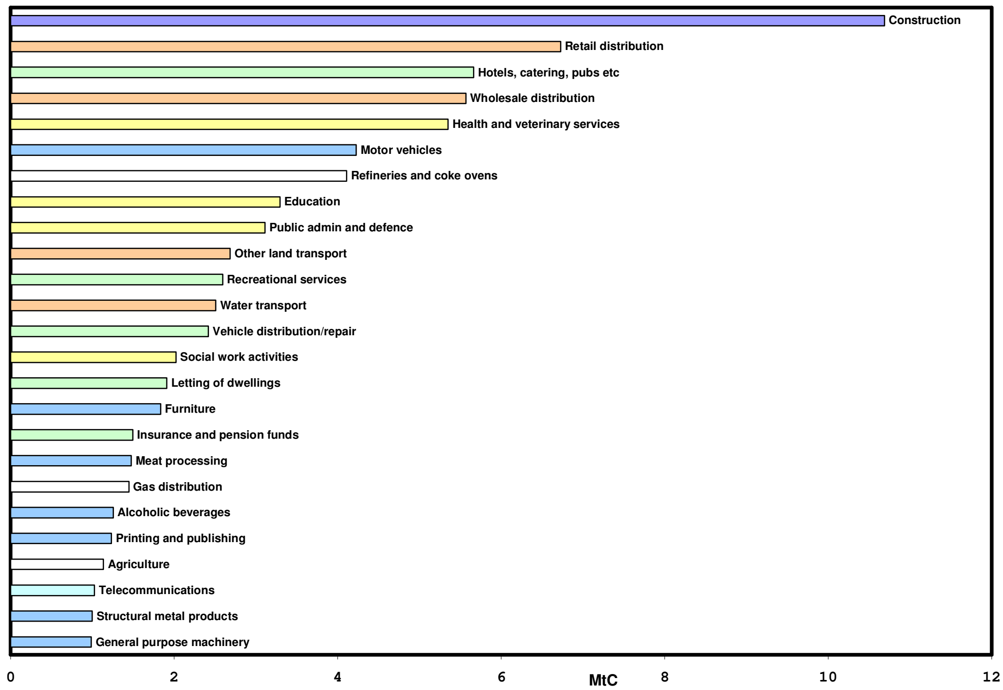

Figure 5: Indirect Carbon Emissions by Commodity Sector (Account 2)

Accounts 3 and 4: Re-allocating Fixed Capital and Distribution Carbon

The total carbon attributable to UK consumption is unchanged in Accounts 3 and 4, since these accounts simply re-distribute the carbon associated with fixed capital (investment) and distribution respectively. However, the priority sectors change on the basis of these re-allocations. After re-distributing investment carbon (Account 3) the most important commodity sectors are the Retail and Wholesale Distribution sectors with a combined emissions total of 17.2 MtC, the Hotels and Catering sector (8.3 MtC), Health Services (6.1 MtC) and the indirect emissions from the Refining Industries (4.3 MtC).

After re-distributing the carbon associated with wholesale and retail distribution the picture changes again (Figure 7). At this point, the most important commodity sector in carbon terms is the Hotel and Catering sector with emissions of 8.3 MtC. The explanation for this is the high level of infrastructure, space and water heating requirements in this sector. Other priority sectors include Motor Vehicle Production (7.1 MtC), Health Services (6.1 MtC), Refining Industries (4.5 MtC), Education (3.8 MtC), Letting of Dwellings (3.2 MtC) and Recreational Services (2.9 MtC).

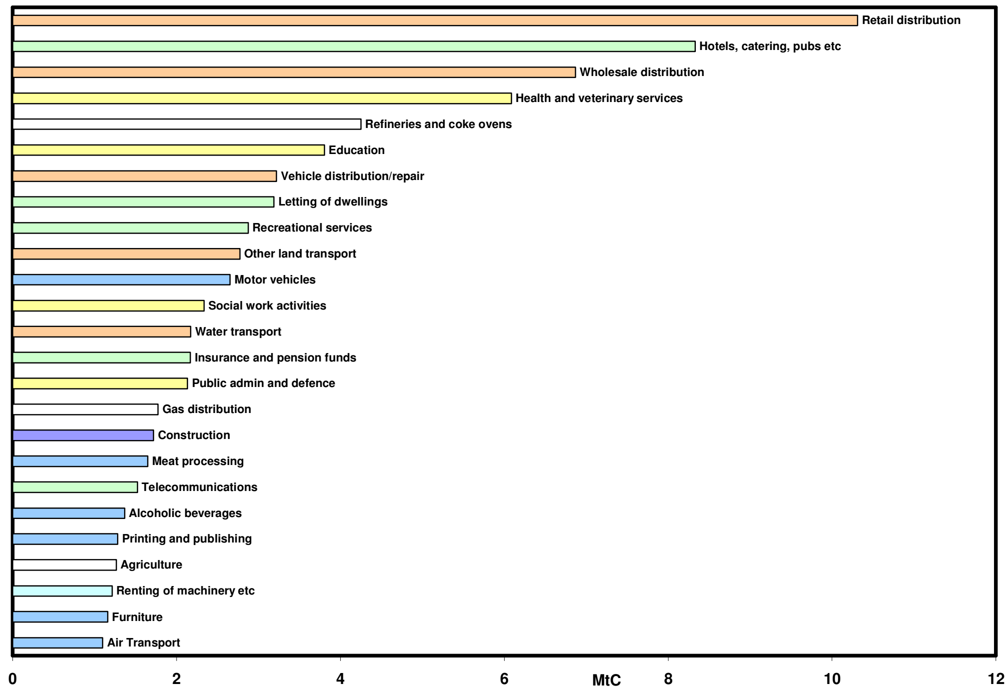

Figure 6: Indirect Carbon Emissions by Commodity Sector (Account 3)

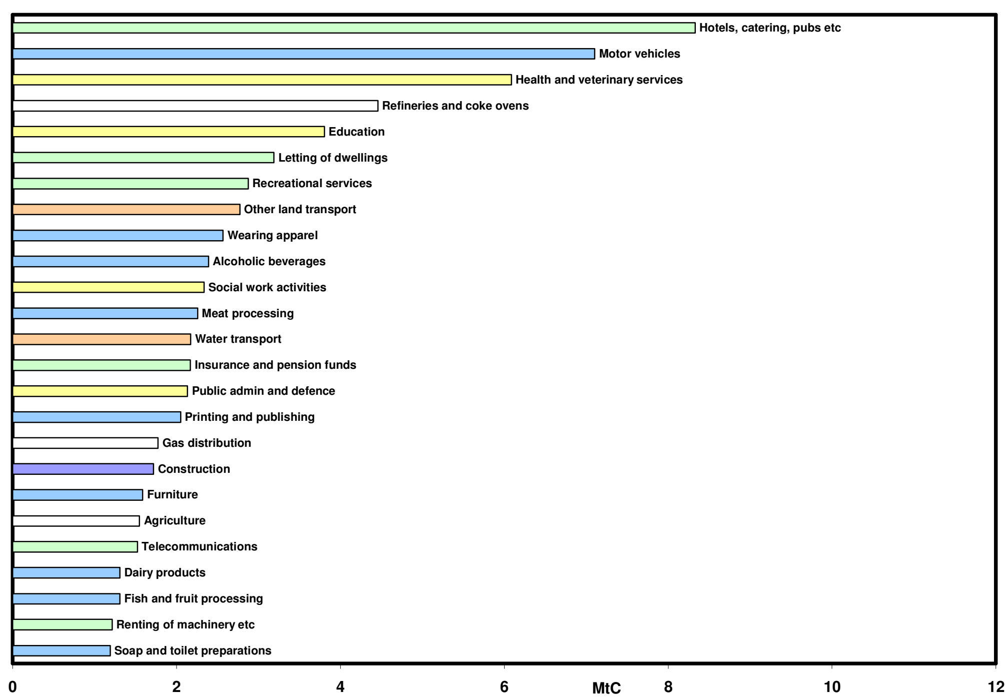

Figure 7: Indirect Carbon Emissions by Commodity Sector (Account 4)

The general trend in priority sectors between Accounts 1 and 4 is worth commenting on briefly.[16] Commodity sectors are colour coded in Figures 4 to 7 and in Table 3 according to the following schema:

- mainly final product sectors are coloured in light blue;
- mainly commercial service sectors are coloured in light green;
- mainly public service sectors are coloured in yellow;
- mainly intermediate product sectors are coloured in darker blue;
- distribution and transport sectors are coloured in orange; and
- delivered fuel sectors, utilities and agriculture are left white.

This colour coding allows us to illustrate graphically the transition through the different Accounts. Whereas Account 1 tends to prioritise primary production, transport and manufacturing sectors, by the time we get to Account 4, more priority is given to commodity sectors which deliver a range of final products and services to consumers. This reflects the general intention in the study to allocate carbon more and more to delivered final services. In Accounts 5 and 6 we take this intention a step further and allocate commodity sector carbon to functional purposes.

Account 5: Domestic Functional Use Account

This account is the first stage in re-allocating the indirect carbon emissions from commodity sectors to functional uses. It employs a variation on the COICOP classification as described in Section 2 and allocates carbon emissions to 27 domestic functional use categories. The total carbon emissions across the Account is exactly as for Accounts 2 to 4, namely 176.4 MtC (including emissions from aviation fuels which are treated separately as for Accounts 2 to 4).

However, the impact of Account 5 is to reduce the number of indirect commodity sectors and to expand the number of delivered fuel consumption sectors, with the aim of getting closer to household functional purposes. The results of this exercise are illustrated in Figure 8, which includes all UK carbon emissions except for those associated with aviation fuels.[17] It can be seen that the most important function categories are for Space Heating (22.6 MtC), Private Transport fuels (18.3 MtC), the indirect emissions associated with the demand for Transport Services (18.2 MtC) and the Food and Non-Alcoholic drink category (14.5 MtC). These findings are in line with a number of other studies which have indicated that Housing, Transport and Food are the three most significant consumption sectors (Tukker et al 2005 eg).

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16 Note that Figures 4 to 7 illustrate only the top 25 categories in each of Accounts 1 to 4.

17 These emissions are excluded from the graphical illustrations in Accounts 5 and 6, because insufficient data were found to allocate them to functional purposes. Though the National Travel Survey provides a useful account of domestic (inland) travel, it does not provide any breakdown of overseas travel by purpose. In addition, aviation emissions have not been through the input-ouput model in the same way that other production sector emissions have, because of the lack of clarity over the precise allocation of final demand for aviation services by UK (as opposed to overseas) consumers.

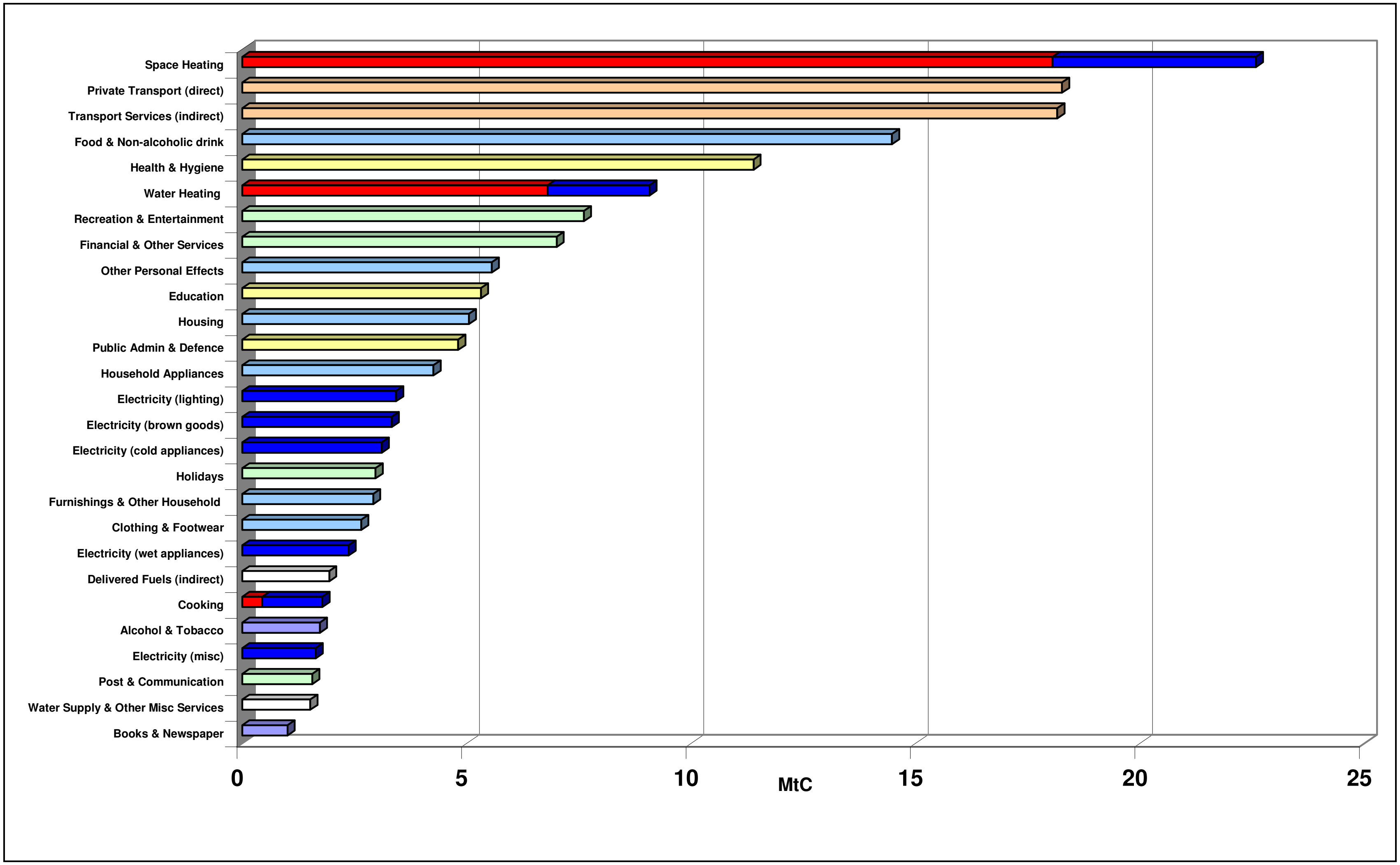

Figure 8: Carbon Allocated to Domestic Functional Uses (Account 5)

Account 6: High Level Consumer Needs Account

The final step in the process is to allocate carbon according to high-level consumer needs as discussed in Section 2. Total carbon emissions remain the same (176.4 MtC). But the number of categories in the high-level account is reduced from 27 functional use categories to 10 high level needs categories.

The most important categories in terms of carbon emissions on this Account are Recreation and Leisure (31.6 MtC), Space Heating (24 MtC) and Food and Catering (22.4 MtC). Carbon attributable to maintaining the household (22.2 MtC) is also significant, as is the carbon attributable to health and hygiene (21.7 MtC). Figure 9 illustrate the final breakdown of carbon emissions according to high-level needs. As with Account 5, aviation emissions are excluded from this breakdown because insufficient data were available to allocate air travel by functional purpose.

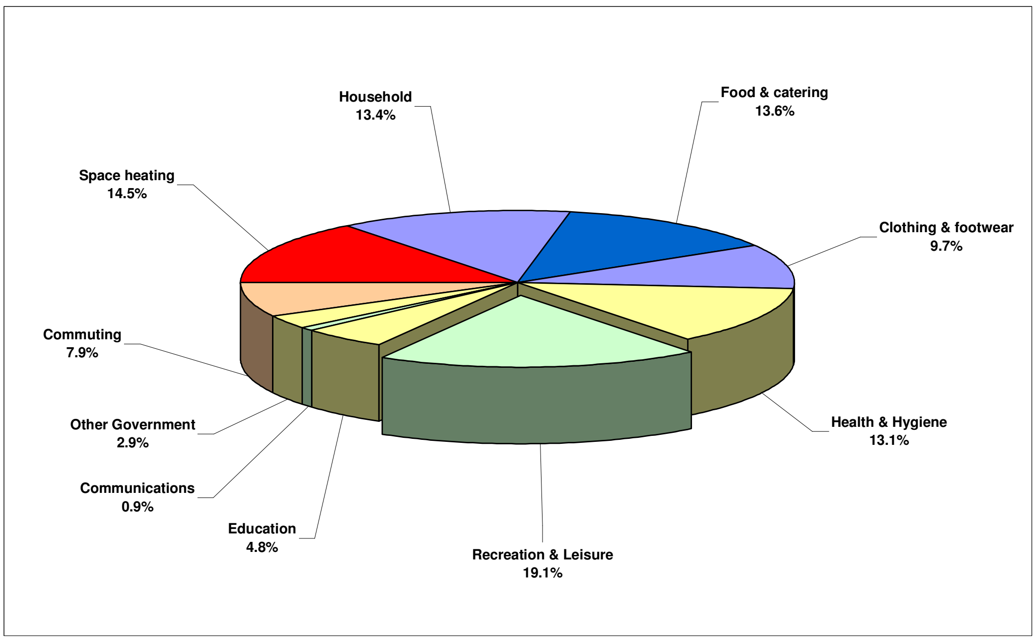

Figure 9: Carbon Allocated to Consumer Needs (Account 6)

4. Discussion

This study has explored the question: which underlying consumer needs and desires are responsible for how much of the UK's overall carbon footprint? Specifically, it has used an input-output based modelling framework progressively to allocate the carbon emissions associated with UK consumption patterns to high-level consumer needs. The analysis has led to several striking results.

In the first place, it makes plain that carbon emissions attributable to UK consumption patterns are significantly higher than those normally accounted for in the national inventory on the basis of UK production processes. This result supports the hypothesis that as industrial nations develop they have increasingly supported their consumption patterns by exporting energy and material intensive industries to less developed countries and importing more finished products. The analysis in this paper – which may substantially underestimate the carbon trade balance because of assumptions made about the energy infrastructure of UK trading partners – underlines the need to include the upstream carbon footprint attributable to UK consumption patterns, irrespective of where this occurs.

A second striking result is the high proportion of UK carbon emissions attributable to the growing Recreation and Leisure sector. At almost 20% of total emissions, this is the single highest emission category on the high-level needs perspective. Although emissions associated with providing essentials such as food, housing and comfort (space heating etc) are also clearly substantial, the increasing demand for recreation and leisure services – which is regarded as symptomatic of the growing service economy in the UK – is clearly problematic from a carbon perspective. The rising aspirations of the UK population for eating out, leisure travel, weekend breaks and other recreational activities is making the task of reaching the UK Government's challenging carbon reduction targets increasingly hard to achieve.

To return briefly to the questions raised in the Introduction about the underlying drivers of UK carbon emissions, it becomes clear that expanding lifestyle aspirations and desires are a very significant factor in this equation. At the same time, a considerable amount of carbon is locked up in some pretty basic household activities: heating and maintaining the home, feeding ourselves and our families, getting to and from work and maintaining our health and hygiene. 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 from the UK economy will require a dedicated and sophisticated effort: to improve production processes across the economy; to reduce the need for everyday travel by improved design and planning processes; to increase the use of renewable (non-fossil) energy in homes, offices and factories; to improve the institutional architecture 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; to exemplify good practice in Government by reducing energy use in public sector buildings and services; and to find new and innovative ways of meeting consumers aspirations for recreation and leisure. These are amongst the challenges that the recent debates about sustainable consumption must now address.

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