A Greenhouse Gas Footprint Analysis of UK Central Government 1990-2008

Research Report to the Department for Environment, Food and Rural Affairs by the Centre for Sustainability Accounting, York

CenSA
Centre for Sustainability Accounting

defra
Department for Environment Food and Rural Affairs

Department for Environment, Food and Rural Affairs
Nobel House
17 Smith Square
London SW1P 3JR
Tel: 020 7238 6000
Website: www.defra.gov.uk

Information about this publication is available from:
SCP&W Evidence Base
Defra
Zone 5D, 5th Floor, Ergon House
c/o Nobel House, 17 Smith Square
London SW1P 3JR

Email: scpevidence@defra.gsi.gov.uk

Published by the Department for Environment, Food and Rural Affairs

A Greenhouse Gas Footprint Analysis of UK Central Government, 1990-2008

Report to the Department for Environment, Food and Rural Affairs

Project ref.: EV0464

Project website accessible via: http://randd.defra.gov.uk

30 November 2010

Suggested citation for this report:

Wiedmann, T. and Barrett, J. (2010) *A Greenhouse Gas Footprint Analysis of UK Central Government, 1990-2008;* Report to the UK Department for Environment, Food and Rural Affairs by the Centre for Sustainability Accounting. Defra, London, UK

Dr Thomas Wiedmann
Dr John Barrett
Centre for Sustainability Accounting, York, UK

TABLE OF CONTENTS

1 Introduction

This study provides the most detailed analysis to date of the total carbon footprint of UK Government. For the first time a detailed carbon footprint analysis of Central Government is presented for a 19-year time series (1990 to 2008). The report covers scope 1, 2 and 3 emissions as outlined in the GHG Protocol. Scope 1 emissions are the direct greenhouse gas (GHG) emissions from Central Government, scope 2 refers to GHG emissions from purchased electricity and scope 3 emissions refer to the complete supply chain GHG emissions of procurement.

The analysis uses a 'multi-regional input output model' (MRIO) that provides a boundary-free system to understand the embedded GHG emissions of every item procured by Central Government for the past 19 years. This analysis is complete in that the economy-wide domestic and international supply chain contributions are calculated for every product group; and every item of procurement is taken into account.

Detailed results have been calculated for

- all years from 1990 to 2008,
- three sub-sections of Central Government (Public administration, Defence and Health services),
- six greenhouse gases (CO_2, CH_4, N_2O, HFC, PFC, SF_6),
- 123 UK products,
- 123 Rest-of-world products (imports),

The key findings are presented in this report. The results highlight both the GHG emissions that occur within the UK and GHG emissions that are emitted abroad as a result of UK Central Government expenditure.

2 Background

The most widely used standard for carbon accounting by organisations and businesses is the Greenhouse Gas Protocol, developed by the World Resources Institute and the World Council for Sustainable Development (WRI and WBCSD, 2004). The standard established three categories of emissions, which are the fundamental building blocks of greenhouse gas reporting. These categories are universally accepted and have been adopted within other, more recent standards.

Scope 1 emissions: Emissions from sources that are owned or controlled by the UK Government. This includes emissions from buildings, vehicles and other equipment owned or controlled by the Government (e.g. including emissions from military activity both within UK and abroad).

Scope 2 emissions: Emissions associated with the Government use of electricity from the grid (incl. heating / cooling and steam production).

Scope 3 emissions: Indirect emissions associated with Government activity, in particular those emissions embodied in the production of goods and services bought (procured) by Government. Scope 3 emissions can be divided into upstream, midstream and downstream emissions. This project has focused on upstream (supply chain / procurement) emissions. This includes all activities the Government is spending money on, so for example, emissions from the operation of sewage and waste treatment plants are included. Business travel is also part of (upstream) scope 3 and has been included in the analysis. Commuting (midstream emissions) is usually not paid for by the Government and is therefore not included. Nor are emissions induced by Government services (downstream emissions) or emissions from indirect land use change. Furthermore, emissions associated with long-term capital investments (capital formation) have not been included in the present analysis. For more details see Table 1 on page 6.

In terms of covering scope 1 and 2 emissions, a standardised process has already been put in place under the Sustainable Operations of Government Estate. The UK Government has placed considerable emphasis on reducing scope 1 and 2 emissions inside all Government departments. Targets have been established and procedures to report the results have been in place for some time. A 30% reduction by 2030 from 2000 levels is the current target reported as part of the “Sustainable Operations on the Government Estate”.

This study represents an important milestone as it is the first time scope 3 emissions of UK Government activities have been analysed in detail and over a 19-year time period. The project has been commissioned by Defra under the Sustainable Consumption and Production (SCP) Evidence Programme and is aimed at understanding:

- all main sources of GHG emissions across Government (i.e. from Government activity),
- how procurement contributes towards overall emissions from Government
- the completeness and robustness of data available for estimating carbon footprint emissions, and
- the priorities for reducing emissions across Government.

3 Methodological Notes

A detailed description of the methodology used to calculate the carbon footprint time series in this report is given in Appendix B: Technical Report (page 23). In this section we summarise salient points and provide important definitions.

Calculation method

The choice of approach very much depends on the application. A ‘footprint’ indicator should, by its nature, encompass all ‘traces’ that an activity leaves behind – in the case of a carbon footprint, all greenhouse gas emissions that can be associated directly and indirectly with this activity. Methodologically, this ‘full life-cycle perspective’ has been addressed from two directions: bottom-up, based on process analysis (PA), and top-down, based on (environmental) input-output analysis (IOA). PA has been developed to understand the environmental impacts of individual products from ‘cradle to grave’. Using specific primary and secondary process data, this approach can achieve results with high specificity for defined products, but has to set a system boundary. This means that contributions from outside the system boundary are being cut off, leading to a significant underestimation of the full carbon footprint in most cases. Due to the particular data requirements, PA is generally a cost and labour-intensive task. GHG estimates might differ substantially depending on which database has been used for a particular study.

Environmentally extended input-output analysis provides an alternative, economy-wide approach, making system cut-offs unnecessary. It is appropriate for larger entities such as product groups, companies or countries or, as in this study, Government activities. Its suitability for assessing the impacts of individual products or processes is limited, however, as it assumes homogeneity of prices, outputs and their carbon emissions at the sector level. Once a suitable input-output model has been set up, a number of analyses can be carried out in a resource-efficient way.

Both methods, PA and IOA, have been used for carbon footprinting. The importance of employing an all-encompassing approach to avoid the underestimation of carbon footprint results has been demonstrated by Matthews et al. (2008) and by Huang et al. (2009). Arguably the best option for a detailed, yet comprehensive and robust carbon footprint analysis is therefore to combine the strengths of both methods by using a hybrid approach where PA and IOA are integrated (Minx et al., 2008). Such a hybrid life cycle assessment (Hybrid-LCA) approach allows the preservation of the detail and accuracy of bottom-up approaches in important processes while the majority of less significant production steps can be covered by the input-output part of the model.

For this study the main objective is to gain an overall picture of the greenhouse gas emissions embedded in goods and services purchased by Central Government. A collection of primary data on the embodied energy / carbon of all products purchased by all Government departments would not be appropriate and indeed impossible as this would require excessive resources and would not be cost-efficient. Instead, input-output analysis was chosen as the most suited approach for this study, because it is comprehensive and complete, makes best use of Central Government expenditure data from the Office for National Statistics (ONS) and is consistent with standardised economic and environmental accounting (see also Minx et al., 2009; Wiedmann, 2009). The IOA model used in this study utilises ONS time series data, including the most up-to-date data available. Therefore the time lag for the analysis can be kept to a minimum. At present the most detailed sector level available comprises 123 product groups. In conclusion, IOA is seen as the most robust and cost-efficient approach for the purpose of this study. The Scottish Government has used the same approach for its public spending carbon footprint assessment (Croasdale and McIntyre, 2010).

Definition of 'Central Government'

The definition of 'General', 'Central' and 'Local' Government used in this study follows the internationally accepted, standardised categorisation of Government activity as defined by the European System of Accounts 1995 (ESA95) (Eurostat, 2007). ESA95 defines the general Government sector as all resident institutional units that are other non-market producers whose output is intended for individual and collective consumption, and are mainly financed by compulsory payments made by units belonging to other sectors, and/or all institutional units principally engaged in the redistribution of national income and wealth. Central Government includes Government departments, agencies, parliamentary bodies, military forces, and non-budgetary institutions serving households that are controlled by Central Government. Local Government is the level of Government applying at the level of cities and towns and other geographically limited entities below the level of regions. The institutions of the devolved administrations of Scotland, Wales and Northern Ireland are as part of the Central Government sector in the UK.

Intermediate consumption of Central Government supplied by ONS has been used in this study to calculate upstream scope 3 emissions and is defined as the value of goods and services consumed by Government such as building rentals, office consumables, energy, consultancy services and military supplies. The ONS data furthermore allow for a breakdown of the consumption data into the sub-sectors Public Administration, Defence, Health Services and Other Services.

Definition of 'carbon footprint'

'Carbon footprint' as defined in this study is a measure of the total amount of greenhouse gas emissions that is directly and indirectly caused by the activities of Central Government. We include all six GHGs of the Kyoto Protocol and express results in CO_2 equivalents (CO_2e).

Scope of the analysis

This analysis provides results for scope1, 2 and some of scope 3. Scope 3 emissions incorporate a wide variety of emissions from supply chains emissions to commuting and the emissions associated with investment. This study has not attempted to quantify all these emissions. Table 1 provides a list of all the different categories included under scope 3 as part of the Greenhouse Protocol and identifies what have been included in this study.

Table 1: Scope 3 emission categories (adapted from GHG Protocol)

Category	Description	Included in study
Purchased goods and services – direct supplier emissions	Scope 1 and 2 emissions of tier 1 suppliers	YES
Purchased good and services – cradle to gate emissions	Extraction and production of inputs (tiers 1, 2, 3, 4 etc.)	YES[1)]
Energy-related activities not included in scope 2	Supply chains impacts of electricity generation	YES
Capital equipment	Manufacturing/Construction of capital equipment	NO[2)]
Transport and distribution	External transportation and distribution of inputs	YES
Business travel	Employee business travel	YES
Waste generated in operations	Disposal / treatment of waste generated in operations	YES
Leased assets	Manufacturing / construction and operation of leased assets	YES
Investments	GHG emissions associated with investments	NO[1)]
Transport and distribution	Transportation and distribution of sold products	YES
Use of sold products	Use of sold goods and services (downstream)	NO
Waste	Disposal of sold products at the end of their life (downstream)	NO
Employee commuting	Employees commuting to and from work	NO

1) The footprint of Defence excludes imported products for defence, see Appendix (page 32).

2) Capital investment (as part of the category 'capital formation' in the final demand section of the National Accounts) has not been included. However, some smaller investments made in whole during the one-year accounting period (e.g. the purchase of office computers) have been included as part of intermediate consumption and the Defence expenditure statistics used to estimate the carbon footprint of defence activities also includes some capital elements (see explanations in Appendix, page 32).

In terms of emissions included we have followed the scope of the UK national Environmental Accounts, i.e. International aviation and shipping bunker emissions, other extra-terrestrial adjustments and CO_2 from biomass are included whereas emissions from Crown Dependencies and land use change / forestry emissions are excluded.

Data

The IOA method applied requires data on the expenditure of different products. Data on Central Government expenditure is available through the Office for National Statistics (ONS) following the ESA95 standard classification. The commodity breakdown is according to Standard Industrial Classification (SIC), aggregated to 123 sectors. Further detail on data is provided in Appendix B: Technical Report (page 23).

4 Results

Headline results

Between 1990 and 2008 Central Government activities have been responsible for producing nearly 1.2 billion tonnes of GHGs. Figure 1 maps the total carbon footprint of Central Government for this time period.

In 2008, the carbon footprint of Central Government was 64.7 million tonnes (Mt) of GHGs. A peak was reached in 2004 of 69.7 Mt CO_2e and a modest decline in the last three years levels out at around 65 Mt CO_2e. Between 1990 and 2008, the carbon footprint has grown by 14.3%, representing an annual increase of 0.71% per year. Annual CO_2e emissions in 2008 are now 8.1 million tonnes higher than they were in 1990.

When comparing the carbon footprint of Central Government with the total UK carbon footprint, the proportion has remained rather constant for the 19-year time series. The carbon footprint of Central Government consistently represents around 6 to 7% of the UK total (Figure 1). As the carbon footprint of UK rose in the early 2000s so had the footprint of Central Government. The overall growth rate in the Central Government carbon footprint is equivalent to the growth in the carbon footprint of the UK as a whole between 1990 and 2008.

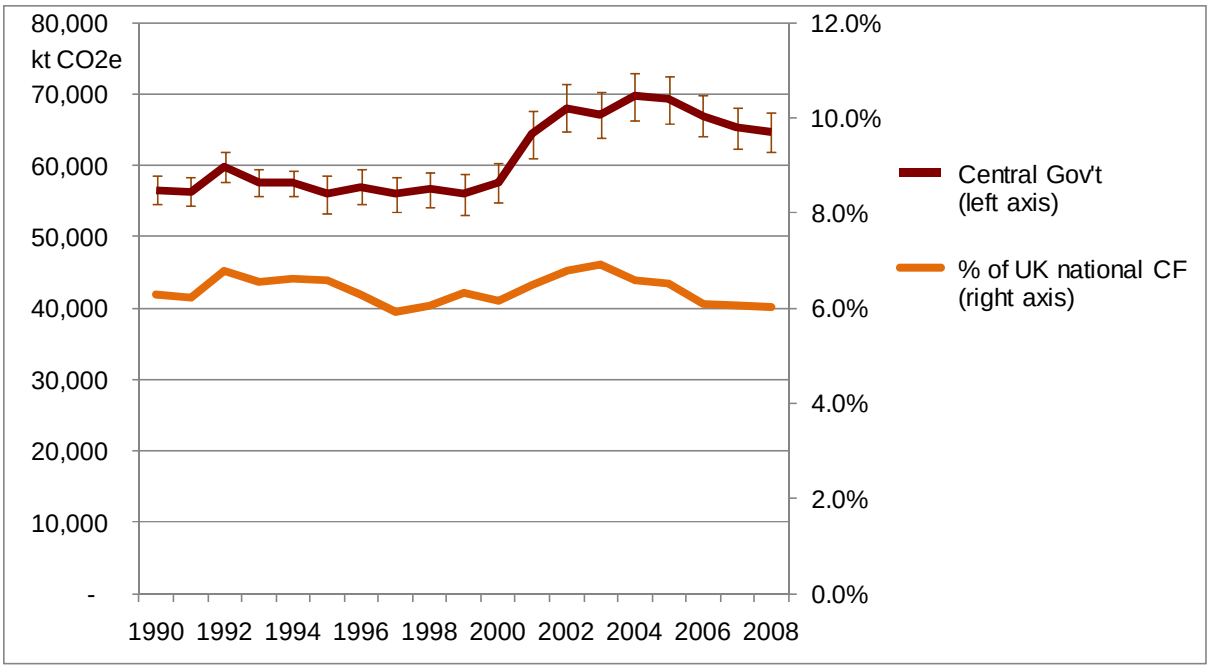

Figure 1: Carbon footprint of Central Government and proportion of total UK national carbon footprint, 1990 to 2008 (six GHGs) (error bars show ± standard deviation based on uncertainty of CO_2 emission results) (kt = kilotonnes = 1000 tonnes) (Source: CenSA)

Uncertainty of results is a complex issue that can be very difficult to calculate. Uncertainty relates to data as well as methods. For this analysis we have relied on a previous study to determine the overall uncertainty of data and methods associated with the use of environmentally extended input-output analysis. This study – a world-first for a multi-region input-output model – employed a statistical approach entitled a 'Monte Carlo Simulation' which is suitable for very large data sets with numerous data inputs from different sources. The method and results of this uncertainty analysis were published as a report to Defra and in a peer-reviewed scientific journal (Wiedmann et al., 2008a; Lenzen et al., 2010b). Based on sectoral uncertainties for CO_2 emissions, our estimate of the uncertainty range of the total carbon footprint of Central Government is in the range of 3 to 5% standard deviation.

To some extent, Central Government expenditure is an artificial distinction from total Government spend in the UK. If the money is spent centrally then the carbon footprint is associated with Central Government. If it is distributed to Local Government then it is not included. One of the possible reasons for a change in the carbon footprint of Central Government could result in the way that funds are allocated between Central and Local Government. Furthermore, some services might have been privatised over time, in which case they no longer fall under the Government's carbon footprint. Figure 2 provides the carbon footprint of all UK Government spend, distinguished by 'central' and 'local'.

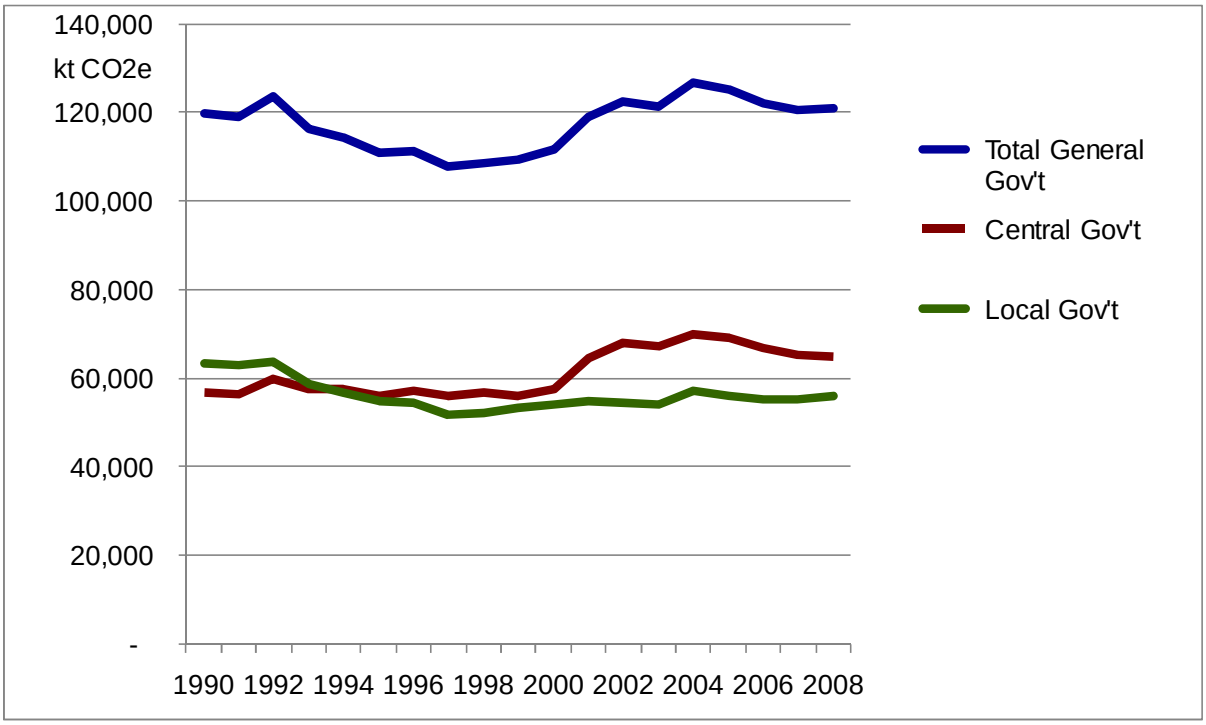

Figure 2: Carbon footprint of Central, Local and total General Government, 1990 to 2008 (six GHGs) (Source: CenSA)

The carbon footprint of total UK Government (General Government) in 2008 was 120.8 million tonnes (Mt) of GHGs and oscillated between 111 Mt CO_2e in 1994 and 127 Mt CO_2e in 2004. The proportion of the total UK carbon footprint is considerable and has only slightly declined from 13.3% in 1990 to 11.2% in 2008. Both Central and Local Government have a similar carbon footprint of around 60 million tonnes, although the balance has slightly shifted, with the Local Government footprint decreasing slightly in the early 1990s and the Central Government footprint increasing significantly in the early 2000s.

Analysis by type of GHG

For Central Government only, the total emissions have been broken down by six greenhouse gases in Figure 3 for the complete time series.

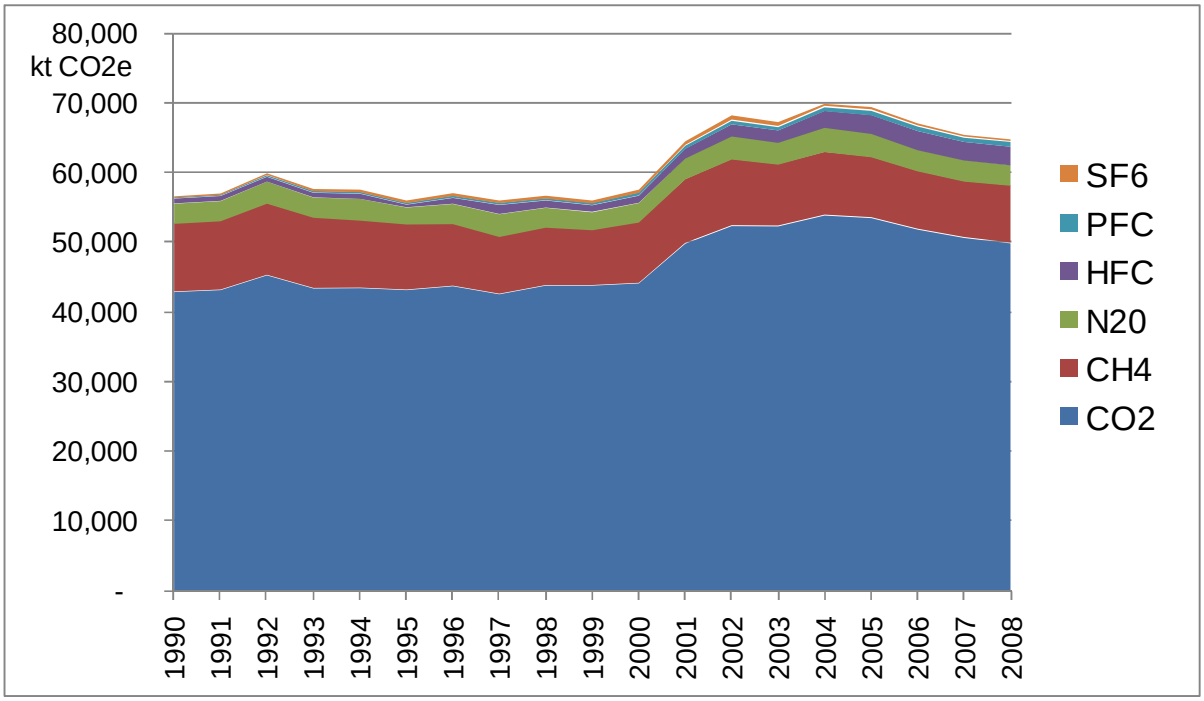

Figure 3: Central Government carbon footprint by type of greenhouse gas, 1990-2008 (Source: CenSA)

Clearly, CO_2 is responsible for the majority of the greenhouse gases, accounting for 77.2% of the total in 2008. This proportion has increased from the 1990 baseline as methane emissions have declined. A reduction of 16% in total methane emissions ('methane footprint') was achieved between 1990 and 2008, mostly due to a reduction of direct emissions from coal mining, landfills and – to a lesser extent – agriculture. However, this had only a marginal effect on the increase in total GHG emissions. Additionally, nitrous oxide emissions have barely changed between 1990 and 2008, meaning that emissions in CO_2 are the key reason for an increase in the Central Government carbon footprint between 1990 and 2008.

About 94% of the carbon footprint is made up of the three main GHGs, these being carbon dioxide, methane and nitrous oxide. Fluorocarbons (HFC and PFC) have both increased by around 400% between 1990 and 2008, due to an increased consumption of refrigerated goods (HFC) and specialist equipment in the NHS (PFC). However, their proportion of the total carbon footprint was still only 5% in 2008.

Analysis by origin of GHG emissions

The two-region input-output model used in this study allows for a distinction of embedded emissions by origin. Government in the UK purchases goods and services from the UK economy and from abroad (from the rest of the world, ROW). In the first case, most of the emissions associated with UK products will occur on UK territory although some of them will occur abroad because some intermediate goods and services from overseas might be needed. We refer to these emissions as 'UK emissions' or, more precisely, as emissions embedded in UK products. Goods and services from the rest of the world mostly lead to emissions overseas. Those are referred to as 'ROW emissions' or as emissions embedded in ROW products. Figure 4 shows how those two strands of emissions have evolved over the 19-year time period.

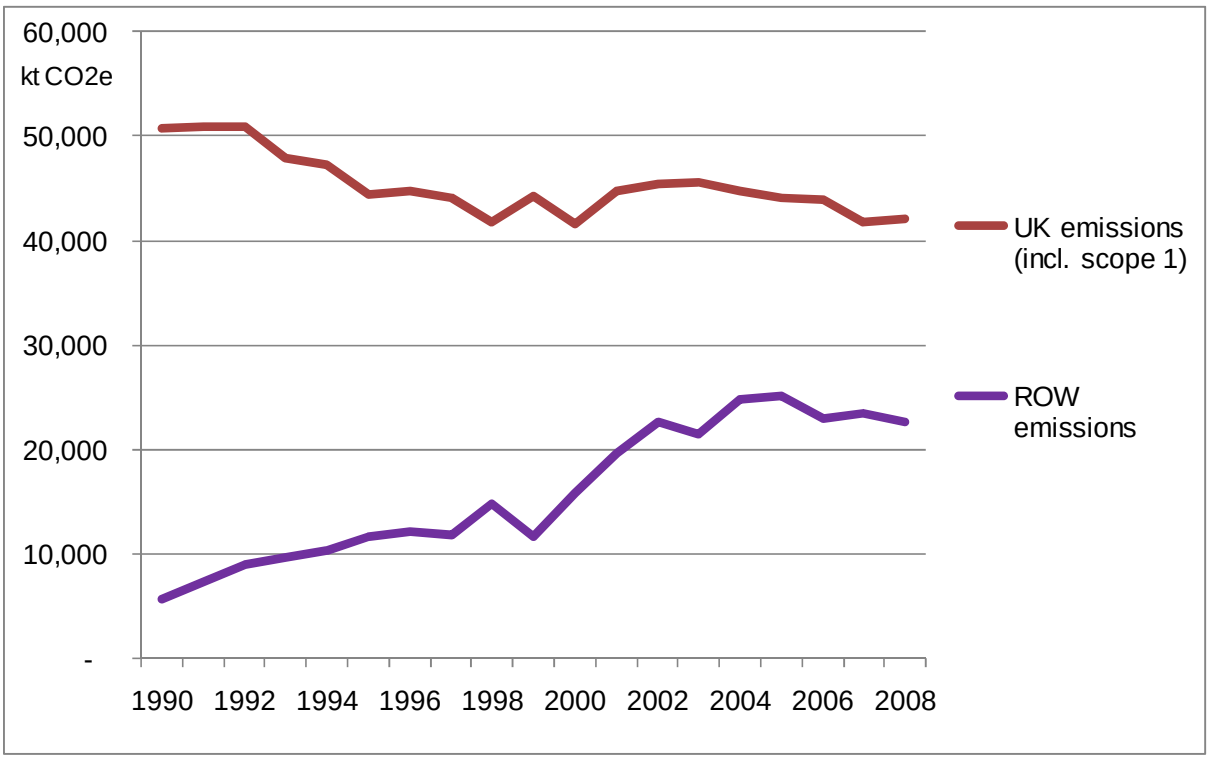

Figure 4: Central Government carbon footprint by UK emissions (embedded in UK products) and ROW emissions (embedded in rest-of-word products), 1990-2008 (all six GHGs) (Source: CenSA)

A similar picture to the one for the total UK carbon footprint emerges (Wiedmann et al., 2008b; Baiocchi and Minx, 2010; Wiedmann et al., 2010). Except for the last few years, emissions embedded in imports (ROW products) have steadily and significantly increased; in total by a factor of 2.9 and on average by over 15% per year between 1990 and 2008. At the same time, emissions embedded in UK products, incl. scope 1 emissions, have declined by 17% (0.9% p.a.) in the same period.

This shift in embedded emissions seems to be a consequence of both a change in spending and a decrease in the carbon intensity of products. A very broad and simple analysis shows that between 1990 and 2008 spending on UK products rose by 149% while spending on ROW products rose by 493%, i.e. almost five-fold. In the same time period the CO_2-intensity of UK products decreased by 34%, that of ROW products by 9.0%. A more detailed analysis reveals that much of the trends in embedded emissions can be explained with a shift in purchasing pharmaceuticals for the NHS from UK-produced to imported products.

GHG Protocol results

The results have been organised in line with the GHG Protocol classification of scope 1, 2 and 3 emissions (see Table 1 for a full description of what is and is not included in the analysis). In 2008, scope 3 emissions were responsible for 77% of the total carbon footprint of Central Government. Scope 1 emissions accounted for 13% of the total and scope 2 emissions for 10%.

Scope 3 emissions have increasingly represented a larger proportion of Central Government GHG emissions. In 1990, scope 3 emissions accounting for 65% of the total, climbing to 77% in 2008. This change relates to two key reasons; a substantial increase in scope 3 emissions coupled with a decline in scope 1 and 2 emissions. If this trend continues, scope 3 emissions could represent up to 90% of the total carbon footprint by 2020.

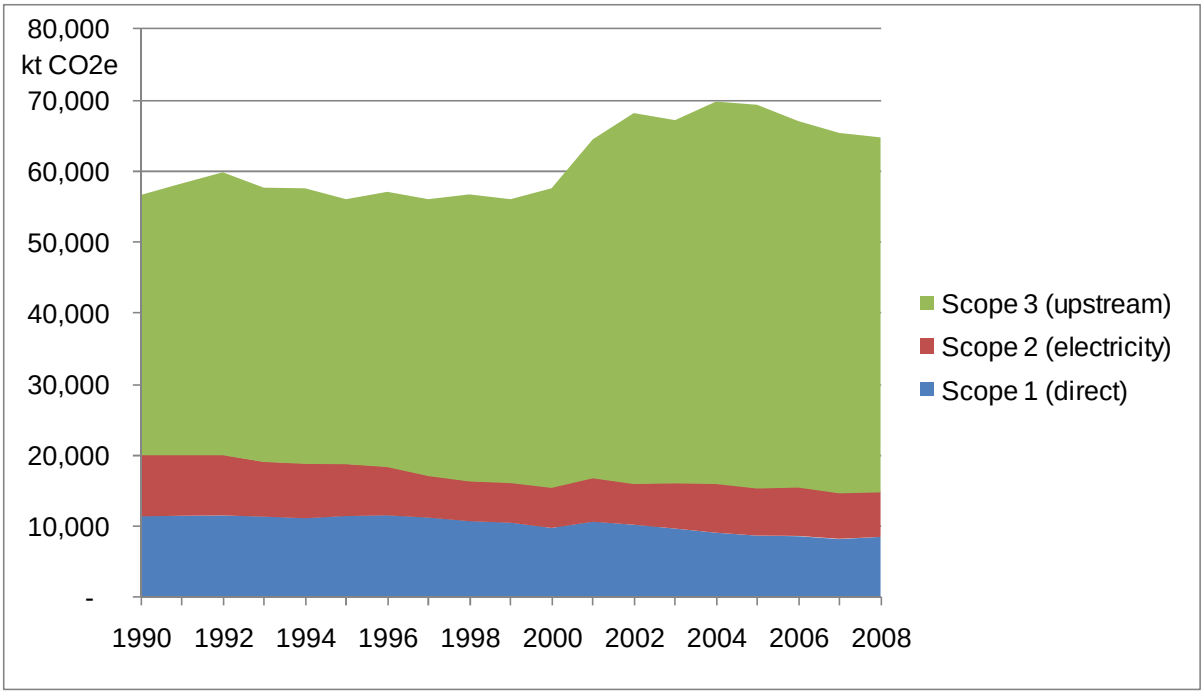

Figure 5: Central Government carbon footprint by GHG Protocol category, 1990-2008 (six GHGs) (Source: CenSA)

Figure 6 highlights the changing pattern of scope 1, 2 and 3 emissions. In the 19 years from 1990, Scope 1 and 2 emissions have both declined by 26%, respectively. The reduction in GHG emissions from electricity are coupled with a significant change in the carbon intensity of electricity generation as coal was substituted with gas in the early 1990s. Since 2000, there is a different picture where scope 2 emissions have risen again by about 10% and have remained rather stable in the last few years. A genuine reduction in scope 1 emissions can also be seen and this reduction has been steadier over the time series.

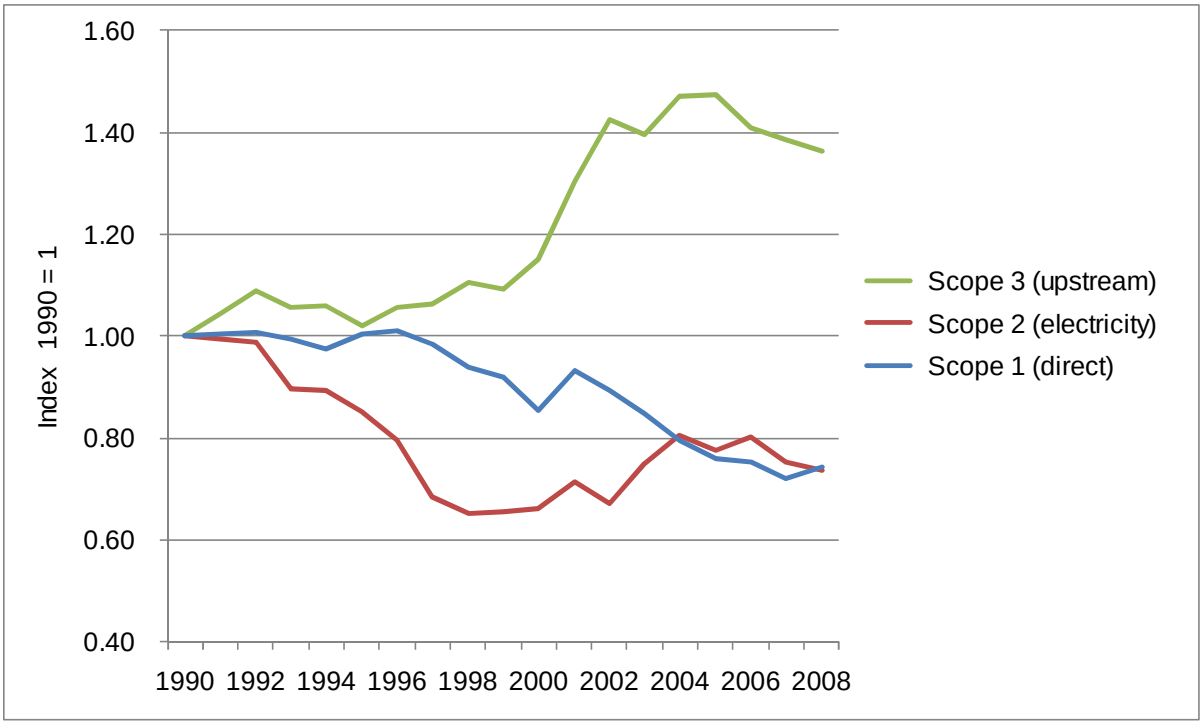

Figure 6: Relative trend of Central Government GHG emissions by GHG Protocol category, 1990-2008 (1990 = 1) (six GHGs)
(Source: CenSA)

While a reduction in scope 1 and 2 emissions can be seen between 1990 and 2008, scope 3 emissions have grown by a larger amount. Overshadowing any improvement is the rise of scope 3 emissions by a substantial 36%. This is a confirmation that scope 3 emissions clearly dominate the carbon footprint of Central Government. Helping to reduce supply chain emissions constitutes an immense potential for the Government to make a change towards reduced carbon budgets. With the immense purchasing power of Central Government, procurement policies provide an ideal leverage for addressing indirect emissions.

Analysis by Central Government activity

The National Accounts divide Central Government activity into five sub-categories. Figure 7 shows the carbon footprint proportions of these categories. Additionally, we break down the category 'Public Administration and Defence' into its two sub-sections.

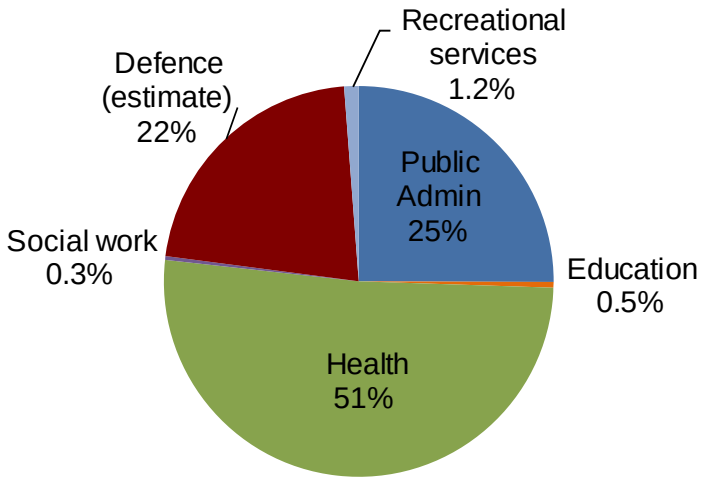

Figure 7: Proportions of total carbon footprint for sub-sections of Central Government in 2008 (all six GHGs) (Source: CenSA) [1]

The carbon footprint of Central Government is dominated by the three areas of Health (51%), Public Administration (25%) and Defence (22%). These three broad-level categories account for the majority (98%) of the carbon footprint. Figure 8 shows how they have changed over time.

It should be noted that schools are not included in the footprint of Education as shown in this study, because they are defined as being part of Local Government which was not included in this study. For a full assessment of schools carbon emissions, readers are referred to the Schools Carbon Footprint report (GAP et al., 2006).

[1] Results for Defence are estimates only; see Appendix (page 33).

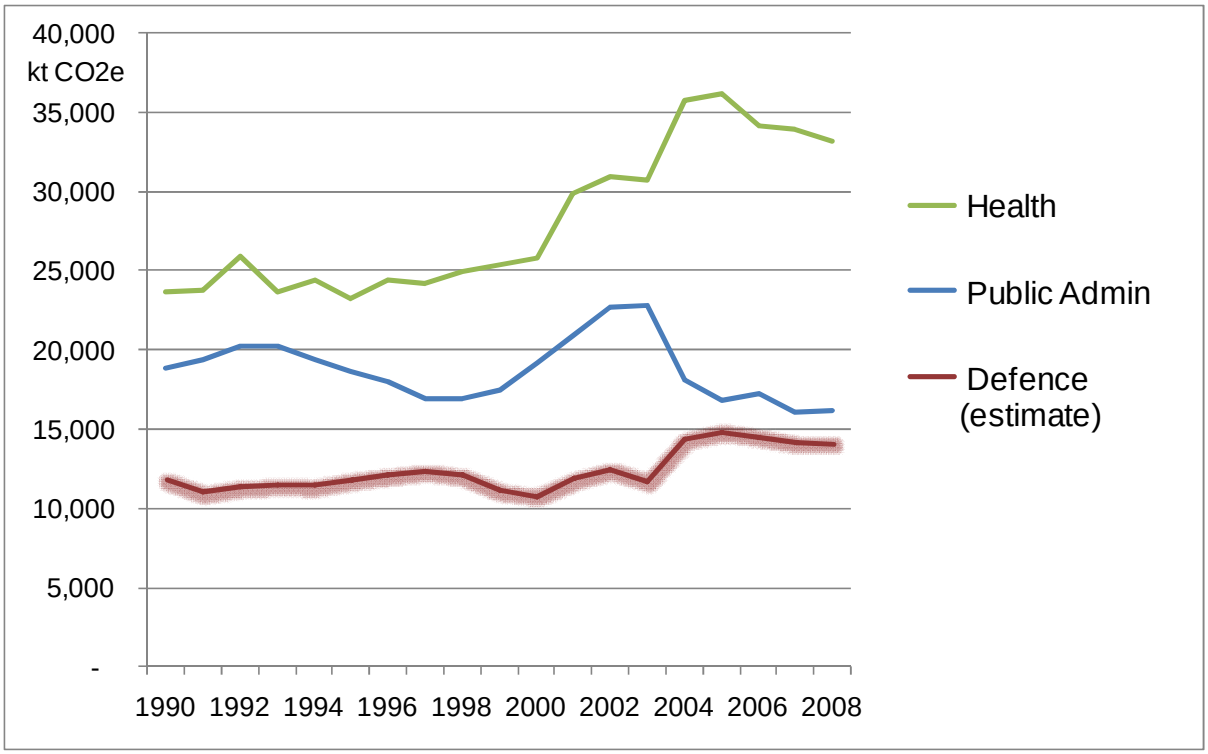

Figure 8: Carbon footprint time series for three dominating sub-sections of Central Government, 1990-2008 (six GHGs) (Source: CenSA)[1]

The overall rise in Central Government carbon footprint mainly related to the increased expenditure in health services during the late 90s and onwards. The carbon footprint of health increased by 41% between 1990 and 2008 and by 31% in the last 10 years alone (from 1999 to 2008). The other two significant areas of spend, Public Administration and Defence, show a different pattern. An increase in expenditure did not occur to the same extent. An increase in the carbon footprint of Public Administration in the early 2000s is followed by a significant decline in later years, and overall the carbon footprint has reduced by 14% from 1990 to 2008. The carbon footprint of Defence on the other hand shows a steady increase by 20% in the 19-year time period. The largest rise occurred between 2003 and 2004, possibly linked to an increased military engagement abroad. (It should be noted, however, that the results for Defence are based on estimated expenditure data with different boundaries than overall Government expenditure data).[1]

Public Administration and Defence footprint by broad product category

The key focus from this point is on the carbon footprint of the two sub-sections Public Administration and Defence (PAD). The Health sector has been taken out of the further analysis as a detailed carbon footprint report on the NHS (England) has been published previously (SDC et al., 2008; SDC et al., 2009)[2]. A high level breakdown of the product groups has been provided below for PAD. The analysis allows the results to be broken down into 123 product groups. For the purpose of illustration, these have been aggregated into eight higher level categories in Figure 9.

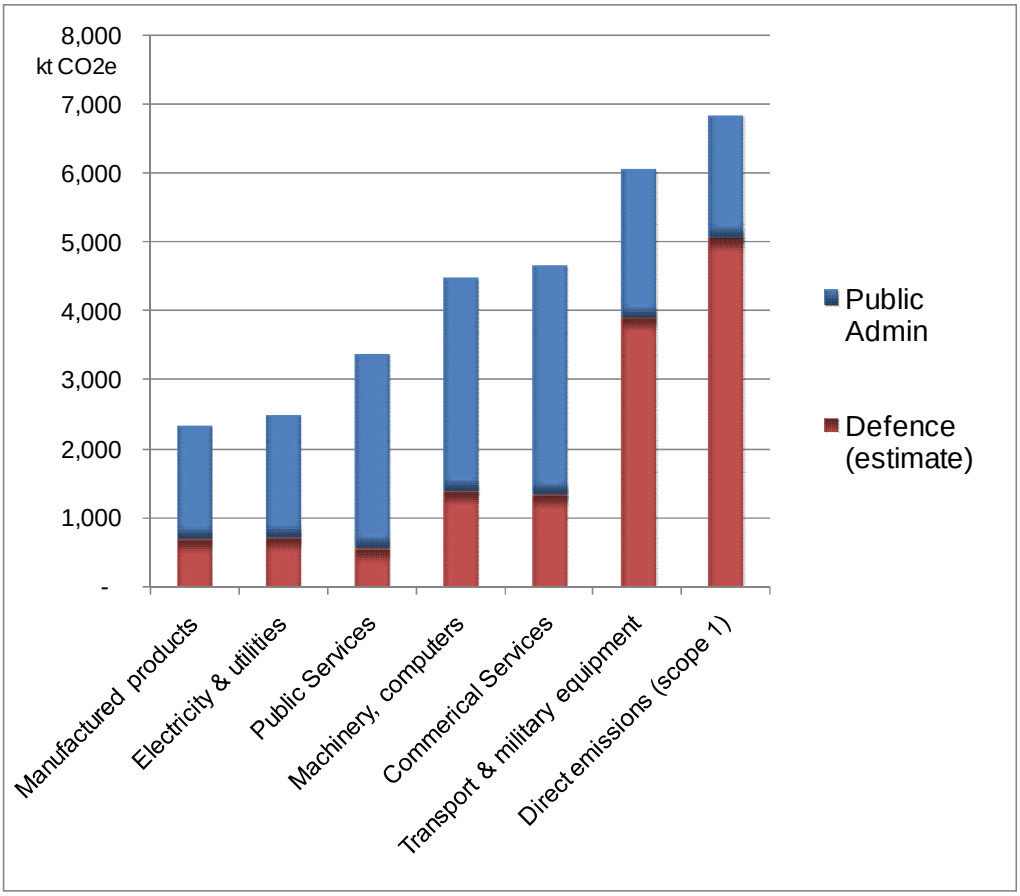

Figure 9: Total carbon footprint of Central Government Public Administration and Defence by broad product category 2008 (all GHGs) (Source: CenSA)[1]

Public Administration has an expenditure pattern which is quite different from other areas of expenditure such as Health. There is a strong reliance on commercial services in 2008 and this is reflected by this category contributing most to the carbon footprint of Public Admin, with nearly 3.5 million tonnes CO2e. The manufacturing and maintenance of machinery for Public Admin, in particular computers, has a

[2] One key result from the first study was that GHG emissions embedded in pharmaceuticals and medical instruments/equipment were main components of the NHS carbon footprint in 2004 (with 21% and 9% of the total, respectively).

similarly large carbon footprint. The carbon footprint of defence activities are dominated by direct emissions (5.6 Mt CO2e) and transport emissions (4.2 Mt CO2e).

Overall, 67% of the total carbon footprint of Public Administration and Defence is made up of scope 3 emissions, with scope 3 clearly being more dominant in Public Admin (78%) than in Defence (53%). Therefore, scope 3 emissions related to the embedded GHG emissions in procurement are responsible for more than three quarters of the carbon footprint of Public Administration.

Figure 10 depicts how the contributions of product categories have changed over time. The total carbon footprint of Public Administration and Defence (PAD) has decreased steadily in the 1990s, followed by a significant increase in the early 2000s, where the carbon footprint rose from its lowest value of 30.6 Mt CO2e in 1999 to its highest value of 36.6 Mt CO2e in 2002. Another steady decline followed in the years since. Over the whole time period the carbon footprint of PAD decreased by 4.8% from 1990 to 2008.

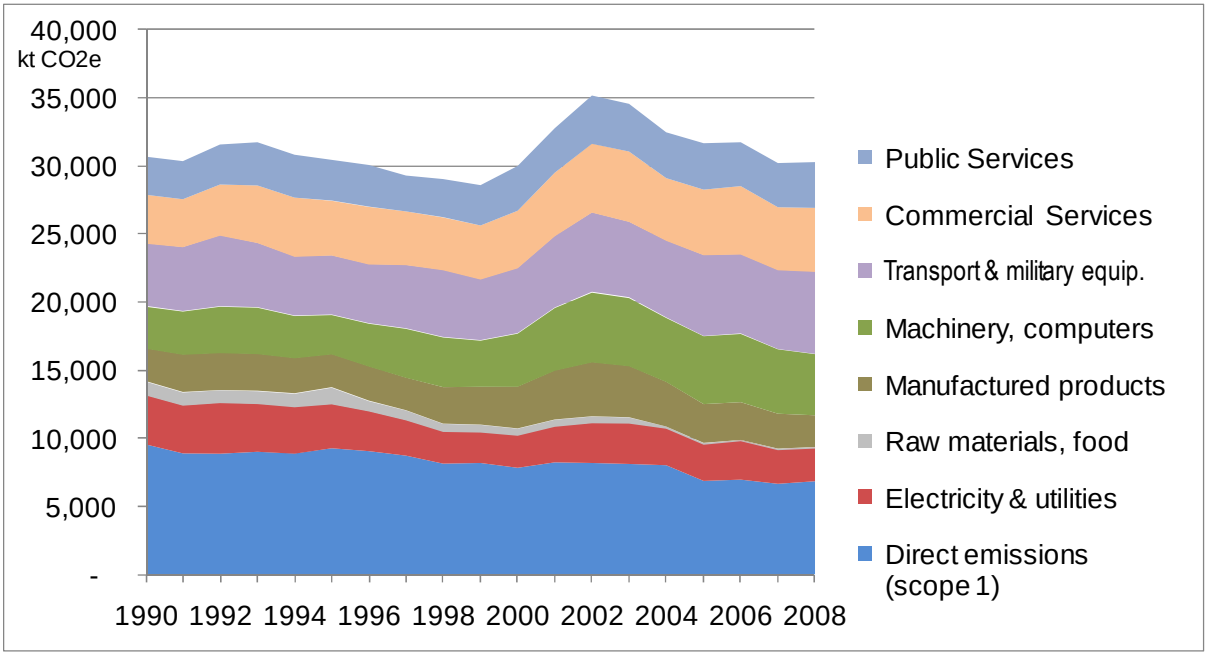

Figure 10: Carbon footprint of Central Government Public Administration and Defence by broad product category, 1990-2008
(all GHGs) (Source: CenSA)

Product categories that contributed to the 19-year decrease of the carbon footprint of PAD are Raw materials & food (-92%), Manufactured products (-9.6%), Electricity (scope 2, -37.1%) and direct emissions (scope 1, -31.5%) (see also Figure 11). As the category Raw materials includes expenditure on Agriculture, the strong reduction in this category might be due to a decrease in farm subsidies (although this has not been analysed in detail).

Other product categories have increased significantly from 1990 to 2008. These are Machinery & computers (+34.7%), Transport (+22.8%), Commercial Services (+21.9%) and Public Services (+12.3%). Transport-related emissions have risen due to a strong increase in the use of transport services for military purposes. From 2003 to 2008 alone the carbon footprint of transport services for Defence has more than doubled (+107%).[3] The increase in the category Machinery & computers is clearly related to the carbon footprint of IT equipment. As mentioned in the latest SDC report (SDC, 2010, p.9) the Department of Work and Pensions has found that £35m could be saved by increasing the cycle of replacement for desktop computers from three to five years. Based on our results, we estimate that such an action alone could potentially save over 400 kt CO_2e in embedded carbon emissions.

Analysis of detailed commodity groups

The results have also been analysed by 123 detailed product groups. Detailed results for the top 15 commodities contributing to the total carbon footprint of Public Administration and Defence in 2008 have been listed for each GHG in Appendix A: Detailed Results. Highlights from Table 2 (page 23) through to Table 8 (page 26) show that:

- The top 15 items account for 75% of the PAD carbon footprint. Direct (scope 1) emissions are dominated by defence activities which are responsible for 5.0 Mt CO_2e or 74% of emissions in this category.
- Direct (scope 1) emissions are ranked no. 1 or 2 only for all GHGs, CO_2 and HFCs and otherwise play a minor role.
- The contribution of national defence activities to the total PAD carbon footprint manifests itself in commodity groups such as Aircraft and spacecraft, Building & repairing of ships and boats and Air transport services.
- Aircraft and spacecraft are consistently placed on the top three ranks for all GHGs.
- Electricity and transport is important for CO_2 emissions, whereas sewage and refuse disposal, sanitation and similar activities are the main contribution to CH_4 and N_2O emissions.
- Medical, precision and optical instruments, together with Aircraft and spacecraft, dominate the indirect emissions of fluorinated gases.

A summary of the key product groups has been provided in Figure 11 (see also Table 8).

[3] Results not shown in graph.

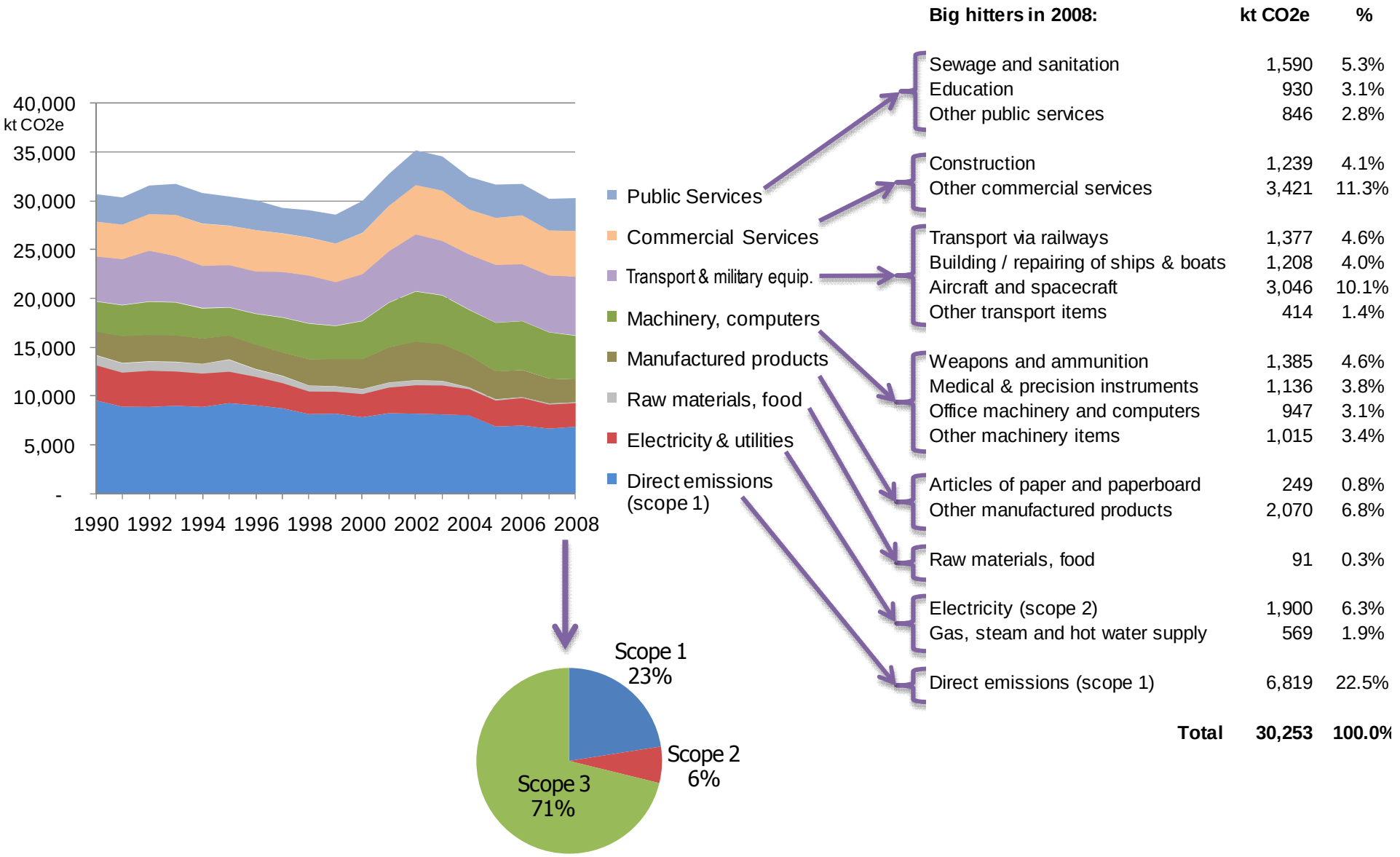

Figure 11: Carbon footprint of Central Government Public Administration and Defence, 1990-2008, and big hitters in 2008 (combination of **Figure 10** and **Table 8**) (all GHGs) (Source: CenSA)

5 Conclusions

Results

- The results clearly demonstrate the need to include scope 3 emissions in a carbon footprint assessment. Being responsible for 77% of the total carbon footprint of Central Government in 2008, it would be a considerable underestimate if they were left out. In this analysis, not all possible categories for scope 3 emissions have been included and the inclusion of both capital investment and staff commuting would increase the proportion of emissions allocated to scope 3 emissions even further.
- Between 1990 and 2008 the total carbon footprint of Central Government has increased by over 14% and any success in reducing scope 1 and 2 emissions has been lost with a subsequent increase in scope 3 emissions. This does mean that attention should be taken away from reducing scope 1 and 2 emissions and instead turned towards considering reduction of scope 3 emissions.
- The distinction of Central and Local Government is not useful in the calculation of a holistic carbon footprint. The Health sector falls under Central Government and dominates the results while Education is almost exclusively classified under Local Government and does not feature in the carbon footprint reported in this study.[4] Within Central Government three main areas are responsible for 98% of the total carbon footprint, these being Health (51%), Public Administration (25%) and Defence (22%). While the carbon footprint of Public Administration declined from 1990 to 2008 that of Defence increased moderately and that of Health increased strongly.
- A number of commodities dominate the carbon footprint of Public Administration and Defence with 15 product groups being responsible for 75% of the total. These products are often consumed by one department or activity highlighting where the highest impact is occurring.
- One of the key questions has to be:

  "How much information is enough to make robust decisions on sustainable procurement?"

  As the carbon footprint is dominated by a small number of product groups, this study provides enough information to know where the focus of a Central Government sustainable procurement strategy should be. Clearly a strategy should not focus on the micro level in terms of products or organisational level, but on the major items of impact that account for the majority of the carbon footprint.

[4] A carbon footprint study of UK schools was published in 2006 (GAP et al., 2006).

- In conclusion, the carbon footprint of Central Government has increased by 14% between 1990 and 2008 due to an increase in scope 3 emissions that falls into a limited number of product groups. These product groups should form part of the sustainable procurement strategy of the UK Government. There needs to be a clear link between the sustainable procurement strategy and the carbon footprint calculations where each policy and programme is quantitatively assessed for its effectiveness.

Suitability of method

- The data available was sufficient to undertake a comprehensive and consistent 19-year scope 3 assessment of the complete public sector, and Central Government in particular. An identical Local Government analysis can be performed by using the same data and method.
- The use of an input-output-based approach was robust and adequate to give a well-informed overview of the key product groups and government activities that had a high carbon impact.
- Two key areas were excluded from this study, these being capital investment and staff commuting. Both would be relatively easy to include in the future, as the methodologies are in place.

6 Acknowledgements

This work has been funded by the UK Department for Environment, Food and Rural Affairs under Project Reference EV0464. We thank staff from the Ministry of Defence for their help with defence expenditure data: Nick Bennett and Nick Sibery from DASA/DESA provided a time series of defence expenditure data and detailed explanations; Iain Brookes from DES Sustainable Procurement helped with data interpretation. David Hastings and Francis Jones from ONS kindly provided detailed Use tables and detailed Government spending data. Manfred Lenzen and Arne Geschke from the University of Sydney helped with constraint optimisation and matrix balancing, and Richard Wood from NTNU Trondheim described the optimisation procedure.

7 Glossary

CO_2e	Carbon dioxide equivalents
Defra	Department for Environment, Food and Rural Affairs
GHG	Greenhouse gas
IO	Input-output
IOA	Input-output analysis
MRIO	Multi-region input-output
MOD	Ministry of Defence
ONS	Office for National Statistics
RSD	Relative Standard Deviation
RSE	Relative Standard Error
ROW	Rest of the world
SCP	Sustainable consumption and production
SD	Standard Deviation
SE	Standard Error
SOGE	Sustainable Operations on the Government Estate
SUT	Supply and Use Table

8 Appendix A: Detailed Results

Table 2: Top 15 commodities contributing to the total CO_2 footprint of Public Administration and Defence in 2008 (Source: CenSA)

Commodity	SIC(03) code	Public Admininistration and Defence
Direct emissions (scope 1)		6633
Aircraft and spacecraft	35.3	2766
Electricity production & distribution (scope 2)	40.1	1827
Transport via railways	60.1	1209
Weapons and ammunition	29.6	1197
Construction	45	1036
Building and repairing of ships and boats	35.1	1208
Medical, precision and optical instruments, watches and clocks	33	774
Education	80	659
Office machinery and computers	30	648
Gas distribution, steam and hot water supply	40.2 + 40.3	487
Air transport	62	405
Furniture	36.1	368
Sewage and refuse disposal, sanitation and similar activities	90	363
Telecommunications	64.2	341

Table 3: Top 15 commodities contributing to the total CH_4 footprint of Public Administration and Defence in 2008 (Source: CenSA)

Commodity	SIC(03) code	Public Admininistration and Defence
Sewage and refuse disposal, sanitation and similar activities	90	1320
Aircraft and spacecraft	35.3	289
Education	80	200
Construction	45	181
Office machinery and computers	30	154
Gas distribution, steam and hot water supply	40.2 + 40.3	137
Weapons and ammunition	29.6	133
Transport via railways	60.1	111
Medical, precision and optical instruments, watches and clocks	33	98.3
Hotels and restaurants	55	81.3
Electricity production & distribution (scope 2)	40.1	80.7
Building and repairing of ships and boats	35.1	89.9
Financial intermediation, except insurance and pension funding	65	54.4
Research and development	73	49.8
Real estate activities with own property	70.1 + 70.2(pt)	42.8

Table 4: Top 15 commodities contributing to the total N_2O footprint of Public Administration and Defence in 2008 (Source: CenSA)

Commodity	SIC(03) code	Public Admininistration and Defence
Sewage and refuse disposal, sanitation and similar activities	90	100.0
Aircraft and spacecraft	35.3	93.5
Education	80	91.8
Transport via railways	60.1	77.2
Direct emissions (scope 1)		67.5
Construction	45	62.3
Weapons and ammunition	29.6	52.3
Hotels and restaurants	55	49.4
Office machinery and computers	30	49.2
Medical, precision and optical instruments, watches and clocks	33	34.4
Real estate activities with own property	70.1 + 70.2(pt)	28.3
Leather goods; luggage, handbags, saddlery and harness	19.1 + 19.2	20.6
Research and development	73	19.8
Building and repairing of ships and boats	35.1	24.8
Wearing apparel; dressing and dyeing of fur	18	18.1

Table 5: Top 15 commodities contributing to the total HFC footprint of Public Administration and Defence in 2008 (Source: CenSA)

Commodity	SIC(03) code	Public Admininistration and Defence
Medical, precision and optical instruments, watches and clocks	33	165.7
Direct emissions (scope 1)		123.5
Aircraft and spacecraft	35.3	96.0
TV & radio transmitters; telephony apparatus	32.2	55.3
Office machinery and computers	30	52.9
Telecommunications	64.2	52.5
Weapons and ammunition	29.6	48.9
Construction	45	32.9
TV & radio receivers, sound or video recording	32.3	31.0
Electronic valves and tubes and other electronic components	32.1	30.5
Education	80	22.9
Building and repairing of ships and boats	35.1	22.7
Sewage and refuse disposal, sanitation and similar activities	90	10.9
Transport via railways	60.1	10.6
Financial intermediation, except insurance and pension funding	65	10.4

Table 6: Top 15 commodities contributing to the total PFC footprint of Public Administration and Defence in 2008 (Source: CenSA)

Commodity	SIC(03) code	Public Admininistration and Defence
Medical, precision and optical instruments, watches and clocks	33	134.5
Aircraft and spacecraft	35.3	45.5
Office machinery and computers	30	25.6
Weapons and ammunition	29.6	16.6
Telecommunications	64.2	8.6
Television and radio transmitters; telephony apparatus	32.2	8.3
Building and repairing of ships and boats	35.1	9.6
Construction	45	5.5
Television and radio receivers; sound or video recording	32.3	4.6
Electronic valves and tubes and other electronic components	32.1	4.6
Education	80	1.9
Research and development	73	1.8
Transport via railways	60.1	1.6
Furniture	36.1	1.5
Financial intermediation, except insurance and pension funding	65	1.5

Table 7: Top 15 commodities contributing to the total SF_6 footprint of Public Administration and Defence in 2008 (Source: CenSA)

Commodity	SIC(03) code	Public Admininistration and Defence
Aircraft and spacecraft	35.3	30.7
Medical, precision and optical instruments, watches and clocks	33	27.2
Office machinery and computers	30	20.0
Weapons and ammunition	29.6	16.6
Sewage and refuse disposal, sanitation and similar activities	90	6.9
Construction	45	5.3
Building and repairing of ships and boats	35.1	6.7
Electricity production & distribution (scope 2)	40.1	3.7
Telecommunications	64.2	3.0
Television and radio transmitters; telephony apparatus	32.2	2.5
Furniture	36.1	1.6
Education	80	1.6
Transport via railways	60.1	1.5
Television and radio receivers, sound or video recording or repr	32.3	1.4
Electronic valves and tubes and other electronic components	32.1	1.4

Table 8: Top 15 commodities contributing to the total GHG footprint of Public Administration and Defence in 2008 (Source: CenSA)

Commodity	SIC(03) code	Public Admininistration and Defence
Direct emissions (scope 1)		6819
Aircraft and spacecraft	35.3	3046
Electricity production & distribution (scope 2)	40.1	1900
Sewage and refuse disposal, sanitation and similar activities	90	1590
Weapons and ammunition	29.6	1385
Transport via railways	60.1	1377
Construction	45	1239
Building and repairing of ships and boats	35.1	1208
Medical, precision and optical instruments, watches and clocks	33	1136
Office machinery and computers	30	947
Education	80	930
Gas distribution, steam and hot water supply	40.2 + 40.3	593
Telecommunications	64.2	439
Air transport	62	405
Furniture	36.1	406

9 Appendix B: Technical Report

Methodology

In this study we have used CenSA's environmental input-output model of the UK economy. National (economic) accounts and environmental accounts from the UK Office for National Statistics (ONS) form the original data upon which the model is built. This technical report describes the structure of the model, the data sources and the procedures to prepare the data for analysis.

Summary

For this work it was necessary to create a time series of input-output tables of the UK economy from 1990 to 2008. As a basis for the time series we have used input-output tables created by the University of York (SEI) and the University of Sydney in the course of a Defra-funded project on embedded emissions in 2008, as a result of which the tables were made publicly available. We refer to the publications for details (Wiedmann et al., 2008b; Wiedmann et al., 2010). Since then, we have extended

and updated the time series from 1990 to 2008 and have made further improvements to the data. Using data published by the ONS on the supply and use of products by UK industries (ONS, 2010c) as external data constraints, we use a sophisticated matrix balancing algorithm to update the input-output tables in the most detailed form of 123x123 sectors. The set of data includes supply and use tables in basic prices, an imports matrix of rest-of-world products to UK industries in basic prices, three margin matrices for intermediate and final demand for automotive fuel and motor vehicle retailing, retail trade and wholesale trade, as well as a tax matrix for intermediate and final demand.

CenSA's input-output model is a two-region model that uses input-output tables for UK domestic demand, imports and the rest of the world (ROW). In total, 246 economic sectors and product groups can be distinguished, 123 for UK commodities and 123 for imported commodities. Annual, sectoral emissions of the six major greenhouse gases (CO_2, CH_4, N_2O, HFC, PFC, SF_6) are taken from the UK national environmental accounts published by ONS (ONS, 2010a) and are added as environmental extensions to the IO tables. A similar extension is made to the ROW table.

For any one year, the UK part of the IO model has 123x123 cells for intermediate demand and 123x11 cells for final demand, together 16,482. For each of these values, there are one tax and three different trading margins: automotive fuel retail, retail trade and wholesale trade. This adds up to 65,928 data points for the margins alone. The same applies for imports to the UK. When updating the data, all these 82,410 data points (for domestic tables only) need to be balanced to comply with external constraints, according to the information provided by ONS in the supply and use tables. We have done this for the newly added years 1990, 1991 and 2005 to 2008. Supply chain conversion factors based on these tables are more detailed, accurate and up-to-date than the basic-price factors for 76 sectors for the year 2004 published by Defra in the 'Guidance on how to measure and report your greenhouse gas emissions' (DEFRA, 2009).

SUT modelling framework

The basic layout of the model framework is depicted in Figure 12 and described in Equation 1. Two regions, the UK and the rest of world (ROW) are represented with supply and use tables (SUT) as well as trade tables, respectively.

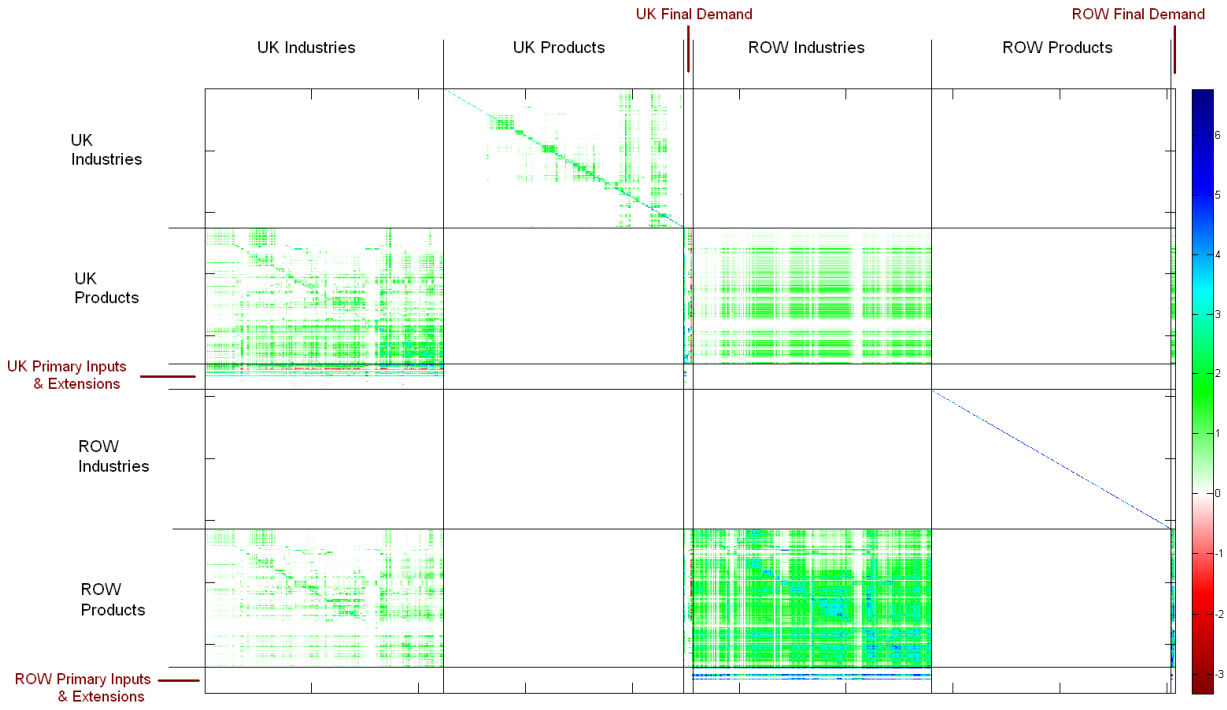

Figure 12: Topographical representation of the two-region SUT framework used in this work (generated using Aisha software developed at the Centre for Integrated Sustainability Analysis, University of Sydney).

Technical coefficient matrices for region r and s are defined as A^{rs} with $a_{ij}^{rs} = u_{ij}^{rs} / g_j^r$ and as B^{rr} with $b_{ij}^{rr} = v_{ij}^{rr} / q_j^r$ where u_{ij}^{rs} is an element of the use or the imports/exports table, indicating the input of commodity *i* from region *r* into industry *j* of country s, and v_{ij}^{rr} is an element of the supply table, indicating the output of commodity *j* by industry *i* in country r. g_j^r and q_j^r are the total output of industries and commodities in country r, respectively. The supply, use and trade tables can be transformed into a compound direct requirements matrix A* (the term 'compound' refers to maintaining the representation of supply and use tables, rather than a symmetric input-output table):

Equation 1: $$A^* = \begin{pmatrix} 0 & B^{uu} & 0 & 0 \\ A^{uu} & 0 & A^{ur} & 0 \\ 0 & 0 & 0 & B^{rr} \\ A^{ru} & 0 & A^{rr} & 0 \end{pmatrix}$$ with u standing for UK and r for ROW.

The final demand and gross output vectors are given as:

Equation 2:

$$y^* = \begin{pmatrix} 0 & 0 \\ y^{uu} & y^{ur} \\ 0 & 0 \\ y^{ru} & y^{rr} \end{pmatrix} \qquad g^* = \begin{pmatrix} g^u \\ q^u \\ g^r \\ q^r \end{pmatrix}$$

with y^{uu} and y^{rr} being domestic final demand in UK and ROW and y^{ur} and y^{ru} being foreign final demand for UK and ROW products (exports), respectively.

The basic input-output relationship is satisfied by:

Equation 3:

$$A^* g^* + y^* = g^* \quad \Leftrightarrow \quad g^* = (I - A^*)^{-1} y^*$$

where *I* is a suitable unity matrix. Column totals of the compound Leontief inverse $(I–A)^{-1}$ represent Leontief type I output multipliers which describe increases in inputs for industry n (left block) or commodity n (right block) per unit increase in final demand for industry n or product n.

Procedure to update UK Supply and Use Tables

It is not a necessary condition to have analytical (symmetric) input-output tables for an environmental input-output model. Instead we use supply and use matrices, the crucial advantage of which is timeliness. The latest available analytical table is from 1995 whereas supply and use tables are published by ONS with a time lag of only two to three years. This reduces uncertainty in the model because changes in the structure of the economy are reflected more accurately if up-to-date input-output information is used. Supply and use tables, the basic building blocks for national economic accounts, as well as environmental accounts are published annually by ONS. We use these tables as initial estimates for the tables in the model.

Once the initial estimates are fully populated, constraints are applied across the full time series. Two types of constraints are applied – *accounting or balancing constraints*, to ensure such relationships such as gross output equals gross input are maintained; and *data constraints*, such as industry, commodity and national accounts data. A list of constraints $\mathbf{C}_r$ is constructed, where *r* refers to a subset of constraints rather than individual constraints. $\mathbf{C}_r$ is constructed alongside a concordance matrix **G** that links the constraint values $\mathbf{C}_r$ with the initial estimate $\mathbf{Z}_0$. **G**

is simply a sparse binary matrix showing the existence or non-existence of a relationship between $\mathbf{C}_r$ and each element of $\mathbf{Z}_0$.

The following constraints are used for the subsequent rebalancing procedure:

- Total (domestic) output/supply of 123 UK products at basic prices as column totals
- Total (domestic) output/supply of 123 UK products at basic prices as row totals
- Total (domestic) output/supply of 123 UK products at basic prices as balancing constraint
- Total of 123 UK industry inputs at basic prices as column totals
- Total of 123 UK industry outputs at basic prices as row totals
- Total UK industry in-/output at basic prices as balancing constraint
- Supply of principal product as a percentage of total industry output and of total commodity output (i.e. the proportion of diagonal versus non-diagonal elements)
- Row total of Taxes less subsidies on production
- Row total of imports of 123 ROW products at basic prices
- Row totals of all trading margins on 123 UK products
- Total of all trading margins must be zero
- Each column in table for automotive fuel and motor vehicle retailing margins must sum to zero
- Each column in table retail trade margins must sum to zero
- Each column in table for wholesale trade margins must sum to zero
- Row totals of taxes plus subsidies on 123 UK products
- Row totals of taxes plus subsidies for intermediate demand
- Row totals of taxes plus subsidies for final demand
- Row totals of taxes plus subsidies for exports
- Row totals of total supply of 123 UK products at purchasers' prices
- Combined Use by 123 UK industries at purchasers' prices
- Combined Final Demand for 123 UK + imported products at purchasers' prices
- Combined Exports of 123 products at purchasers' prices

A multi-stage process then employs a sophisticated approach of constraint optimisation, called KRAS, which balances data according to constraints that are defined by available data. The methodology has been described in a journal publication (Lenzen et al., 2009) and has been implemented in the Aisha software developed at the University of Sydney (Lenzen et al., 2010a).

The initial estimate $\mathbf{Z}_0$ does not necessarily (and is unlikely to) satisfy the list of constraints **C**. Hence, the optimisation process is required in order to obtain **Z*** such that:

Equation 4

$$\mathbf{Z}^* = \mathbf{Z}_n \Leftrightarrow \mathbf{C} = \mathbf{G} \times \mathbf{Z}_n$$

where $\mathbf{Z}_n$ is solved iteratively through minimising a distance function between **C** and **G** x **Z**. The balancing process is undertaken for each year of the input-output system, in this case, covering the time period 1990-2008.

Data sources and data preparation

Supply and Use Tables of the UK

In the UK, input-output data are collated and published regularly by the Office for National Statistics as part of the National Accounting framework (ONS, 2006; Mahajan, 2006; ONS, 2010b). Supply and use tables for the years 1990 to 2008 are publicly available (ONS, 2010b). Over the years, less and less information has been published. For example, industries in the use tables are now published by 108 industries (instead of 123 industries previously) and supply tables have been reduced to column vectors showing only the total supply of products by 123 categories. Additional information was therefore requested from ONS. Use tables for the years 2004 to 2007 by 123 industries were kindly provided by ONS with the note that the additional splits should be treated with caution. For 2008 we use the 2007 table as initial estimate and rebalance with published sector totals for 2008 as constraints. In the course of the project we revised all supply and use data for the years 2004 to 2008 according to the newly published Blue Book 2010 (ONS, 2010c), i.e. new industry and product totals were used as constraints.

General government final consumption by type of service

These tables show expenditure (intermediate consumption) of UK Government by 123 products groups broken down into the categories Public administration & defence, Education, Health and veterinary services, Social work activities, Sewage and Sanitary services and Recreational services for both Central and Local Government. The data have previously been published as part of the SUTs as Tables no. 5. Tables for the years 2004 to 2007 were provided by ONS upon request with the note that the product breakdown of this data is based largely on a set of factors which are unchanged during this period. For 2008 we use the 2007 table as initial estimate and rebalance with published sector totals as constraints.

The intermediate consumption (expenditure) data used to calculate the GHG footprint do not include Gross Capital Formation (consisting of Gross fixed capital formation, Valuables and Changes in inventories) as this is recorded under Final Demand in the National Accounts and is not broken down by industry. This means that no data is available that would separately identify the Government's acquisitions minus disposals of fixed assets, tangible assets (buildings, machinery, transport equipment, etc.) and intangible assets (subsoil assets, software assets, entertainment, literary and artistic originals), improvements to non-produced assets (land), changes in inventories of materials, supplies and goods and expenditure on precious metals and stones (gold, diamonds etc.), jewels made from them, as well as paintings and sculptures recognised as works of art, which are acquired as stores of value and not to be used for production or consumption purposes. Therefore, these capital categories have not been included in the analysis.

Direct Defence expenditure by industry

In order to separate defence activities from other public administration services, expenditure data from the UK Defence Statistics were prepared. Upon request, the Defence Analytical Services & Advice Directorate (DASA) of the Ministry of Defence (MOD) kindly provided a complete time series of 'Estimated Defence Expenditure Outturn in UK by Industry Group' from 1990 to 2007 in accordance with the Freedom of Information Act 2000. This was accompanied by the following statement: "This information is broken down into two sections, one covering the period preceding 2002/03 when the MOD used to prepare its accounts on a Cash basis and the other covering the period from 2002/03 when the MOD moved to a Resource Accounting and Budgeting (RAB) regime. It should be noted that the post RAB estimates are not directly comparable to those which were prepared under the old Cash accounting system. This is largely because the RAB data has been prepared on an accruals basis which […] records revenues and expenses when they are incurred, regardless of when cash is exchanged." For the year 2008, data for 2007/08 were used in this study as the estimates for 2008/09 were only published on 29th September 2010 in the latest UK Defence Statistics, after the calculations for this analysis had been completed (DASA/MOD, 2010).

The 'Estimated Defence Expenditure Outturn in UK by Industry Group' from the UK Defence Statistics is the only high-level statistic that aligns direct expenditure with the industry classification used in the ONS National Accounts. It estimates the amount of money the MOD spends directly with UK industry broken down by industrial group. It therefore appeared to be ideal data source for the purpose of the analysis in this report which was to identify the GHG footprint of Defence within the broader category of Public Administration and Defence (PAD). However, there are some differences in the boundaries of the two statistics making an exact alignment

difficult. Therefore the results for Defence have to be interpreted with the following caveats in mind.

There is no SIC code which relates to the Defence industry. The MOD procures from a broad range of industries. It does not procure from suppliers which have been classified under the Public Administration and Defence division of the Standard Industrial Classification.

Estimated Defence Expenditure Outturn figures include MOD expenditure on equipment and non-equipment. Aggregate MOD Equipment expenditure has been used to indicate capital expenditure on acquisition, maintenance, repair and update of items such as plant, machinery and vehicles and fighting equipment plus associated Research & Development, Non Equipment expenditure includes expenditure on items such as utilities (gas, water and electricity) and maintaining the defence estate. These estimates relate to expenditure in UK industry and commerce only and therefore exclude (amongst others):

- Payments against contracts where the primary location of the work task is overseas are removed (only spending with UK industry is included).
- Payments made against US contracts where the work is performed overseas and that are managed by the Foreign Military Sales unit of the British Defence Attache in the US.
- Payments made internally by MOD to MOD Trading funds (DSTL, Met Office, Defence Support Group) are removed although payments to these Trading Funds are included in the MOD accounts as external payments. Revenue earned by these Trading Funds are included.
- Payments on Collaborative Projects such as Tornado and Typhoon are treated as exports and are removed. The proportion of the project costs which relates to the UK workshare (around 35%) is then added back in.

In 2007/08 the total of expenditure not included was around £5 billion, compared to £16.5 billion included. It should be noted that because of the complexity of the process of attributing Defence payments to SIC codes the data are clearly labelled as 'Estimates' and hence the results for the footprint of Defence have also to be seen as estimates and have been labelled accordingly in this report.

The estimated Defence expenditure accounts distinguish 28 industry categories and a further breakdown to the 123-sector working level was required. This was accomplished by breaking down aggregated totals pro-rata to the more detailed level according to total expenditure by Central Government.

Further information relating the underlying methodology and data used to calculate the estimates presented in Table 1.11 of UK Defence Statistics can be found in

DASA Defence Statistics Bulletins Nos. 5 and 5A. These are available on the DASA website.[5]

Greenhouse gas emissions

Annual, sectoral emissions of the six major greenhouse gases (CO_2, CH_4, N_2O, HFC, PFC, SF_6) are taken from the UK national environmental accounts published by ONS and are added as environmental extensions to the use tables. In cases where the industry categories are more aggregated than those at the 123 level, emissions were attributed to sub-sectors pro rata by using total economic output. We refer to previous publications for detail (Wiedmann et al., 2008b). Data from the latest release of UK environmental accounts (ONS, 2010a) were used for the time series 1990 to 2008 in this work.

The time series of sectoral greenhouse gas emissions for the rest of the world was extended for the years 2005 to 2008 by using data from three different data sources as constraints. These are GTAP[6], CAIT[7] and CDIAC[8]. None of these data sources contain all the necessary information alone, but by using them in combination it is possible to break down ROW emissions by the six GHGs, by 57 economic sectors and by year. As in the case of the UK, a further disaggregation to 123 sectors was achieved by allocating emissions to sub-sectors pro rata by using the total economic output of UK sub-sectors.

Specific calculations

Estimation of scope 1 and scope 2 emissions

The direct (scope 1) emissions of Central Government and its sub-sections had to be estimated in this work. As a robust and consistent data basis we use the latest edition of the national Environmental Accounts (EA) which was published by ONS on 10th June 2010 and identifies greenhouse gas emissions for 93 industries (ONS, 2010a). The EA sectors 81 to 89 are relevant for Government activities in general; for Central Government in particular the sectors EA81 (Public administration, not defence), EA82 (Public administration, defence) and EA84 (Health and vet services, social work) are relevant. To allocate emissions to the sub-sections of Central Government analysed in this study we employ the following approach. Emissions of EA82 (Public administration, defence) were directly allocated to Defence activities.

[5] http://www.dasa.mod.uk/applications/newWeb/www/index.php?page=67&pubType=0&thiscontent=1200&date=2010-03-30

[6] Global Trade Analysis Project, GTAP 7 database, Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana, USA. https://www.gtap.agecon.purdue.edu.

[7] Climate Analysis Indicators Tool (CAIT) Version 7.0, World Resources Institute (WRI), Washington DC, USA. http://cait.wri.org.

[8] The Carbon Dioxide Information Analysis Center (CDIAC) is the primary climate-change data and information analysis center of the U.S. Department of Energy (DOE). http://cdiac.ornl.gov.

The remaining emissions were allocated to sub-sections based on the share of Central Government spending on the total expenditure of Government at basic prices. This approach ensures consistency and preserves national accounting identities for both economic and environmental accounts (e.g. all sub-sections add up to the total). This procedure was repeated for all 19 years of the time series.

The approach described above was used in this report rather than using the Scope 1 emissions reported under the SOGE Framework (Sustainable Operations on the Government Estate) Framework (see SDC, 2010). This is for two reasons. First, only three years have been reported under SOGE (2006/07 to 2008/09), not a time series from 1990 to 2008, and second, not all activities (e.g. buildings) of Government Departments have been included under SOGE, meaning that there would be a difference in the totals reported under SOGE and Central Government emissions in this report.

The full carbon footprint emissions of electricity, i.e. scope 2 emissions, have been calculated in the same way as those of other commodities, i.e. by using expenditure data on electricity. This approach ensures consistency across the analysis and completeness of scope, i.e. not only the direct emissions of power stations and transmissions networks but also emissions embedded in the goods and services required by the electricity industry have been taken into account.

Uncertainty

In 2008, the Stockholm Environment Institute at the University of York and the Centre for Integrated Sustainability Analysis at the University of Sydney, on behalf of Defra, undertook a world-first Monte-Carlo analysis of the UK multi-region input-output model upon which the present study is based (Wiedmann et al., 2008a). The aim was to quantify the uncertainties associated with multi-regional input-output modelling for national carbon footprint analysis. The approach and results of the project have now been published in a peer-reviewed, scientific journal (Lenzen et al., 2010b).

In the present study we have used the results from this ground-breaking work to estimate the error margins of the top-level results presented in Figure 12. For this purpose we have used the relative standard error of CO_2 consumer emissions for each of the 123 sectors for the year 2004 as identified and documented in the previous Defra report (Wiedmann et al., 2008a, p.55-56). These margins were applied to the 123-sector-level results in this study and the overall standard error margins in Figure 12 were calculated by using the general error propagation formula (Wiedmann et al., 2008a, p.16-17). It was beyond the scope of this work to undertake an actual Monte-Carlo analysis (which would require thousands of runs of

the model), nor was it possible to do such an analysis for greenhouse gases other than carbon dioxide.

We hope that this additional information will help decision-makers to get a clearer understanding of robustness and reliability of the carbon footprint calculations. Other methodologies often ignore uncertainties altogether or treat them in a very rudimentary way. None of the methods available for carbon accounting is without error. It is also a widely held belief that physical data are inherently and always more accurate than financial data. This is not the case. In reality, the accuracy, relevance and robustness of data is determined by the quality and age of the data and how representative they are for the research question. This is true for both physical and monetary data.

In the following we provide some qualitative considerations of uncertainty issues specific to this study. When calculating a time series of UK Central Government carbon footprint by using environmental input-output analysis, as was the case in this study, specific uncertainty is introduced through:

- the unavailability in the UK of either analytical input-output tables for years more recent than 1995 or supply and use tables at basic prices and in 123 x 123 format for any years (different but similar restrictions apply to ROW tables),
- the difference in sector classification of environmental and economic accounts (93 versus 108 or 123) (different but similar restrictions apply to ROW data),
- the way in which some of the detailed data for intermediate consumption of Central and Local Government sub-sections was derived for more recent years, and
- the aggregation and change of accounting basis of defence expenditure data.

On the other hand, uncertainty is reduced and accuracy is improved by:

- employing a consistent and economy-wide approach across the whole time series,
- using specific data for each individual year of the analysis, based on the latest releases (2010 editions) of national environmental and economic accounts (meaning that the time lag to the latest year analysed is only two years!).

10 Appendix C: References

Baiocchi, G. and Minx, J. C. (2010) Understanding Changes in the UK's CO_2 Emissions: A Global Perspective. *Environmental Science & Technology*, **44**(4), 1177-1184. http://dx.doi.org/10.1021/es902662h.

Croasdale, S. and McIntyre, S. (2010) Summary paper on the 'carbon accounting' methodology applied to the assessment of the Scottish Government's 2010-11 budget. *Fraser of Allander Institute Economic Commentary*, **33**(3), 48-54. http://www.strath.ac.uk/fraser.

DASA/MOD (2010) *United Kingdom Defence Statistics 2010*. 29 September 2010. Defence Analytical Services & Advice Directorate, Ministry of Defence, London, UK. http://www.dasa.mod.uk.

DEFRA (2009) *Guidance on how to measure and report your greenhouse gas emissions*. September 2009. UK Department for Environment, Food and Rural Affairs, London. http://www.defra.gov.uk/environment/business/reporting/index.htm.

Eurostat (2007) *Manual on sources and methods for the compilation of COFOG Statistics - Classification of the Functions of Government (COFOG) (2007 edition)*. Methodologies and working papers. KS-RA-07-022-EN. Statistical Office of the European Communities (Ed.), Office for Official Publications of the European Communities, Luxembourg. http://epp.eurostat.ec.europa.eu.

GAP, SEI and Eco-Logica (2006) *UK Schools Carbon Footprint Scoping Study*. March 2006. Report by Global Action Plan, Stockholm Environment Institute and Eco-Logica Ltd for the Sustainable Development Commission, London http://www.sd-commission.org.uk/publications.php?id=389

Huang, Y. A., Lenzen, M., Weber, C. L., Murray, J. and Matthews, H. S. (2009) The role of input-output analysis for the screening of corporate carbon footprints. *Economic Systems Research*, **21**(3), 217-242. http://dx.doi.org/10.1080/09535310903541348.

Lenzen, M., Gallego, B. and Wood, R. (2009) Matrix balancing under conflicting information. *Economic Systems Research*, **21**(1), 23-44. http://dx.doi.org/10.1080/09535310802688661.

Lenzen, M., Kanemoto, K., Geschke, A., Moran, D., Muñoz, P., Ugon, J., Wood, R. and Yu, T. (2010a) A global multi-region input-output time series at high country and sector detail. *18th International Input-Output Conference of the International Input-Output Association (IIOA)*, 20-25 June 2010. Sydney, Australia. http://www.isa.org.usyd.edu.au/io_2010/.

Lenzen, M., Wood, R. and Wiedmann, T. (2010b) Uncertainty analysis for Multi-Region Input-Output Models – a case study of the UK's carbon footprint. *Economic Systems Research*, **22**(1), 43–63. http://dx.doi.org/10.1080/09535311003661226.

Mahajan, S. (2006) Development, Compilation and Use of Input-Output Suppy and Use Tables. *Economic Trends*(634), 28-46. http://www.statistics.gov.uk/cci/article.asp?ID=1611.

Matthews, H. S., Hendrickson, C. T. and Weber, C. L. (2008) The Importance of Carbon Footprint Estimation Boundaries. *Environmental Science & Technology*, **42**(16), 5839-5842. http://dx.doi.org/10.1021/es703112w.

Minx, J., Wiedmann, T., Barrett, J. and Suh, S. (2008) *Methods review to support the PAS process for the calculation of greenhouse gas emissions embodied in goods and services. Report to the UK Department for Environment, Food and Rural Affairs by Stockholm Environment Institute at the University of York and Department for Bio-based Products at the University of Minnesota.* Project Ref.: EV2074, February 2008. Defra, London, UK. Executive summary: http://randd.defra.gov.uk/Document.aspx?Document=EV02074_7070_EXE.pdf. Full report: http://randd.defra.gov.uk/Document.aspx?Document=EV02074_7071_FRP.pdf.

Minx, J. C., Wiedmann, T., Wood, R., Peters, G. P., Lenzen, M., Owen, A., Scott, K., Barrett, J., Hubacek, K., Baiocchi, G., Paul, A., Dawkins, E., Briggs, J., Guan, D., Suh, S. and Ackerman, F. (2009) Input-output analysis and carbon footprinting: An overview of applications. *Economic Systems Research*, **21**(3), 187-216. http://dx.doi.org/10.1080/09535310903541298.

ONS (2006) *United Kingdom Input-Output Analyses, 2006 Edition*. Office for National Statistics (ONS), London. http://www.statistics.gov.uk/downloads/theme_economy/Input_Output_Analyses_2006_edition.pdf

ONS (2010a) *Environmental Accounts: Greenhouse Gas Emissions for 93 industries, 2010 Edition (last update 10/06/2010).* Office for National Statistics (ONS), London, UK. Retrieved July 2010, from http://www.statistics.gov.uk/statbase/ssdataset.asp?vlnk=5695&More=Y.

ONS (2010b) *United Kingdom input-output statistics*. London, UK, Office for National Statistics (ONS). http://www.statistics.gov.uk/inputoutput

ONS (2010c) *United Kingdom National Accounts - The Blue Book 2010 edition*. July 2010. Editors: John Dye and James Sosimi, Office for National Statistics (ONS), London, UK. http://www.statistics.gov.uk/downloads/theme_economy/bluebook2010.pdf.

SDC (2010) *Becoming the "Greenest Government Ever"? Sustainable Development in Government, Reporting period 2006-2009*. July 2010. Sustainable Development Commission, London, UK. http://www.sd-commission.org.uk.

SDC, NHS and SEI (2008) *NHS England Carbon Emissions - Carbon Footprinting Report*. September 2008. Sustainable Development Commission, NHS Sustainable Development Unit & Stockholm Environment Institute, London, UK. http://www.sd-commission.org.uk.

SDC, NHS, SEI and ARUP (2009) *NHS England Carbon Emissions - Carbon Footprint modelling to 2020*. January 2009. Sustainable Development Commission, NHS Sustainable Development Unit, Stockholm Environment Institute & ARUP, London, UK. http://www.sd-commission.org.uk.

Wiedmann, T. (2009) Carbon Footprint and Input-Output Analysis - An Introduction. *Economic Systems Research*, **21**(3), 175-186. http://dx.doi.org/10.1080/09535310903541256.

Wiedmann, T., Lenzen, M. and Wood, R. (2008a) *Uncertainty Analysis of the UK-MRIO Model – Results from a Monte-Carlo Analysis of the UK Multi-Region Input-Output Model (Embedded Carbon Dioxide Emissions Indicator).* Report to the UK Department for Environment, Food and Rural Affairs by Stockholm Environment Institute at the University of York and Centre for Integrated Sustainability Analysis at the University of Sydney. Project Ref.: EV02033, July 2008. Defra, London, UK. http://randd.defra.gov.uk/Document.aspx?Document=EV02033_7332_FRP.pdf.

Wiedmann, T., Wood, R., Lenzen, M., Minx, J., Guan, D. and Barrett, J. (2008b) *Development of an Embedded Carbon Emissions Indicator - Producing a Time Series of Input-Output Tables and Embedded Carbon Dioxide Emissions for the UK by Using a MRIO Data Optimisation System.* Report to the UK Department for Environment, Food and Rural Affairs by Stockholm Environment Institute at the University of York and Centre for Integrated Sustainability Analysis at the University of Sydney. Project Ref.: EV02033, July 2008. Defra, London, UK. Executive summary: http://randd.defra.gov.uk/Document.aspx?Document=EV02033_7333_EXE.pdf. Full report: http://randd.defra.gov.uk/Document.aspx?Document=EV02033_7331_FRP.pdf.

Wiedmann, T., Wood, R., Minx, J., Lenzen, M., Guan, D. and Harris, R. (2010) A Carbon Footprint Time Series of the UK - Results from a Multi-Region Input-Output Model. *Economic Systems Research*, **22**(1), 19-42. http://dx.doi.org/10.1080/09535311003612591.

WRI and WBCSD (2004) *The Greenhouse Gas Protocol - A Corporate Accounting and Reporting Standard*. March 2004. World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD). http://www.ghgprotocol.org/standards/corporate-standard.