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Emissions Embedded in UK Trade – UK-MRIO Model Results and Error Estimates

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Abstract

Results are presented for carbon dioxide emissions embedded in imports to and exports from the United Kingdom as calculated by an international multi-region input-output model (UK-MRIO). The work was commissioned by the UK Department for Environment, Food and Rural Affairs (Defra). The aim was to construct a robust account of the carbon impacts of trade and thus overall carbon consumption as a headline indicator for Sustainable Development. It has been recognised that the adoption of such a consumption-based perspective – in addition to the traditional approach of territorial emissions accounting – opens up the possibility of extending the range of policy and research applications considerably to cover sectoral, country and product analysis.

A time series of balanced input-output tables for the UK was constructed from publicly available supply and use tables for each year from 1992 to 2004. We use a modified matrix balancing procedure ('CRAS') that is able to handle conflicting external data and inconsistent constraints. The resulting symmetrical input-output tables (SIOT) distinguish domestic transactions and imports in 123 sector resolution.

Three world regions, OECD-Europe, other OECD and non-OECD countries, covering the global economy, were used as trading partners in the model with a resolution of 30 economic sectors each. Input-output data were augmented with carbon dioxide emissions data from UK Environmental Accounts, the International Energy Agency and the EDGAR database. Limitations are posed by detail and classification differences between the economic and environmental data for both the UK and the three world regions. The sensitivity of the model system with respect to parameter uncertainty is tested by carrying out a Monte-Carlo simulation. This allows for the results to be presented with error margins.

Greenhouse gas emissions embedded in imports (EEI) and exports (EEE) are distinguished by three world regions, 123 economic sectors, and whether they are destined for intermediate or final demand. CO_2 EEI are higher than CO_2 emissions embedded in exports (EEE) for all years and there is a clear trend towards increasing EEI, which went up from 4.3% of producer emissions in 1997 to 21% in 2004. The largest and increasing proportion of CO_2 EEI are from the Rest of the World region (which includes Asia). The results from the UK-MRIO model are in line with findings from other researchers.

The current model is a major step towards a fully fledged multi-region input-output model featuring multidirectional trade of a substantial number of UK trading partners. UK-MRIO is already the most detailed and comprehensive modelling approach for the estimation of emissions embedded in UK trade with high relevance for national and international environmental policy-making.

Keywords: embedded (carbon) emissions, multi-region input-output model, international trade, balance of emissions embedded in trade (BEET), UK

TABLE OF CONTENTS

1 Project Context

1.1 Project background

In 2003, the UK Department for the Environment, Food and Rural Affairs (Defra) published a 'Framework for Sustainable Consumption and Production (SCP)', accompanied by a consultation paper setting out a basket of supporting sustainable development indicators. Respondents to the consultation reported that many of the indicators were difficult to interpret without a better understanding of the effect of structural change within the British economy, and in particular the extent to which any reductions in the environmental impact of the UK economy were being offset by increases in the impacts associated with the production of imports to the UK.

At the same time the launch of the SCP framework has led to an increasing policy focus on the environmental impacts of the products consumed by households within the UK, wherever those impacts occur, and to a demand for a better understanding of the life cycle impacts of the whole range of goods and services consumed by British households. More recently there has been an increasing emphasis on the idea that British companies take some responsibility for the upstream impacts of the goods which they sell or use, on the environmental impacts of particular products such as clothing which are heavily dependent upon imports, and on the importance of 'sustainability dialogues' between the UK Government and key trading partners. Attention is therefore focusing not just on the overall impacts of trade to and from the UK, but on which sectors, products and countries the trade relates to.

In 2005, Defra commissioned the Stockholm Environment Institute to identify the most appropriate approach to constructing an indicator for emissions embedded in trade flows to and from the UK (Wiedmann et al. 2006)[1]. One of the conclusions from that study was that, in order to derive reliable and robust estimates for embedded emissions, it is important to explicitly consider the production efficiency and emissions intensity of a number of trading countries and world regions in an international trade model, which is globally closed and sectorally deeply disaggregated (Wiedmann et al. 2007a).

While one of Defra's goals was to be able to produce a robust account of impacts of trade and thus overall consumption in a headline indicator for Sustainable Development, it was recognised that the adoption of such a consumption-based perspective – in addition to the 'traditional' approach of territorial emissions accounting – opened up the possibility of extending the range of policy and research applications considerably to cover sectoral, country and product analysis.

Two recent studies report an increase in UK carbon dioxide emissions when calculated according to the consumption perspective. Druckman et al. (2007) estimate a rise of 7.7% in total UK consumer emissions of CO_2 between 1990 and 2004, suggesting "that the UK is increasingly exporting its more

[1] Defra project ref. EV02001, 'Resource Flows'. Stockholm Environment Institute, York and Policy Studies Institute, London. Published by Defra, August 2006. http://www2.defra.gov.uk/research/project_data/More.asp?I=EV02001&M=KWS&V=EV02001&SCOPE=0

carbon intensive industries" (p.19) and confirming the trend that consumer products are increasingly imported and not produced within the UK. The authors stress the "severe policy implications" (p.23) in conjunction with any emission reduction targets. The second study by Helm et al. (2007) presents a consumption account of UK greenhouse gas emissions including indirect emissions from overseas tourism, international aviation and shipping and embedded emissions in the UK's trade balance.[2] The latter estimate was derived by multiplying values of imports and exports with average carbon dioxide intensities by country. The study finds a steep increase in emissions embedded in imports (from below 300 Mt CO_2-e in 1992 to almost 1000 Mt CO_2-e in 2006) while emissions embedded in exports increase much more modestly. The greenhouse gas trade deficit has reportedly increased six-fold from 110 Mt CO_2-e in 1990 to 620 Mt CO_2-e in 2006. Overall, the consumption-based estimations of Helm et al. (2007) indicate a rise of 19% in total for UK GHG consumer emissions between 1990 and 2003.

As a follow-up to our previous work, the current work[3] is the first stage of the implementation of an international multi-region input-output model for the UK (UK-MRIO 1). As a crucial part of an operational MRIO framework we develop a code protocol that processes data of any kind in a highly efficient way. In essence, this is a sophisticated computer programme that can ‘digest’ data from different countries and years in different classifications and valuations with data gaps and inconsistencies.

The model has been set up in a way that allows for the consistent integration of additional data in a step-wise extension of the model as well as its adaptation towards alternative research questions (see Section 2). The eventual model will also allow a flexible breakdown of economic sectors if this is required to answer specific questions – a capability which is important for the most widespread applications (and therefore the associated cost-return rate of the project) in different areas such as global supply chain analysis, life cycle assessments or conventional environmental input-output analysis. An efficient data handling protocol of this type helps reducing cost and time requirements while at the same time allowing a consistent update of the model.

The Stockholm Environment Institute[4] at the University of York has collaborated with The Centre for Integrated Sustainability Analysis (ISA) at the University of Sydney[5] in this project to develop the required data and model basis.

1.2 Aim of the project

For this stage of the project (UK-MRIO 1), the aim was to develop and implement an initial, relatively small, data and model framework that is easily expandable without major adaptations. A data

[2] The report does not specify which greenhouse gases were included in the analysis and presents some results for CO_2 only and some results for GHGs.

[3] Defra project ref. EV02033, ‘Development of an Embedded Carbon Emissions Indicator. Stockholm Environment Institute, York and Centre for Integrated Sustainability Analysis (ISA), University of Sydney. Commissioned by Defra, December 2006. http://www2.defra.gov.uk/research/project_data/More.asp?I=EV02033&M=KWS&V=EV02033&SUBMIT1=Search&SCOPE=0

[4] http://www.sei.se

[5] http://www.isa.org.usyd.edu.au

optimisation procedure is to allow the flexible adaptation of national input-output and environmental databases for use in a multi-region environmental input-output model in the future. Thus the work was to set the basis for multi-country analyses of environmental impacts associated with UK trade flows, including detailed accounts of emissions embedded in trade flows to and from the UK over a period of time.

In order to achieve this aim, initial data estimates have been made, data constraints have been defined and specific optimisation algorithms have been developed and implemented. As a tangible outcome of the current project we have constructed a time series of annual input-output tables for the UK from 1992 to 2004 by using a modified RAS[6] procedure for balancing (referred to as 'Conflicting RAS' or 'CRAS'). These tables are similar to the "Analytical IO Tables 1995" published by ONS, including symmetric input-output tables (SIOT) for domestic transactions and imports for each year from 1992 to 2004 (Wiedmann et al. 2008b).

In addition to the original project aim, we have also calculated a time series of direct and indirect carbon dioxide emissions associated with UK economic activities, in particular emissions that are embedded in imports to and exports from the UK.

1.3 Review of recent literature on the estimation of emissions embedded in international trade

The following is an update of a previous literature review on models and approaches that are capable of estimating emission embodiments in international trade (Wiedmann et al. 2007a; Wiedmann et al. 2006). The main finding from the review is that in 2007 and 2008 a respectable number of models has been developed worldwide in order to estimate emissions embedded in international trade of numerous countries and regions. Almost all of the studies present input-output based approaches and the use of multi-region input-output models is already well established.

A follow-up of a previous OECD study (Ahmad 2003; Ahmad and Wyckoff 2003) was undertaken by (Yamano et al. 2006). Using the sector harmonised OECD input-output tables, STAN bilateral trade data and IEA CO_2 emissions database for years around 1995 and 2000, the authors developed an international linked world economic model which covers 17 sectors and 42 countries/regions. CO_2 embodiments in international trade are derived from direct and indirect energy consumptions.

(Tunç et al. 2007) estimate the CO_2 content of imports to the Turkish economy by industrial sector in a single-region IO model. They find that the total estimated "CO_2 responsibility" for the Turkish economy in 1996 was 341.7 Mt, of which 17% are due to imported intermediate goods to be used in domestic production and 5% are due to imported goods to satisfy private and public consumption. The authors conclude that consumer-related environmental policies for CO_2 reduction will not necessarily be more effective than policies aimed at producers since the major part of CO_2 responsibility – domestically and imported – arises as a result of the production process.

[6] Synonym for a matrix balancing approach used mainly to update input-output tables, developed by Richard A. Stone in 1961 (see United Nations 1999).

(Limmeechokchai and Suksuntornsiri 2007) calculate energy and greenhouse gas embodiments of final consumption in Thailand for a number of years, taking into account greenhouse gases embedded in imported energy, in particular imported electricity.

The impact of different assumptions concerning the emissions embedded in imports in the case of Finland was tested by (Mäenpää and Siikavirta 2007). Using domestic emission intensities and data from the OECD study by Ahmad and Wyckoff (Ahmad and Wyckoff 2003) in a 139-sector single-region input-output model, the authors found relatively small differences: in the analysis for 1999 the net export of CO_2 from fossil fuel combustion changed from 4.2 to 3.6 Mt. Results for 1990-2003 show that Finland has increasingly been a net exporter of GHG emissions.

There are several follow-up applications of the MRIO model described by (Peters and Hertwich 2004). In (Peters and Hertwich 2006c) the authors use their MRIO model for a structural path analysis (SPA) across borders, thus enabling the investigation of international supply chains (on an aggregation level of 49 sectors). Embedded impacts in household and government consumption and exports are quantified, identifying high ranking impacts from imports, for example the household purchase of clothing from developing countries in the case of CO_2. Furthermore, the authors use SPA in a consumption and a production perspective, offering complementary insights, both in terms of analysis and policy.

Another application focuses on household consumption and impacts of imports to Norway (Peters and Hertwich 2006a). The study finds that household environmental impacts occurring in foreign regions represent 61% of indirect CO_2 emissions, 87% for SO_2, and 34% for NO_x, whereas imports represent only 22% of household expenditure in Norway. Furthermore, a disproportionately large amount of pollution embedded in Norwegian household imports can be traced back to developing countries.

All studies by Peters and Hertwich confirm the importance of considering regional technology differences in a multi-region model when calculating pollution embedded in trade. The pollution intensity of the electricity sector in China, for example, is 231 times higher for CO_2 and 1078 times higher for SO2 than in Norway (Peters and Hertwich 2006b; Peters et al. in press).

(Hoekstra and Janssen 2006) use a dynamic input-output model of two trading countries to explore the effects of taxes in different scenarios for environmental responsibility. The study is specified in a hypothetical framework and does not use empirical data.

The hypothesis that there is a shift of high polluting industries from developed countries to those with lower environmental standards ("pollution haven hypothesis") is examined by (Wilting et al. 2006) for the Netherlands. Developments in emissions of CO_2, CH_4, N_2O, NO_x, SO_2 and NH_3 in Dutch industries from 1990 to 2004 are related to changes in trade patterns in the same period by using a structural decomposition analysis based on a single-region input-output model of Denmark. The analyses show that the export effect compensates the import effect for all air emissions except of CO_2, implicating that there is no net shift of pollution to abroad. Only CO_2 shows a small decrease in emissions resulting from trade effects, but the effect is too small to draw robust conclusions.

Environmental impacts of USA trade has recently attracted the attention of several research groups. (Norman et al. 2007) create a 76 sector bi-national Canada-US EIO-LCA model by linking the national input-output models through trade flows by industrial sector. They find that US manufacturing and resource industries are about 1.15 times as energy-intensive and 1.3 times as GHG-intensive as Canadian industries, with significant sector-specific discrepancies in energy and GHG intensity. Accounting for trade can significantly alter the results of purely national life-cycle assessment studies, particularly for many Canadian manufacturing sectors. (Norman et al. 2007) show that the production and consumption of goods in one country often exerts significant energy and GHG influences on the other.

(Weber and Matthews 2007) use a multi-country input-output model of the USA and its seven largest trading partners to analyze the environmental effects of changes to US trade structure and volume from 1997 to 2004. They show that increased import volume and shifting trade patterns during this time period led to a large increase in embedded emissions in US trade for CO_2, SO_2, and NO_x. It is estimated that the overall embedded CO_2 in US imports has grown from between 0.5 and 0.8 Gt of CO_2 in 1997 to between 0.8 and 1.8 Gt of CO_2 in 2004, representing between 9-14% and 13-30% of US (2-4% to 3-7% of global) CO_2 emissions, respectively.

International trade can reduce overall CO_2 emissions if imported products are consumed that were produced with a lower carbon intensity than in the domestic industry. This is the case for trade between Japan and the USA, for example. By using a two-region input-output model, (Ackerman et al. 2007) estimate that in 1995, Japan-US trade reduced US industrial emissions by 14.6 million tons of CO_2-equivalent, and increased emissions in Japan by 6.7 million tons, for a global savings of 7.9 million tons. These quantities are less than one percent of each country's total emissions but trade of Japan and the USA with the rest of the world reduced emissions by larger amounts, roughly four percent of each country's emissions. The authors estimate that US industry could cut its carbon emissions by more than half if it matched the environmental performance of industry in Japan.

Another study investigating the environmental impacts of US trade is presented by (Ghertner and Fripp 2007). A single region EIO-LCA model is combined with trade data for 1998 to 2004 to generate a US balance of emissions embedded in trade (BEET) for Global Warming Potential (GWP), energy, and other emissions. The amount of leakage of environmental impact through trade is modelled under different scenarios varying the environmental intensity of production of US trading partners. It is found that in 2004, with reasonable assumptions about the environmental intensity of imports and exports, this leakage exceeds 10% for all studied impacts and exceeds 20% for GWP.

Systematic environmental accounting alongside national economic accounting has long been recognised as a very useful source of information for ecological-economic modelling and (political) decision-making (see Lange 2007 for an introduction to a special issue of Ecological Economics on Environmental Accounting, Vol. 61, 2007). A new FP7 European Integrated Project, EXIOPOL, will contribute to the extension, consolidation and application of environmental-economic accounts in Europe. EXIOPOL stands for an 'Environmental Accounting Framework Using Externality Data and Input-Output Tools for Policy Analysis'[7]. EXIOPOL aims to develop estimates of external costs of a broad set of economic activities for Europe and to set up a detailed environmentally extended input-output framework including these estimates, in order to apply the results of this analysis to address

[7] http://www.feem.it/Feem/Pub/Programmes/Sustainability+Indicators+and+Environmental+Valuation/Activities/200703-EXIOPOL.htm, see also http://www.seri.at/EXIOPOL

policy questions in fields such as Integrated Product Policy or Sustainable Consumption and Production. One work area of the new project which was kick-started in April 2007 is the creation of a detailed input-output framework for the EU 25 which is extended with environmental information and will enable the creation of MRIO models in the future. The database will enable estimating environmental impacts and external costs of different economic sector activities, final consumption activities and resource consumption for countries in the EU (Tukker 2006, 2007).

A number of multi-region input-output models with world coverage using the GTAP database and results for environmental impacts embedded in trade have also been presented very recently at the 16th International Input-Output Conference 2007 in Istanbul (www.io2007.itu.edu.tr)[9]. While both (Wilting and Vringer 2007) and (Friot et al. 2007) have constructed a 12 region model based on GTAP, allowing for individual countries to be analysed on a regional average, (Peters 2007) presents a full GTAP-MRIO model where all 87 regions and 57 sectors remain disaggregated. The latter study also provides a critical assessment of GTAP data.

2 Methodology and Data

2.1 Methodology for constructing the UK-MRIO model

The methodology and data preparation part of the project have been described in detail in the project report (Wiedmann et al. 2008b) and a conference paper (Wiedmann et al. 2007b). As the main focus of this particular contribution is on the results and uncertainties of the model we refer to these documents for further information.

In essence, the following procedure was applied. A time series of balanced input-output tables for the UK was constructed from publicly available supply and use tables for each year from 1992 to 2004. We use a modified matrix balancing procedure ('CRAS') that is able to handle conflicting external data and inconsistent constraints. The resulting symmetrical input-output tables (SIOT) distinguish domestic transactions and imports in 123 sector resolution.

Three world regions, OECD-Europe, other OECD and non-OECD countries, covering the global economy, were used as trading partners in the model with a resolution of 30 economic sectors each. We have used publicly available input-output data from the UK Office for National Statistics (ONS)[10,11] and from Eurostat, trade data from HM Revenue and Customs, foreign input-output data from the Global Trade Analysis Project (GTAP) provided by the Netherlands Environmental Assessment Agency (MNP), price indices from OECD, GDP data by sector from UN statistics and CO_2 emissions data from ONS Environmental Accounts and from the International Energy Agency.

8 The UK-MRIO 1 model was also presented at this conference (Wiedmann et al. 2007b).

9 The UK-MRIO 1 model was also presented at this conference (Wiedmann et al. 2007b).

10 Only data available from the ONS website http://www.statistics.gov.uk/inputoutput were used. No additional input-output data could be made available by ONS upon request.

11 All input-output data were left in current years prices in order to minimise error through price conversion (see also Section 4).

Limitations are posed by detail and classification differences between the economic and environmental data for both the UK and the three world regions. The sensitivity of the model system with respect to parameter uncertainty has been tested by carrying out a Monte-Carlo simulation. This is described in the next section.

2.2 Methodology for estimating uncertainties of model input data

2.2.1 General procedure for estimating data uncertainties

We define the *order of magnitude* of a data item x as its logarithm $\log_{10}(x)$. For example, the order of magnitude of £1,000 is 3, the order of magnitude of £10,000 is 4. Let the absolute standard error of a data item x be Δx, so that its Relative Standard Error (RSE) is $r_x = \Delta x/x$. The absolute error in the logarithms (the “order-of-magnitude” error) is then

Eq. 1 $$\Delta(\log_{10} x) \approx \log_{10}(x + \Delta x) - \log_{10}(x) = \log_{10}(\frac{x + \Delta x}{x}) = \log_{10}(1 + r_x).$$

Relative standard errors r_x can sometimes be obtained or derived from public data sources. If there are no data, error estimates can be solicited from informed judgement of statistical agency staff (Lenzen 2001). These relative standard error can then be transformed into the “order-of-magnitude” errors (or *log-normal errors*) by the approximation above.

The rationale for estimating error coefficients for the logarithms and not for the data values as such is based on the assumption that data are distributed log-normally, and not normally. The assumption of log-normality effectively ensures that all values in the error range of a data item remain positive.

Large data items are generally known with higher accuracy than small data items. This is due to the fact that large items often consist of many smaller data points (e.g. purchases by companies, emissions data from individual sources, etc.), thus cancelling out stochastic errors when accumulating. This holds in general for any data: For example employment in service sectors of an economy is large, because there is a large number businesses employing a small number of people. Another example is energy use in the electricity sector. Even though there may not be many power plants in the country, the amount of black coal or natural gas is usually comprised of many supply batches adding up over the year.

For the sake of consistency and simplicity, we have chosen to regress all log-normal standard error data with a *linear function on the logarithms of the data*:

Eq. 2 $$\log_{10}(1 + r_x) = a \ln x + b.$$

where a and b are *regression coefficients*.

In order to perform a Monte-Carlo analysis of the UK-MRIO model, the uncertainties of all underlying input data had first to be determined. There are five types of data with their specific uncertainties:

- UK input-output data,
- UK CO_2 data,
- GTAP input-output data for three world regions,
- CPI data used for deflation,
- International CO_2 data, and
- Trade data.

A detailed description of how the uncertainties in each case were derived is beyond the scope of this paper but is available in the project report (Wiedmann et al. 2008a).

2.3 Methodology for calculating the uncertainty of embedded emissions

2.3.1 Introduction

The UK input-output tables for the UK-MRIO model were obtained using a multi-proportional balancing algorithm (CRAS; described in the original consultancy report, Wiedmann et al. 2007c), with the aim of having the entries of the input-output table (vectorised as **p**) satisfy constraints **c** according to **Gp** = **c**, where **G** is a constraints coefficients matrix, and **c** holds the constraints values. The balancing algorithm starts with an initial estimate $\mathbf{p}_0$ for **p**, and arrives at a final solution $\mathbf{p}^{(\text{final})}$. This $\mathbf{p}^{(\text{final})}$ is a vectorised form of the input-output table **T**.

The aim of the present work was to establish uncertainty estimates for the carbon multipliers **m**, which are calculated from **T** according **m** = **q** [**I** - **TError! Objects cannot be created from editing field codes.**]$^{-1}$, where **q** are sectoral carbon intensities, **x** is sectoral gross output, and **I** is a suitable unity matrix. These uncertainties will be expressed as standard deviations Δ**m**. A standard deviation Δ**m** denotes the 67% confidence interval around the mean **m**; in other words, 67% of a large number of observations of **m** would fall into the interval [**m**–Δ**m** , **m**+Δ**m**].

In order to calculate the Δ**m**, it is necessary to determine the standard deviations Δ**T** of the input-output table **T** itself. Hence, the calculations carried out in this work proceed in 2 stages: 1) determine standard deviations Δ**T** of **T**, and 2) determine standard deviations Δ**m** of **m**. These stages are described in detail in the following.

2.3.2 Estimate table uncertainties ΔT from balancing procedure

A first estimate of the uncertainties of **p** (vectorised as Δp) can be obtained by the shift that the $\mathbf{p}_0$ experience during the balancing run: $\mathbf{dp}^{(0)} = \mathbf{p}^{(\text{final})} - \mathbf{p}_0$. Results from the work performed in the previous project (Wiedmann et al. 2007c) has been used to quantify $\mathbf{dp}^{(0)}$.

2.3.3 Estimate table uncertainties from constraint uncertainties

The uncertainties of constraint values **c** are known as **dc**. These **dc** have been sourced for all constraint values, see Section 2.2 (uncertainties of model input data).

Taking the first estimate of the **dp** as a starting point, the uncertainties of the constraints would be $\mathbf{dc}^{(0)} = \mathbf{G}\,\mathbf{dp}^{(0)}$. Generally, $\mathbf{dc}^{(0)} \neq \mathbf{dc} = \mathbf{G}\,\mathbf{dp}$.

The **dp** can now be subjected to a RAS-type adjustment process as follows:

a) Calculate $dc_1 / dc^{(0)}_1$

b) Adjust $dp_j^{(1)} = dp_j^{(0)} \times dc_1 / dc^{(0)}_1$ $\forall j$ where $G_{1j} \neq 0$, so that $dc_1 = \sqrt{\sum_j \left(G_{1j} dp_j^{(1)}\right)^2}$

c) Calculate $dc_2 / dc^{(0)}_2$.

d) Adjust $dp_j^{(1)} = dp_j^{(0)} \times dc_2 / dc^{(0)}_2$ $\forall j$ where $G_{2j} \neq 0$, so that $dc_2 = \sqrt{\sum_j \left(G_{2j} dp_j^{(1)}\right)^2}$

e) And so on $\forall$ c_i

f) And so on $\forall$ $dc_i / dc^{(n)}_i$

g) Exit if $\|\mathbf{dc} - \mathbf{dc}^{(n)}\| \leq$ some small ε, else goto a) and calculate $dc_1 / dc^{(n+1)}_1$

h) The $\mathbf{dp}^{(n)}$ are the solution for $\Delta\mathbf{p}$; they are the uncertainties $\Delta\mathbf{T}$ of the entries of the input-output table **T.**

2.3.4 Assembling uncertainties into one table

The $\Delta\mathbf{T}$ obtained from the stages above yield the standard deviations of the UK input-output tables for all years. Estimates of GTAP standard deviations and of carbon emissions were added, and from the combined information uncertainty tables **dT** and **dq** were constructed.

2.3.5 Estimate multiplier uncertainties using Monte-Carlo simulation

Multipliers **m** are calculated from direct intensities **q**, the input-output table **T** as well as gross output **x** according to **m** = **q** [**I - TError! Objects cannot be created from editing field codes.**]$^{-1}$, where **I** is a suitable unity matrix. The uncertainties **dm** of the multipliers **m** cannot be obtained analytically, but for example via Monte-Carlo analysis (Bullard and Sebald 1977, 1988; Lenzen 2001). Here, a perturbation of the input-output table $\mathbf{T} \rightarrow \mathbf{T} + \mathbf{dT}$ results in perturbed gross output $\mathbf{x} \rightarrow \mathbf{x} + \mathbf{dx}$, and together with the perturbed direct intensities $\mathbf{q} \rightarrow \mathbf{q} + \mathbf{dq}$, they result in a perturbed multiplier $\mathbf{m} \rightarrow \mathbf{m} + \mathbf{dm} = (\mathbf{q} + \mathbf{dq})\,[\,\mathbf{I} - (\mathbf{T} + \mathbf{dT})\,(\mathbf{x} + \mathbf{dx})\,]^{-1}$. This procedure has been repeated a large number of times (5,000 × per year), and multiplier uncertainties are extracted from the distribution of the **m** + **dm**.

In carrying out the Monte-Carlo analysis, we have followed a conservative approach, which results in slightly higher uncertainty estimates, in two aspects:

1. (Bullard and Sebald 1977, 1988; Lenzen 2001) exclude "infeasible" Monte-Carlo runs with $|\mathbf{dx}| / \mathbf{x} > 3\%$, since they assume that gross output is a macro quantity that known with relatively high

certainty. However, we do not require this knowledge of gross output, and hence include all Monte-Carlo runs, thus including runs yielding higher standard deviations $\Delta\mathbf{T}$.

2. Perturbing the input-output table $\mathbf{T} \rightarrow \mathbf{T} + \mathbf{dT}$ results in the perturbed table $\mathbf{T} + \mathbf{dT}$ being unbalanced, that is row sums will not necessarily equal column sums. In theory, row sums and column sums must balance (gross input = gross output). Applying a RAS-type balancing procedure so that $\mathbf{T} + \mathbf{dT}$ conformed to row and column balance, would result in a reduced perturbance, and hence in reduced standard deviations. We have decided not to balance the perturbed table in order to reflect uncertainty of gross input and output, thus resulting in elevated standard deviations.

5000 Monte-Carlo simulation runs were performed on two parallel UNIX processors, taking about 60 hours of calculation time, respectively.

2.3.6 Error propagation and uncertainty in embedded emissions

Embedded emissions uncertainties are hence calculated as follows. Let J be a set of sectors, and AE_j its embedded emissions. Using

- final demand y, with absolute standard deviation $\mathbf{\Delta y}$,
- multipliers m, with absolute standard deviation $\mathbf{\Delta m}$,
- sectoral embedded emissions E, with absolute standard deviation ΔE,
- aggregate embedded emissions AE, with absolute standard deviation ΔAE.
- $E_i = m_i y_i$, and
- $AE_j = \sum_{i \in J} E_i$,

Using the general error propagation for a function $f(x_i)$ as

$$\Delta f = \sqrt{\left(\frac{\partial f}{\partial x_i}\right)^2 \Delta x_i^2} \quad , \qquad (1)$$

we find

$$\Delta E_i = \sqrt{m_i^2 \Delta y_i^2 + \Delta m_i^2 y_i^2} \Leftrightarrow \frac{\Delta E_i}{E_i} = \sqrt{\frac{\Delta y_i^2}{y_i^2} + \frac{\Delta m_i^2}{m_i^2}} \qquad (2)$$

$$\Delta E_i = \sqrt{m_i^2 \Delta y_i^2 + \Delta m_i^2 y_i^2} \Leftrightarrow \frac{\Delta E_i}{E_i} = \sqrt{\frac{\Delta y_i^2}{y_i^2} + \frac{\Delta m_i^2}{m_i^2}} \text{ and}$$

$$\Delta AE_j = \sqrt{\sum_{i \in J} \Delta E_i^2} \qquad (3).$$

3 Results

3.1 Production of a time series of symmetric input-output tables for the UK from 1992 to 2004

Using publicly available supply and use tables and input-output data and the CRAS method described above for balancing we have produced symmetric input-output flow tables (SIOTs), based on the industry technology assumption.[12] They represent the domestic UK economy in current basic prices in product by product format and by 123 sectors for each year from 1992 to 2004 (Wiedmann et al. 2008b). We have also estimated imports and margins matrices in the same format, product by product and 123 sectors. The latter one contains both taxes and distribution margins combined in one table. All three tables – SIOT, imports and margins – show inter-industrial transactions (123x123) and final demand.

Supply and use tables are revised annually by the Office for National Statistics, and thus discrepancies will be found between the data in the 1995 Analytical Tables (Ruiz and Mahajan (Ed.) 2002), and the most recently revised SUTs which we have used in this project (2006 Edition: ONS 2006b, 2007c). The most discrepancies occur with the application of taxes and subsidies.[13] We corrected for these differences and brought our estimates in line with the most recent annual SUTs.

With limits on data availability, time and resources in projects such as this, it is not possible to produce symmetric tables of the same quality as the Analytical Tables produced by ONS. This is because substantial specific information from a great amount of disparate data sources as well as special knowledge is required to deal with issues such as price conversion and secondary production appropriately (Mahajan 2006). Nevertheless, we think that the SIOTs produced in this project represent an approximation of real economic activity close and robust enough for modelling purposes. The full time series also fills a gap in the public availability of symmetric tables which is due to an ongoing modernisation programme at ONS (Beadle 2007; Mahajan 2007).

[12] This assumption could also be called *"assumption of fixed product sales structures"* according to (Thage 2005). The decision to use this assumption is based on practical considerations. It should be emphasised that the model can be constructed with any technology assumption, provided the data is available. By far the most favourable option would be a hybrid technology assumption. However, this is only possible with specific information which is held by ONS but is not publicly available.

[13] Figures between updated SUTs and 1995 Analytical Tables vary substantially; for alcoholic beverages in particular by a factor of 10. This can be explained by a one-off methodological change in 2003 bringing the estimates of household final consumption expenditure on IO product groups 18 (alcoholic beverages) and 92 (hotels and catering) into line with the SIC (92). The purchase of alcoholic beverages by households from pubs and restaurants is now shown as a purchase of the catering product. The catering industry is now shown as purchasing alcoholic beverages as intermediate consumption, being used up in the production of its catering output. Previously (in the 1995 AT), the catering industry was shown as making a retail margin on all sales of alcoholic beverages, both on-sales and off-sales, and households were shown as purchasing the alcoholic beverages product. The catering industry is now shown as making a retail margin only on off-sales, and on-sales of alcoholic beverages are treated as catering output with households shown as purchasing the catering product.

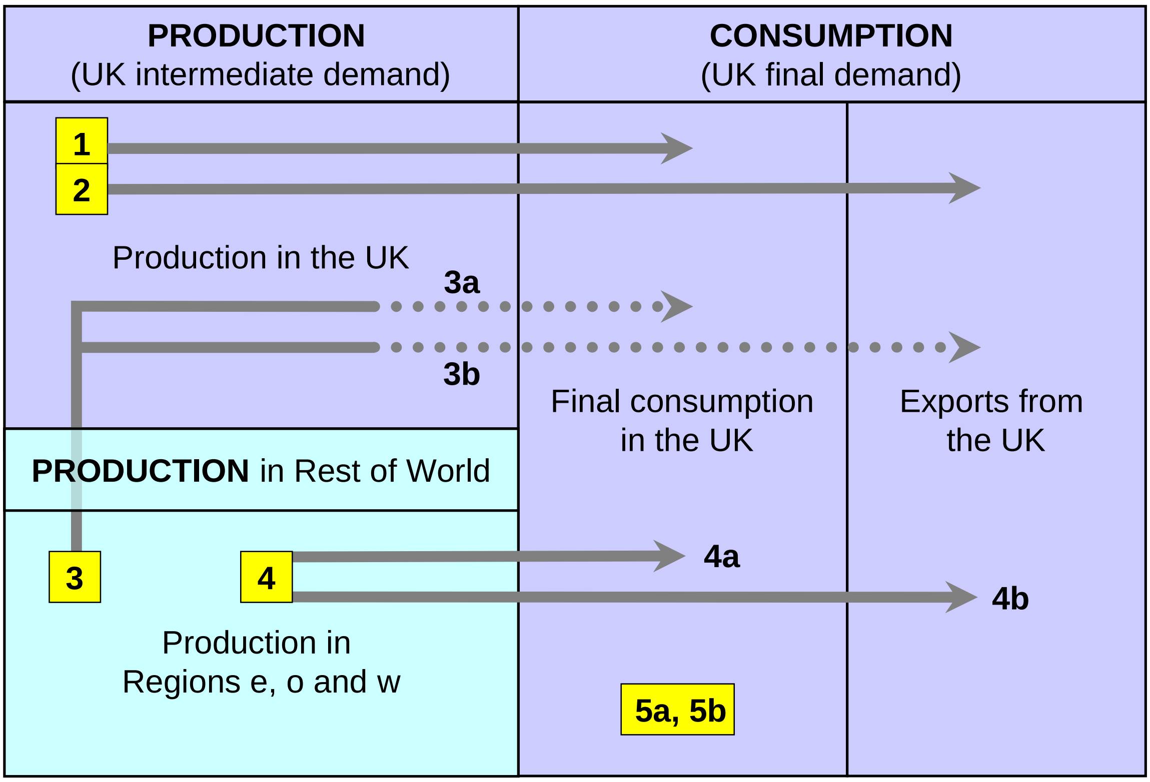
3.2 Embedded carbon dioxide emissions

Governments that are Party to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol have agreed under the provisions of these treaties to report national emissions using the greenhouse gas inventory guidelines developed by the Intergovernmental Panel on Climate Change (IPCC) (DEFRA 2007). The coverage of these National Greenhouse Gas Inventories generally corresponds to the national territory and includes all greenhouse gas emissions from the production of goods and services within a country (e.g. the UK) wherever these are consumed (either in the UK or exported). The statistics supplied to the UNFCCC do not, by international agreement, include emissions from international aviation and shipping in national totals. A measure of these can to be included in order to calculate the total emissions produced by a country's activities[14]. This report refers to these estimates as 'producer emissions (PE)', 'production based indicator', 'producer responsibility' or 'producer principle'. This measure does not, however, take into account emissions generated in the production of *imports* to the UK. Accounting for "emissions from consumption" on the other hand – also referred to as 'consumer emissions (CE)', 'consumption based indicator', 'consumer responsibility' or 'consumer principle' – includes the emissions from goods and services consumed by UK residents, wherever they come from. While including import-related emissions in the estimation procedure, this indicator excludes export-related emissions.

The two approaches serve different purposes, have different applications and complement each other. The producer emissions indicator is relatively simple to estimate and helps pinpoint the drivers behind changes in emissions rooted in the way the UK economy provides goods and services to final consumers within the UK and across the world. Its coverage corresponds to UK political jurisdiction and is based upon the territorial inventories which are the agreed legal basis for reporting under international treaties. The consumer emissions indicator on the other hand can help to identify the driving forces behind changes in the worldwide impact of emissions from UK consumption patterns. Both indicators are relevant to the decisions needed to develop efficacious and fair policies, and specific abatement strategies, which would need to be consistent with the requirements of the world trade regime.

Discussions and suggestions on how to allocate responsibility for emissions can be found in the scientific literature (Bastianoni et al. 2004; Eder and Narodoslawsky 1999; Ferng 2003; Hoekstra and Janssen 2006; Kondo et al. 1998; Mongelli et al. 2006; Munksgaard et al. 2008; Munksgaard et al. 2005; Munksgaard and Pedersen 2001; Muradian et al. 2002; Peters and Hertwich submitted). With the UK-MRIO 1 model developed in this project we have quantified the carbon dioxide (CO_2) emissions that can be associated with UK production and UK imports and exports as depicted in Figure 1.

[14] Estimates of emissions produced by UK residents are provided each year as part of the Environmental Accounts published by the ONS (ONS 2007b). They are based upon the UK's Greenhouse Gas Emissions Inventory with adjustments for emissions from UK operators of international aviation and shipping (DEFRA 2007); see also Table 1 which shows the bridging between the different GHG accounts.



Arrows should be read as **"Emissions occurring in** [*beginning of arrow*] **due to** [*end of arrow*]**"**

Producer Emissions (production-based inventory): 1 + 2 + 5a + 5b

Consumer Emissions (consumption-based inventory): 1 + 3a + 4a + 5a + 5b

Figure 1: Depiction of emissions occurring through UK economic activity, including trade, and different principles of emissions accounting

Legend to Figure 1:

1 Domestic UK Emissions due to UK final consumption

2 Domestic UK Emissions due to export

3a Imported emissions to domestic industry due to UK final consumption

3b Imported emissions to domestic industry due to UK exports

4a Imported emissions direct to final demand due to UK final consumption

4b Imported emissions direct to final demand due to UK exports

5a UK residential emissions due to travel

5b UK residential emissions not due to travel (e.g. housing)

Producer Emissions (PE): A production-based indicator (emissions accounting based on the producer principle) adds together all emissions that occur on UK territory, i.e. **1 + 2 + 5a + 5b** (blue shaded areas in Figure 1).

Consumer Emissions (CE): A consumption-based indicator (emissions accounting based on the consumption principle) adds together emissions that are required to satisfy final consumption in the UK (as shown in Figure 1), i.e. **1 + 3a + 4a + 5a + 5b**.

Emissions Embedded[15] in Imports (EEI) are those emissions that occur outside the UK territory (green shaded areas) but are caused by UK economic activity (incl. production, consumption and exports): **3a + 3b + 4a + 4b**.

Emissions Embedded in Exports (EEE) are caused by exports from the UK and occur mostly in the UK territory (**2**) but some of these emissions occur outside of the UK (**3b + 4b**) when imports are re-exported: **2 + 3b + 4b**.

Balance of Emissions Embedded in Trade (BEET): A balance of trade is defined as (value of) exports minus (value of) imports, i.e. if a country exports more than it imports it has a trade surplus, if it imports more than it exports it has a trade deficit. This principle can be adopted for emissions embedded in trade and the BEET becomes: **2 – 3a – 4a**.

Figure 1 also reminds of the fact that the method of allocation is driven by consumption as all emissions are ultimately allocated to final demand (all arrows in the figure end in the final demand box).

Table 1 below shows the modelling results for all categories of embedded emissions as a time series from 1992 to 2004. The main findings are:

- Consumer emissions are significantly higher than producer or UNFCCC reported emissions (in 2004, CE are 132 Mt or 21% higher than PE and more than 200 Mt or 37% higher than the number reported under the Kyoto protocol, see also Figure 2).
- Consumer emissions have risen steadily over the period and are now 18% higher than in 1992 (while emissions on a Kyoto basis have declined by 5%; this is not shown in Table 1).
- CO_2 emissions embedded in imports (EEI) are higher than emissions embedded in exports (EEE) for all years.
- There is a clear trend towards increasing EEI, which went up from 4.3% of producer emissions in 1997 to 21% in 2004. Emissions in net trade have increased from 27 Mt of CO_2 to 132 Mt, with emissions relating to imports nearly doubling over the period.
- EEI from the Rest of the World were about half the total in 1992 and have increased markedly in recent years.

[15] In the literature the term 'embodied' emissions seems to be more widespread. We treat 'embedded' and 'embodied' as synonyms.

Table 1: CO_2 emissions associated with UK economic activity and embedded in international trade from and to the UK. The upper part of the table shows the results from the UK-MRIO 1 model, the lower part shows the comparison with the Environmental Accounts and the emissions reported to the UNFCCC (bridging table) (all numbers in Mt of CO_2).

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Embedded Emissions													
Domestic UK Emissions due to UK final consumption (1)	343.0	318.6	315.1	310.1	316.9	314.0	315.0	314.9	316.2	329.1	320.1	326.4	329.0
Domestic UK Emissions due to export (2)	131.3	139.4	141.8	144.9	151.1	139.9	143.1	134.0	143.8	143.4	138.8	147.5	148.7
Imported emissions to domestic industry due to UK final consumption (3a)	74.6	78.8	79.1	97.1	86.6	86.0	94.4	75.5	98.2	117.6	120.1	133.5	133.1
Imported emissions to domestic industry due to UK exports (3b)	35.8	42.5	45.3	62.5	53.6	46.2	54.8	40.3	56.0	64.1	64.5	74.3	73.6
Imported emissions direct to final demand due to UK final consumption (4a)	84.0	91.6	95.7	106.7	94.7	114.0	122.6	125.7	117.3	133.5	139.1	152.8	147.5
Imported emissions direct to final demand due to UK exports (4b)	12.3	14.4	14.7	15.0	17.7	12.4	19.1	22.1	18.6	21.4	19.0	19.7	19.8
UK residential emissions due to travel (5a)[16]	86.4	90.3	86.0	81.7	92.8	85.7	87.7	87.2	87.7	90.0	86.9	87.7	89.4
UK residential emissions not due to travel (e.g. housing) (5b)[16]	59.2	59.4	58.1	56.8	60.0	61.0	60.5	61.6	61.2	62.0	63.9	63.2	63.5

[16] Note that ONS Environmental Accounts include a small amount of direct emissions from British tourists overseas which do not occur on UK territory (categories **5a** and **5b**). The Accounts measure puts emissions on an UK residents basis by including all emissions generated by UK households and businesses transport at home and abroad and excluding emissions generated by non-residents [tourist] travel and transport in the UK. This allows for a more consistent comparison with key National Account indicators such as gross domestic product and gross value added (ONS 2007a, page 28). See also page **Error! Bookmark not defined.** and following.

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Consumer Emissions (CE = 1+3a+4a+5a+5b)	**647.2**	**638.8**	**634.0**	**652.3**	**651.0**	**660.6**	**680.3**	**664.9**	**680.7**	**732.1**	**730.1**	**763.6**	**762.4**
Emissions embedded in total trade (EET) (2+3a+3b+4a+4b)	332.2	366.7	376.7	426.2	403.7	398.5	434.0	397.6	434.0	480.0	481.4	527.9	522.7
Emissions Embedded in Exports (EEE) (2+3b+4b)	179.2	196.3	201.8	222.4	222.4	198.5	217.0	196.4	218.4	228.9	222.2	241.6	242.2
Emissions Embedded in Imports (EEI) (3a+3b+4a+4b)	206.0	227.3	234.9	281.3	252.6	258.6	290.9	263.6	290.2	336.4	342.6	380.4	374.0
Balance of Emissions Embedded in UK Trade (BEET) (2-3a-4a)	**-26.8**	**-31.1**	**-33.0**	**-58.9**	**-30.2**	**-60.0**	**-73.9**	**-67.2**	**-71.7**	**-107.5**	**-120.4**	**-138.8**	**-131.8**
BEET as percentage of producer emissions	**-4.3%**	**-5.1%**	**-5.5%**	**-9.9%**	**-4.9%**	**-10.0%**	**-12.2%**	**-11.2%**	**-11.8%**	**-17.2%**	**-19.7%**	**-22.2%**	**-20.9%**
National emission accounts *(ONS 2007b and personal comm.)*													
Env. Accounts Producer Emiss. (PE = 1+2+5a+5b)	**620.0**	**607.7**	**601.0**	**593.5**	**620.8**	**600.6**	**606.3**	**597.7**	**609.0**	**624.4**	**609.7**	**624.8**	**630.6**
International aviation and shipping bunker emissions (-)	23.8	24.9	25.2	26.8	28.7	30.9	34.2	33.9	36.0	35.9	34.3	34.8	39.0
Other extra-territorial adjustments (-) [17]	12.9	13.2	12.6	12.8	16.2	16.1	16.2	16.3	17.2	21.1	23.6	25.4	25.8
CO2 biomass (-)	3.55	3.71	4.91	5.24	5.48	5.76	5.80	6.41	6.57	7.26	7.51	8.35	9.36
Crown Dependencies (+)	0.018	0.019	0.019	0.020	0.021	0.021	0.022	0.023	0.023	0.024	0.024	0.025	0.048
Land use change / forestry (+)	2.25	1.07	0.86	0.99	0.85	0.50	-0.05	-0.27	-0.45	-0.60	-1.12	-1.18	-1.93
UNFCCC Reported (Excl. Overseas Territories)	**581.9**	**567.0**	**559.2**	**549.6**	**571.3**	**548.4**	**550.1**	**540.8**	**548.8**	**559.6**	**543.2**	**555.1**	**554.6**

[17] These adjustments are (i) to adjust international aviation and shipping bunker emissions to cover emissions from UK resident operators; and (ii) to allow for the emissions produced by UK tourists abroad, net of emissions from visitors to the UK.

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
UNFCCC Reported (Incl. Overseas Territories)	583.1	568.1	560.3	550.8	572.5	549.5	551.3	542.0	550.0	560.9	544.5	556.4	555.9

Before more details on embedded emissions are presented further below, we compare graphically the CO_2 emissions as accounted by three different indicators: consumer emissions, producer emissions and Kyoto protocol (UNFCCC reported) emissions; see Figure 2.

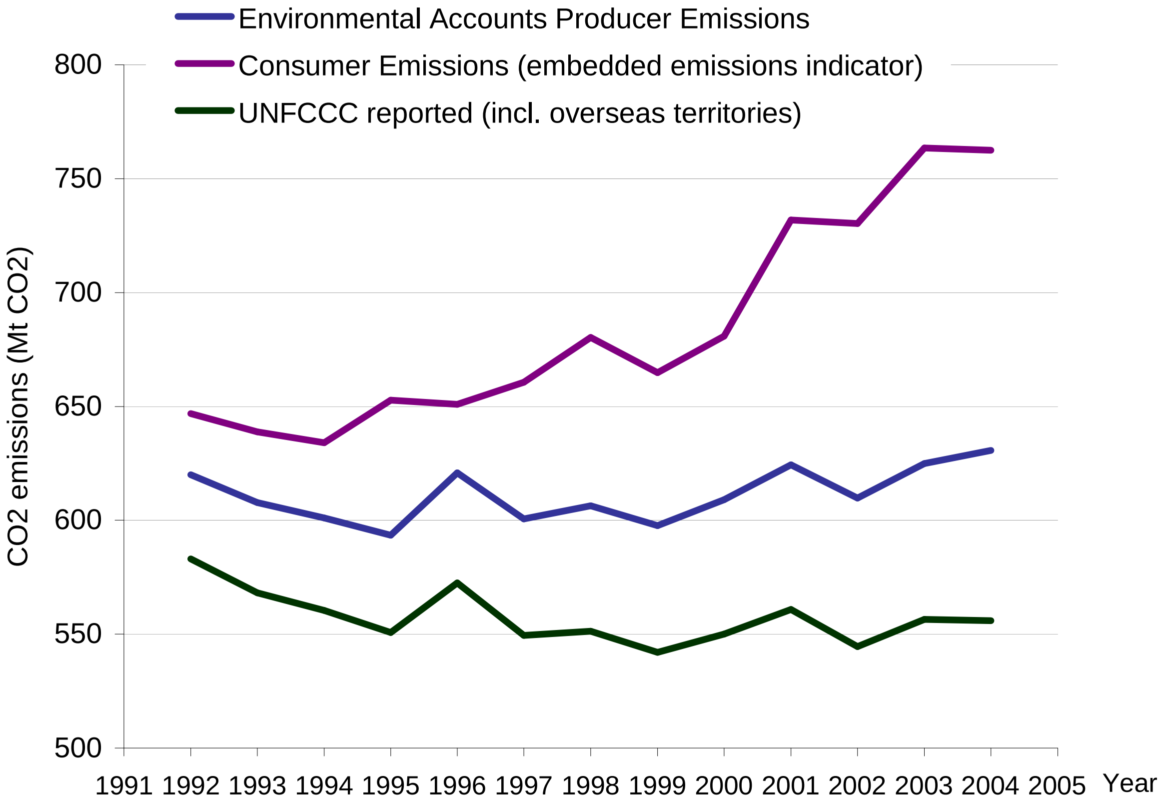


Figure 2: Development of UK CO_2 emissions from 1992 to 2004 according to different accounting principles
(note that the vertical scale doesn't start at zero).

The following graphs and tables present the uncertainty results for total embedded emissions. The relative standard error (RSE) for total CO_2 consumer emissions lies within 3.3% for 1994 and 5.5% for 2004 (see Table 1). The uncertainty range of +/- RSE covers 67% of all observed data from the Monte-Carlo analysis. 95% of all variation lies within a +/- 2RSE band (see Figure 3).

Table 2: Total CO_2 consumer emissions and their uncertainty ranges (results from the UK-MRIO 1 model; numbers in Mt of CO_2)

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Consumer Emissions (CE) (1+3a+4a+5a+5b)	**647**	**639**	**634**	**653**	**651**	**661**	**680**	**665**	**681**	**732**	**730**	**763**	**762**
Relative standard error	**4.2%**	**3.4%**	**3.3%**	**4.4%**	**4.0%**	**4.3%**	**4.3%**	**5.0%**	**4.5%**	**4.9%**	**5.2%**	**5.4%**	**5.5%**
Lower uncertainty (- standard error)	620	617	613	624	625	632	651	632	650	696	692	722	720
Upper uncertainty (+standard error)	674	661	655	681	677	689	710	698	711	768	768	805	804

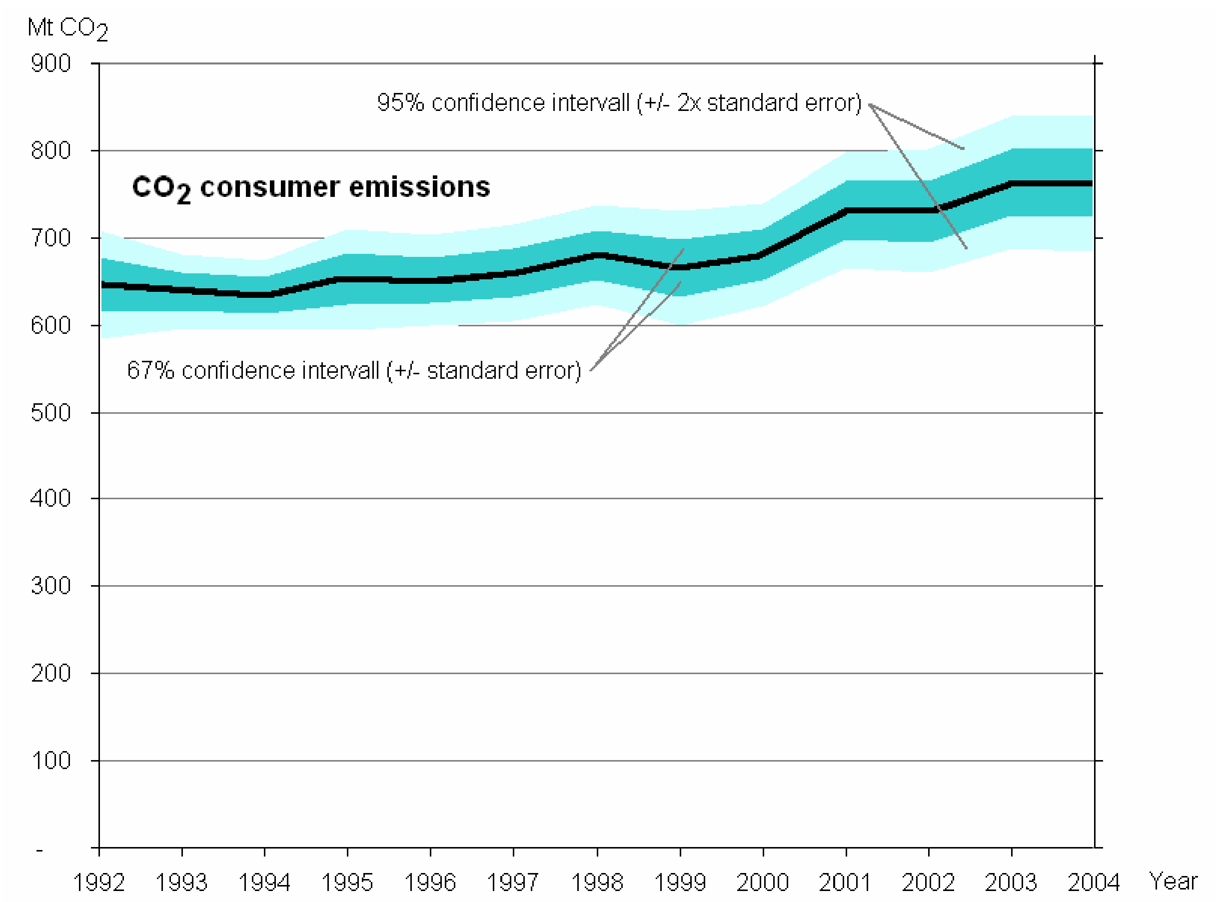


Figure 3: UK CO_2 emissions from a consumer perspective ("consumer emissions") between 1992 and 2004. Uncertainty ranges are presented as bands of +/- RSE and +/- 2RSE.

Statistically, there is a significant increase in consumer emissions; in the last four years CE were significantly higher than in the first five years of the time series.

Over the time period 1994 to 2004 there is a tendency towards larger error margins. It is likely that this increase is connected to the distance from the Analytical (IO) Table for 1995. The ATs 1995 were the only available information on the true structure of imports to the UK. The import matrices for all other years were derived through CRAS balancing to match actual year totals (Wiedmann et al. 2007c). It is logical to assume that uncertainties rise when these totals are increasingly different from the 1995 base year, although this has not been proven analytically in this study. Other tendencies are overlapping, e.g. an increasing distance from the two base years for GTAP data, 1997 and 2001, will also increase error margins.

Table 3 below shows detailed results for CO_2 emissions embedded in UK trade. The relative standard error for these results is larger than for total consumer emissions because additional uncertainties for IO and CO_2 data for the three world regions come into play. Generally, the higher aggregated the results, the smaller is the relative error because the standard errors of parts of emissions are added together via the "square root of square sums" formula (see Eq.10). However, if a subtraction is involved in the calculation, as is the case for BEET (= 2-3a-4a), relative standard errors can become very large and even indefinite if the subtraction results in zero.

Table 3: CO_2 emissions embedded in UK trade and their uncertainties. (results from the UK-MRIO 1 model; numbers in Mt of CO_2)

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
EEI (3a+3b+4a+4b)	206	227	235	282	253	259	291	263	291	336	343	380	374
Absolute standard error of EEI	20.2	21.3	20.3	26.9	23.5	25.1	27.3	30.4	25.4	30.9	33.1	36.0	35.1
Relative standard error of EEI	9.8%	9.3%	8.6%	9.5%	9.3%	9.7%	9.4%	11.5%	8.7%	9.2%	9.7%	9.5%	9.4%
EEE (2+3b+4b)	179	196	202	223	222	199	217	196	219	229	222	242	242
Absolute standard error of EEE	9.7	10.7	11.5	16.2	16.5	14.8	16.9	13.9	11.7	14.2	14.0	16.6	16.6
Relative standard error of EEE	5.4%	5.5%	5.7%	7.3%	7.4%	7.5%	7.8%	7.1%	5.3%	6.2%	6.3%	6.9%	6.9%
BEET (2-3a-4a)	-27	-31	-33	-59	-30	-60	-74	-67	-72	-107	-121	-139	-132
EEI-EEE (= -BEET)	27	31	33	59	30	60	74	67	72	107	121	139	132
Absolute standard error of BEET	18.8	19.6	18.1	23.3	19.5	22.9	23.8	29.2	24.1	28.9	31.3	33.5	32.7
Relative standard error of BEET	70.2%	63.1%	54.9%	39.3%	64.7%	38.2%	32.3%	43.6%	33.5%	26.9%	26.0%	24.2%	24.8%

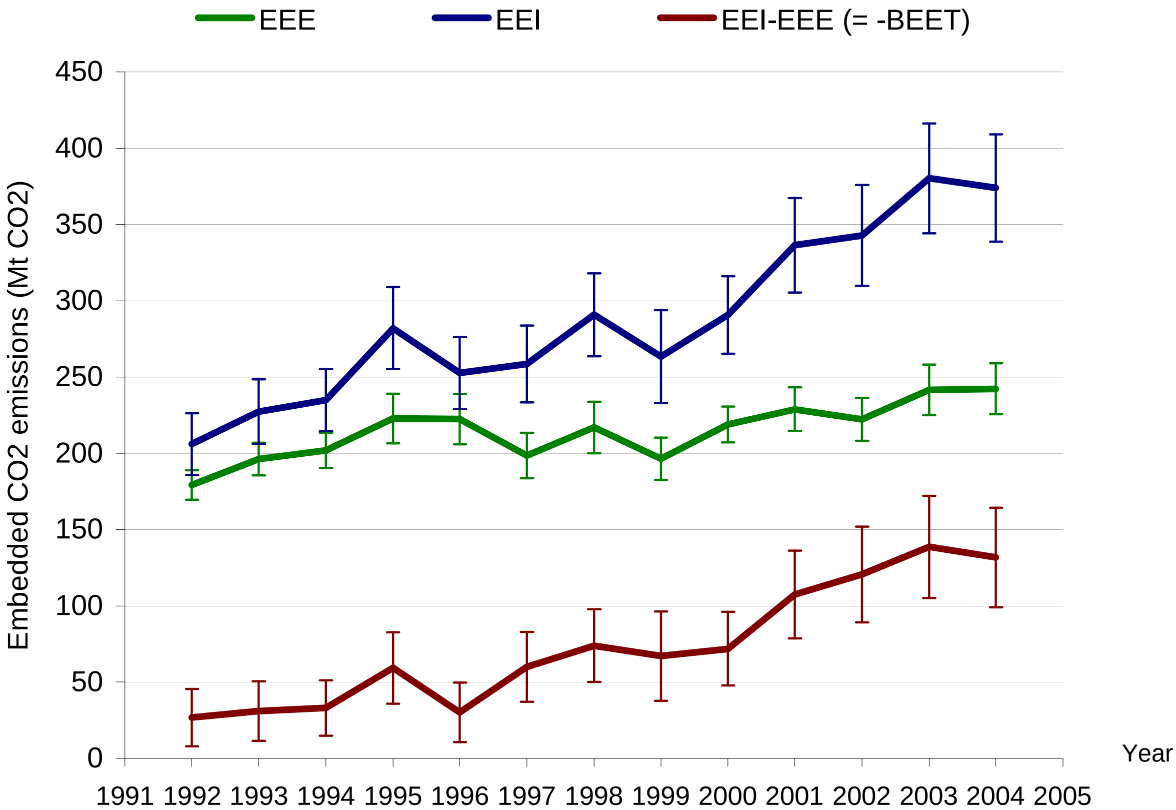


Figure 4: CO_2 emissions embedded in total UK imports (EEI), total UK exports (EEE) and the difference EEI-EEE (equal to –BEET) from 1992 to 2004. The error bars represent standard errors, covering 67% of data obtained with Monte-Carlo analysis.

This shows that the increase in EEI is statistically significant, at least for the last four years compared to the first three years of the time series.

As discussed above, a small difference of two large numbers is always associated with a high relative error. If emissions embedded in trade were almost balanced, the error could become larger than BEET itself, and it would not be possible to conclude whether there was a net import or export. However, the results of the uncertainty analysis in this study show with statistical significance that EEI were higher than EEE in all years from 1992 to 2004 and that EEI were growing faster than EEE thus widening the gap between territorial (producer) emissions and consumer emissions.

As each data point in the figure above has a specified uncertainty it is reasonable to depict the general trend over time by a smoothed line that still lies within the standard error ranges but flattens the ups and downs from one year to another. Polynomial trendlines of fourth order seem to best represent the general trend; they are shown in the following figure.

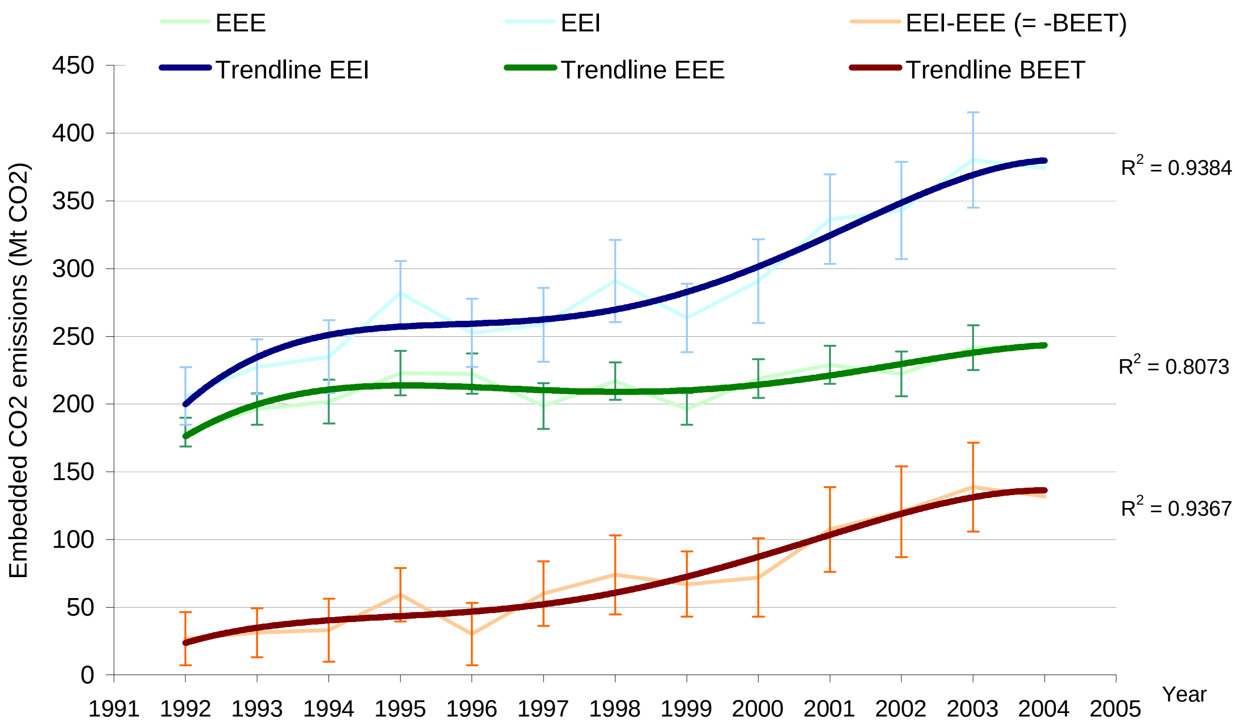
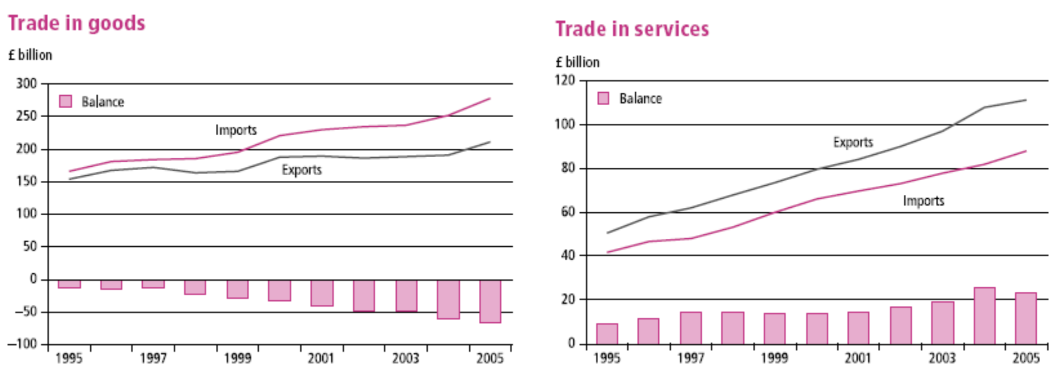


Figure 5: Polynomial trendlines for CO_2 emissions embedded in UK trade (the polynomial trendlines are of fourth order).

The increase of embedded emissions over time can be compared with a general increase in the trade of goods and services, see Figures 6. Imports and exports of services have grown faster than those for goods and the trade balance for both goes in an opposite direction. The finding that CO_2 EEI grow considerably faster than CO_2 EEE can thus be explained by the increase in imports of goods that have a higher direct CO_2 intensity than services. Detailed results by 123 sectors are shown in Appendix A: Detailed Results for CO2 Emissions Embedded in UK Trade on page 35.



Figures 6: Volume of UK trade in goods and services from 1995 to 2005 (lines) and balance of trade (columns) (ONS 2006a)

Table 1 shows another interesting result. Emissions embedded in 'through trade' make up a considerable proportion of emissions embedded in imports and exports. These are emissions that are embedded in goods and services that are required to produce UK exports. These products go either through an intermediate production process (emission category **3b**) or they are re-exported in a more or less unaltered state (**4b**). On average, 3b is 36% of total imported emissions to domestic industry (**3a+3b**) and 4b is 13% of total imported emissions to final demand (**4a+4b**). From all emissions embedded in exports (EEE), 27% came from imports (**3b+4b**) in 1997; this figure increased steadily over the years ending up with 39% of EEE coming from import sources in 2004.

In this context it is worth mentioning that final UK demand can be disaggregated into the following main elements: "Households", "Non-profit institutions serving households", "Central government", "Local government", "Gross fixed capital formation", "Valuables", "Changes in inventories", "Exports of goods" to EU and non-EU countries and "Exports of services" to EU and non-EU countries. Most of these categories can be further disaggregated (ONS 2007c) and embedded emissions can be assigned to them with the current model which would provide further insight into the causes for embedded emissions.[18] However, this task was beyond the scope of the project.

Figure 7 shows the origin of emissions embedded in UK imports over the years. While imports from the Rest of the World region have always carried the biggest load of EEI, their dominance seem to have increased sharply in the last couple of years while EEI from non-European OECD countries have fallen significantly at the same time. This apparent and rather sudden shift can be explained by a real change in trade patterns away from more traditional trade partners such as Japan and the US towards newly emerging economies like China and Eastern European countries.

[18] For example, household consumption can be split into COICOP consumption categories allowing, amongst many other categories, an estimation of emissions from UK tourists abroad and foreign tourists coming to the UK.

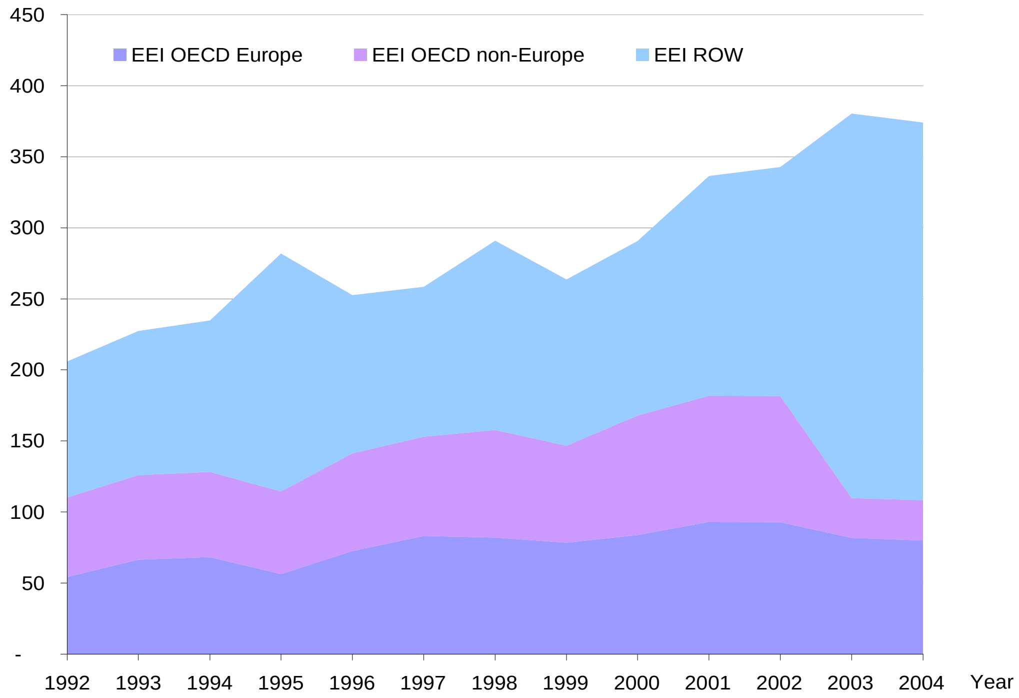


Figure 7: Origin of CO_2 emissions embedded in imports to the UK (in Mt of CO_2)

The results from the UK-MRIO 1 model are in line with findings from other researchers. Previous studies applying a range of different methodologies (SRIO, MRIO, MFA) also suggest that more embedded CO_2 emissions are imported to the UK than exported (see Table 4).

Table 4: Comparison of CO_2 emissions embedded in UK trade as estimated by different studies (all numbers in Mt of CO_2)

	(Druckman et al. 2007)	(Harrison et al. 2003)	SEI MFA/REAP analysis (SEI et al. 2006)	SEI SRIO analysis from 2007	(Peters and Hertwich submitted)	(Wilting 2007; Wilting and Vringer 2007)	(Carbon Trust 2006)	(Druckman et al. 2007)
Year	**1990**	**1995**	**2001**	**2001**	**2001**	**2000**	**2002**	**2004**
PE	638.0	536.0	636.5	624.4	620.1	580.8	603.9	639.5
CE	643.1	549.0	703.0	690.6	715.3	819.8	646.8	692.6
BEET	-5.1	-13.0	-66.5	-66.2	-95.2	-239.1	-42.9	-53.2
BEET as % of PE	**-0.8%**	**-2.4%**	**-10.5%**	**-10.6%**	**-15.3%**	**-41.2%**	**-7.1%**	**-8.3%**
		UK-MRIO (this work)			**UK-MRIO (this work)**			**UK-MRIO (this work)**
Year		**1992**			**2001**			**2004**
PE		620.0			624.4			630.6
CE		646.8			731.9			762.4
BEET		-26.8			-107.5			-131.8
BEET as % of PE		**-4.3%**			**-17.2%**			**-20.9%**

The most likely reasons for the differences between other studies and this study are the use of domestic intensities (single region instead of multi-region assumption) in (Carbon Trust 2006; Druckman et al. 2007; SEI, 2007), the use of non-(MR)IO techniques in (Harrison et al. 2003; SEI et al. 2006) and the use of out-of-date IO tables in (Carbon Trust 2006; Druckman et al. 2007). None of these significant weaknesses occur in the UK-MRIO model which is why UK-MRIO 1 can be seen as having the highest level of reliability, together with only one other model – the one presented by (Peters and Hertwich submitted). Both, from a model set-up perspective as well as from the results, the UK-MRIO model compares best with this more detailed, GTAP-based MRIO model constructed by (Peters and Hertwich submitted). The calculations by (Wilting 2007; Wilting and Vringer 2007) produce the highest estimate for consumer emissions. In this study emissions based on the consumer principle in a country (both domestic as imports) were calculated with the total sectoral intensities of the world region the country belongs to. This can only provide a rather crude estimate of country-specific consumer emissions.

As an extension to the project a sensitivity analysis based on Monte-Carlo simulations was undertaken in order to assess the range of uncertainty associated with the final estimates. This allows for a more sound comparison with other findings (Wiedmann et al. 2008a).

4 Discussion

4.1 Discussion of Assumptions and Limitations of the Current UK-MRIO Model

The following paragraphs provide an overview of the main assumptions and limitations of the current model and a discussion of possible improvements (however, suggestions for further research are presented in the next section). Apart from the usual limitations of environmental input-output models for which we refer to the literature (Miller and Blair 1985; Wood et al. 2006), the peculiarities of the UK-MRIO model are as follows.

The original basis for UK input-output data in the UK-MRIO 1 model is thin. Although supply and use tables are annually published by ONS, these are not fit for modelling purposes and therefore had to be supplemented with information from Eurostat and balanced before they could be used. Crucial information such as imports and transition matrices are only available for the year 1995 and therefore it had to be assumed that the structure of these matrices would not change over a period of twelve years.

Nevertheless, we think that the input-output tables produced in this project represent an approximation of real economic activity close and robust enough for MRIO modelling purposes and that they will be the best publicly available input-output information for the UK for some time.

The modernisation of UK National Accounts (Beadle 2007) will eventually provide more up-to-date and in-depth information useful for (environmental) input-output modelling. The plan to produce the most useful type of tables, IO Analytical Tables, on an annual basis has been in abeyance. In 2002, these plans were reconsidered in the light of changed priorities within the ONS. In particular, National Accounts production was being thoroughly reviewed as part of a re-engineering project within the ONS Statistical Modernisation Programme, and the need to free up resources within National Accounts to support this work. As a result, it was agreed that these tables would not be produced annually but considered as part of the re-engineering project. At present, there are still no explicit plans for producing the next set of UK IO Analytical Tables until the higher priority parts of the National Accounts re-engineering programme are complete. It is not expected that any UK IO Analytical Tables would be produced by the ONS until 2010/11 at the earliest.

Great care was taken to obtain an accurate picture of imports to the UK from the three world regions. We have used specific UK trade data, detailing imports of goods and services from all countries in the world (subsequently aggregated to three world regions) by 5-digit SITC code (subsequently aggregated to 123 input-output sectors). Total imports were brought in line with totals in the official SUTs provided by ONS. As mentioned above however, no information on the structure of imports to intermediate and final demand was available, other than one imports matrix from the Analytical Tables 1995. Hence we had to assume that the relative proportions of imports to domestic production would not change over time, a potentially far-reaching and undesirable assumption.

We do not consider all possible trade flows between the four trading partners in the model (UK plus three world regions). This is due to the fact that imports (exports) matrices between the three world regions are not available and would take additional resources to compile. Therefore our model only considers trade to and from the UK, assuming that this is dominant in determining the emissions embedded in total UK trade. Such a set-up is called a uni-directional trade model. Uni-directional trade makes the model specific to the UK only, but also greatly reduces the data requirement. The effect of not considering extra-UK trade on the estimation of emissions embedded in UK trade is thought to be small; (Lenzen et al. 2004) report feedback loop effects of 1.5%.

Due to the original setup of the (Nijdam et al. 2005) model, the A matrix from Region e (OECD Europe countries) includes technical coefficients from the UK and excludes those from the Netherlands. Thus, the economic structure of this region is not exactly in line with the actual trading partners of the UK, but the associated error should be relatively small given the fact that both the UK and the Netherlands are developed western economies. The errors associated with the sector aggregation (30 sectors for the three regions vs 123 sectors in the UK) as well as the unavailability of coefficient matrices for all years are thought to constitute a further reaching limitation of the model. This is because the impact (CO_2) intensities of 30 sectors are mapped onto the 123 sectors of the UK, thus treating the imports to all UK sectors mapped onto the same foreign sector with an average intensity. Future extensions should therefore use the full detail from the GTAP and OECD input-output databases and additional thoughts should be given to whether and how it is possible to produce a 1992-2004 time series for all countries involved.

For CO_2 emissions, however, we have included CO_2 data for the Netherlands in Region e and excluded those for the UK, thus partially correcting the discrepancy mentioned above (Wiedmann et al. 2008b).

All input-output data were left in current years prices in order to minimise error through price conversion. It is possible to use current prices because the model calculates embedded emissions on a year by year basis. However, for the three world regions, input-output data were only available for two years, 1997 and 2001, and therefore exact CO_2 intensities (tonnes of CO_2 per £ of output) can only be calculated for these two years. However, estimates for CO_2 intensities for all years from 1992 to 2004 were derived by using GDP data from UN statistics to approximate total industry outputs for years other than 1997 and 2001 (Wiedmann et al. 2008b).

We have used data for CO_2 from the combustion of fossil fuels from the International Energy Agency, which provide data in a breakdown of 18 sectors (IEA 2006). Hence, the 30 sectors from the three world regions can only be assigned 18 different CO_2 intensities. This means that for some important industries CO_2 intensities cannot be distinguished, a relatively far-reaching limitation if trade volumes for these sectors are high. A detailed sector analysis has shown that, for example, using the same average carbon intensity for the sectors 'Electricity supply', 'Gas supply' and 'Water collection and supply' in the three world regions would be completely inadequate and therefore separate carbon intensities were used for all years derived from initial information from the 1997 and 2001 data.

Another limitation is posed by detail and classification differences between the economic and environmental accounts published in the UK: full correspondence can only be established at the 76 sector level. For more policy relevant analysis in many important sectors such as food, transport or energy more detail is required. Apart from the need to urge the Office for National Statistics to reconcile the two classifications and provide more detailed data, the next version of the model will use more sophisticated estimation methods using detailed emission estimates from other databases such as CEDA from the US (Suh 2005) or the detailed Japanese environmental and economic accounts to break down (CO_2) emissions. This will allow the distinction of 123 instead of only 76 emission intensities across the input-output sectors and help to further improve the relevance of direct and embedded emission estimates associated with goods and services produced in the UK.

Further shortcomings with respect to data availability and quality are discussed in (Wiedmann et al. 2008b).

4.2 Discussion of Uncertainty Analysis

The presented analysis of uncertainties of UK-MRIO model results tries to capture all possible variations of underlying data and calculation procedures. For the majority of data this takes account of the random uncertainty of data points due to statistical variation and random errors. In other words, we have determined the stochastic variation of the whole model system.

There are also possible systematic error sources:

1) structural change of foreign input-output data that cannot be captured systematically due to the lack of time series data;
2) sectoral distinction of changes in prices of foreign input-output data over time;
3) systematic over- and underestimation of carbon intensities of foreign industries due to the mismatch of sectors in UK and foreign IO and CO_2 data;
4) change of import structure over time due to the lack of imports matrices (Analytical Tables) for the UK for years other than 1995; and
5) choice of price conversion factors, e.g. 'purchasing power parity' versus 'market exchange rate' or choice of lead countries for CPI.

In principle it is possible to investigate and model these systematic errors methodically. For each data cell in the environmental input-output system one could, in principle, assume a function associated with uncertainty over time. Also, some cell entries are dependent from each other and it is conceivable that this dependency can be defined mathematically. Such detailed modelling of systematic uncertainty, however, was way beyond the scope of the current study and instead we have dealt with the uncertainties arising from systematic changes by allowing a stochastic variation large enough to capture anticipated systematic variation.

As a result, the presented error margins can be seen as conservative estimates which are rather over- than underestimated. In other words, the calculated uncertainties are on the "safe side" and the true values are likely to lie within the presented error bars and confidence intervals.

A final note on the purpose of the UK-MRIO 1 model. For aggregated results (CO_2 consumer emissions), the relative standard error has been shown to be between 3.3% and 5.5%. Therefore, the estimate of total embedded emissions can be regarded as robust and reliable. One should bear in mind though that on an individual sector level these errors are generally. Relative standard errors can be large, especially when the absolute value for E in a sector is small. Results on a sectoral level should therefore be interpreted with more caution, not least because of the sector aggregation leading to different product mixes in sectors from different countries/regions. At this stage, i.e. with the current resolution and underlying database, the UK-MRIO 1 model is not capable of performing detailed life-cycle analyses of individual products with sufficient accuracy. More work is needed if the model is to be developed with this aim.

5 Recommendations for Further Research

The aim of this project was "to develop and implement an initial, relatively small, data and model framework that is easily expandable without major adaptations" and to "…set the basis for multi-regional analyses of environmental impacts associated with UK trade flows."

This aim was not only achieved but actually exceeded in that a fully functional MRIO model with four regions (UK + 3 world regions) was assembled and a time series of balanced input-output data and embedded CO_2 emissions was produced on the full 123 sector level – an encouraging outcome that was not part of the project deliverables. Hence, a solid data and modelling basis was created upon which future research can build. As discussed in the last Section, further improvements and research is desirable in a range of areas.

5.1 General model expansion: UK-MRIO 2

The UK-MRIO 1 project has prepared the ground for a more extensive multi-region input-output model with the UK at its heart. The completion of this full system requires further steps of extension and sophistication which would have been beyond the scope of the first model stage. Tasks for a 'second stage' model (UK-MRIO 2) would include the following:

- identifying and including the UK’s main and most important trading partners,
- compiling detailed input-output, environmental and trade data for these individual countries or regions,
- establishing cross-classifications for all data,
- constructing a fully linked, fully automated, multi-directional MRIO system,
- improving the accuracy and speed of optimisation,
- coding an automated and self-sustaining updating capability,
- analysing specific research and policy questions, e.g. by using Structural Path Analysis and other analytical techniques.

The conceptual and computational tasks involved in such a second stage are substantial and it is anticipated that cutting-edge mathematical skills will be required. We would like to emphasise that the implementation of such a comprehensive environmental MRIO system would allow answering very specific policy (and research) questions for which examples are given in the project report SCP001 to

Defra (Wiedmann et al. 2006, see section "Policy and Other Applications" therein). In particular, the model would include multi-directional trade and thus be able to trace the origin of and the cause for embedded emissions in unprecedented detail. Because the dynamics of industrial ecosystems is embedded in the larger-scale physical and economic transactions described in input-output frameworks, the insights gained from the use of generalised multi-region input-output models can be extended to the understanding of long-term international dynamics of industrial ecosystems. Existing links with other research groups can and should be utilized to streamline the development of larger and more sophisticated MRIO models.

5.2 Improved input-output data

The reliability of the model would benefit from improved IO data. Particular request include

- final demand in basic prices,
- total intermediate inputs and outputs at basic prices,
- detailed supply tables (with either the least possible suppression or with controlled access to disclosive data),
- a larger number of product and industry sectors in the Supply-Use tables
- a finer breakdown of the trade (imports and exports) in goods and services by world regions or countries, not only EU/non-EU,
- information on how Gross Fixed Capital Formation is distributed across industries (intermediate GFCF matrix).

5.3 Improvement of CO_2 and other environmental data

The data for carbon dioxide emissions can further be improved for both the UK and the other regions/countries in the model. In the UK, emission data for CO_2 and other environmental data (such as other greenhouse gas emissions, air pollutants, fuel use, water use, etc) should either be made available by ONS for all 123 input-output sectors or they should be estimated by using foreign databases as mentioned above.

Environmental data from foreign countries can be improved by utilising country-specific NAMEAs[19], thus providing much better sector specifity of CO_2 emissions and other environmental load factors. Once available, data from the European EXIOPOL project[20] can be used to make the data and modelling basis for European countries more consistent and accurate. For world regions, information from economic accounts as published, for example, by the United Nations or Eurostat can be used to estimate more detailed region-specific emission intensities. Absolute CO_2 and greenhouse gas emissions for foreign countries and regions, so far based on IEA data, can further be derived and

[19] National Accounting Matrix including Environmental Accounts (de Haan and Keuning 1996; Keuning et al. 1999)

[20] http://www.feem.it/Feem/Pub/Programmes/Sustainability+Indicators+and+Environmental+Valuation/Activities/200703-EXIOPOL.htm, see also http://www.seri.at/EXIOPOL

refined by using data from EDGAR (van Aardenne et al. 2005) and GTAP as done by (Wilting and Vringer 2007).

A MRIO system can be complemented with physical data on any social and environmental parameters, such as employment, water use or greenhouse gas emissions. This generalisation allows tracing social and environmental impacts along international supply chains, for example using Structural Path Analysis (see e.g. Lenzen, 2003; Peters and Hertwich, 2006b).

5.4 Inclusion of individual countries and multi-directional trade

A future version of the model should include explicit (and more) countries as trading partners (instead of world regions) for which it is easier to obtain input-output and trade data. Logically, such a model would include the main individual trading partners of the UK.

There are several advantages when using (more) individual countries in a future model. Supply and use tables can be used instead of aggregated matrices which immensely improves data coverage for time series. This will also allow increasing the number of economic sectors to well over 30 as most SUTs are provided in greater detail by national statistical offices. Furthermore, bilateral trade data can be exploited in detail which is crucial to establish meaningful bilateral trade matrices that are necessary for a truly multi-directional model. In this context, it would make sense to create a consistent and bespoke international trade database, e.g. by exploiting the UN Comtrade database. This would also allow to address the problem of bi- and multilateral international transportation which is currently insufficiently dealt with in MRIO modelling (for a discussion see Peters 2007).

5.5 Further sector disaggregation

It is possible to create a model with more than 123 sectors for the UK by disaggregating existing sectors in a meaningful way. This would be particularly help for specific policy and research questions such as analysing the environmental impacts of food production, for example. Currently, agriculture is only represented with one sector in official UK input-output and environmental data whereas the GTAP database features twelve(!) agricultural sectors[21]. With the flexible set-up of the UK-MRIO model it is possible to disaggregate (or aggregate) specific sectors *depending on the policy question*. Of course, specific data for such a sector disaggregation must be available. In the UK, the Office for National Statistics holds the necessary data and we propose an increased engagement of the ONS in environmental analysis of this kind.

5.6 Currency conversion

Future research should also look into the best ways of dealing with currency conversion. In the context of MRIO modelling the pros and cons of Purchasing Power Parity (PPP) or Market Exchange Rate (MER) as a mean for currency conversion have been discussed (Ahmad and Wyckoff 2003; Peters 2007; Peters et al. in press) and the difference between the two methods has been quantified in a

21 https://www.gtap.agecon.purdue.edu/databases/v6/v6_sectors.asp

MRIO study (Weber and Matthews 2007). Arguably PPPs are better for cross-country comparisons of GDP and MERs are better for trade data. In the UK-MRIO 1 model we used PPP to convert the world regions' total industrial output from US$ to £ (to derive CO_2 intensities). It should be investigated whether the use of PPP and MER can be combined in an automated hybrid technique and what the quantitative effect would be of using one method over the other in the UK-MRIO model.

5.7 Publications

Last but not least, we suggest that an 'embedded CO_2 indicator' showing a time series of CO_2 emissions from a consumption perspective ("carbon consumption") should be considered for publication with official UK statistics, alongside already existing greenhouse gas emission trends. This would give a more complete picture of emissions induced by UK economic activity. Further revisions to the methodology as recommended above will lead to revisions of the results (not least because of ongoing revisions of Environmental Accounts data). However, these revisions will not generally refute the clear and robust trend that has emerged for consumer emissions.

6 Conclusions

The completion of the first stage of a UK specific multi-region input-output model has achieved its project objective, namely the production of a time series of balanced input-output tables for the UK from 1992 to 2004, thus providing the basis for detailed modelling of environmental impacts such as the estimation of CO_2 emissions embedded in UK trade. Main features and strenghts are:

- UK-MRIO 1 explicitly models the trade of the UK with three world regions and the associated flow of CO_2 emissions,
- UK-MRIO 1 distinguishes 123 sectors of domestic production and trade,
- UK-MRIO 1 looks at a complete time series from 1992 to 2004,
- UK-MRIO 1 is the most detailed and comprehensive modelling approach for the estimation of CO_2 emissions embedded in UK trade to date with relevance for national and international environmental policy-making.

The construction of symmetric input-output tables for each year from 1992 to 2004 also fills a current gap in UK input-output data as 'Analytical Tables' are only produced every five years with the last one being from 1995. Due to a major National Accounts modernisation programme at ONS (Beadle 2007), Analytical Tables for the year 2000 will not be produced. The Office for National Statistics (ONS) plays an important role in that it holds essential economic and environmental data that could help to improve the accuracy and policy relevance of the model.

The UK-MRIO 1 model is the first 'real world' application of a novel matrix balancing procedure, called CRAS (Conflicting RAS), developed at the University of Sydney. This shows that CRAS is able to provide useful results in an empirical context.

This is also the **first study in the world** that has undertaken a comprehensive Monte-Carlo analysis of the uncertainties in a global multi-region input-output model.[22] Uncertainty functions were determined for all input variables to the model, the IO tables uncertainties were estimated from constraint uncertainties and matrix balancing, 5000 Monte-Carlo simulation runs were carried out to determine the multiplier uncertainties and the error propagation for embedded emissions was calculated.

The results of the uncertainty analysis in this study show with statistical significance that CO_2 emissions embedded in UK imports (EEI) were higher than those for exports (EEE) in all years from 1992 to 2004 and that EEI were growing faster than EEE thus widening the gap between territorial (producer) emissions and consumer emissions.

We think that with the available resources, a comprehensive, adequate and robust estimation of uncertainties was undertaken. The results prove that the UK-MRIO model is robust enough to provide a reliable indication of CO_2 emissions embedded in UK economic activity, including trade from and to the UK.

In summary, the current model is a major step towards a fully fledged multi-region input-output model featuring multi-directional trade of a substantial number of UK trading partners, capable of answering specific policy questions around the subject of trade and environment.

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8 Appendix A: Detailed Results for CO_2 Emissions Embedded in UK Trade

The following tables show detailed results for embedded CO_2 emissions as calculated with the UK MRIO 1 model. All numbers are in Mt of CO_2.

[22] Weber and Matthews (2007) vary their MRIO calculations by using different input parameters for two of the major uncertainties in their model, the ROW approximation and the MER/PPP issue, and present "feasible ranges for EEE and EEI" (page 4876); but they do not carry out a Monte-Carlo analysis.

DESCRIPTION	Source	TRANSITION	Destin-ation	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
			Unit >	Mt	Mt	Mt	Mt	Mt	Mt	Mt	Mt	Mt	Mt	Mt	Mt	Mt
Dom. UK emissions due to dom. cons.	UK	Domestic Industry	UK FC	343.1	318.6	315.1	310.0	317.0	314.0	315.1	315.0	316.1	329.1	320.2	326.4	329.0
Domestic UK Emissions due to export	UK	Domestic Industry	EU Goods	62.1	62.0	63.4	66.5	65.6	58.0	64.2	59.5	64.6	63.1	61.5	64.9	61.7
	UK	Domestic Industry	NonEU Goods	35.9	42.3	43.3	42.0	46.1	41.2	39.2	35.4	39.8	38.5	36.0	40.5	38.7
	UK	Domestic Industry	EU Services	12.5	12.8	12.8	13.9	14.7	15.0	15.4	16.1	16.6	18.2	18.1	19.2	20.0
	UK	Domestic Industry	NonEU Services	20.8	22.3	22.3	22.6	24.6	25.7	24.2	23.0	22.9	23.5	23.1	22.9	28.3
EEI due to dom. UK final cons.	OECD-EU	Imp. to dom. industry	UK FC	21.5	25.5	25.8	21.6	27.1	33.5	29.6	25.7	30.1	34.1	34.1	29.8	29.1
EEI due to export	OECD-EU	Imp. to dom. industry	EU Goods	5.1	6.1	6.7	6.9	7.4	7.2	7.7	6.2	8.1	8.9	8.3	7.1	6.7
	OECD-EU	Imp. to dom. industry	NonEU Goods	3.1	4.5	4.8	4.7	5.6	5.9	5.1	3.5	5.2	5.6	5.1	4.8	4.7
	OECD-EU	Imp. to dom. industry	EU Services	0.7	0.8	0.9	0.8	1.0	1.1	1.2	1.0	1.4	1.6	1.5	1.4	1.4
	OECD-EU	Imp. to dom. industry	NonEU Services	1.1	1.4	1.5	1.3	1.7	1.9	1.8	1.4	1.9	2.1	2.0	1.8	1.9
EEI due to dom. UK final cons.	Non-EU OECD	Imp. to dom. industry	UK FC	20.8	21.3	20.6	20.2	25.1	23.7	25.0	20.2	31.8	34.0	34.1	8.5	8.6
EEI due to export	Non-EU OECD	Imp. to dom. industry	EU Goods	5.3	5.8	5.7	5.9	7.3	6.2	7.5	6.2	9.2	9.7	9.5	1.5	1.5
	Non-EU OECD	Imp. to dom. industry	NonEU Goods	3.1	4.0	4.1	4.0	5.6	4.7	5.1	3.7	6.1	6.4	5.8	1.2	1.2
	Non-EU OECD	Imp. to dom. industry	EU Services	0.6	0.7	0.7	0.8	1.0	0.8	1.0	0.8	1.3	1.4	1.4	0.5	0.6
	Non-EU OECD	Imp. to dom. industry	NonEU Services	1.1	1.2	1.3	1.2	1.6	1.4	1.6	1.2	1.8	1.9	1.9	0.7	0.8
EEI due to dom. UK final cons.	ROW	Imp. to dom. industry	UK FC	31.8	32.1	32.7	55.6	34.1	28.8	39.4	29.3	36.2	49.2	51.5	94.9	95.2
EEI due to export	ROW	Imp. to dom. industry	EU Goods	7.7	8.2	9.0	18.9	10.4	7.3	11.2	8.1	10.5	13.0	14.9	27.7	26.7
	ROW	Imp. to dom. industry	NonEU Goods	5.2	6.7	7.2	13.4	8.6	6.6	8.5	5.4	7.0	8.6	8.9	19.0	19.0
	ROW	Imp. to dom. industry	EU Services	1.0	1.1	1.2	1.9	1.3	1.1	1.6	1.2	1.6	2.1	2.3	3.8	3.9
	ROW	Imp. to dom. industry	NonEU Services	1.6	1.9	2.0	3.0	2.2	1.9	2.5	1.7	2.3	2.8	3.0	4.9	5.4
EEI due to dom. UK final cons.	OECD-EU	Imp. direct to FC	UK FC	19.9	24.3	24.9	19.1	25.6	30.3	32.1	34.8	33.7	36.7	37.7	33.7	32.8
EEI due to export	OECD-EU	Imp. direct to FC	EU Goods	1.2	1.6	1.5	0.7	1.6	1.3	1.7	2.4	1.0	1.1	1.1	0.8	0.8
	OECD-EU	Imp. direct to FC	NonEU Goods	0.9	1.2	1.2	0.5	1.3	1.1	1.2	1.9	0.8	0.9	0.9	0.7	0.7
	OECD-EU	Imp. direct to FC	EU Services	0.3	0.3	0.4	0.3	0.5	0.2	0.6	0.6	0.7	0.8	0.8	0.7	0.7
	OECD-EU	Imp. direct to FC	NonEU Services	0.4	0.6	0.6	0.5	0.8	0.4	0.9	1.0	1.1	1.2	1.3	1.2	1.2
EEI due to dom. UK final cons.	Non-EU OECD	Imp. direct to FC	UK FC	21.6	22.7	23.4	23.2	23.2	29.8	30.0	29.8	28.1	30.2	31.8	12.8	12.8
EEI due to export	Non-EU OECD	Imp. direct to FC	EU Goods	1.4	1.5	1.5	0.8	2.0	1.4	2.2	2.6	2.5	1.9	1.5	0.5	0.6
	Non-EU OECD	Imp. direct to FC	NonEU Goods	1.0	1.1	1.2	0.6	1.5	1.3	1.6	1.9	1.7	1.4	1.2	0.5	0.5
	Non-EU OECD	Imp. direct to FC	EU Services	0.4	0.4	0.4	0.4	0.5	0.2	0.6	0.6	0.6	0.7	0.7	0.7	0.7
	Non-EU OECD	Imp. direct to FC	NonEU Services	0.6	0.7	0.7	0.7	0.9	0.4	1.0	1.0	1.0	1.1	1.1	1.1	1.2
EEI due to dom. UK final cons.	ROW	Imp. direct to FC	UK FC	42.4	44.6	47.4	64.5	46.1	53.9	60.7	61.1	55.8	66.6	70.0	106.6	101.9
EEI due to export	ROW	Imp. direct to FC	EU Goods	2.8	3.1	3.1	4.9	4.0	2.6	4.2	4.4	4.0	5.5	4.6	6.3	6.1
	ROW	Imp. direct to FC	NonEU Goods	2.0	2.3	2.4	3.8	2.8	2.7	3.0	3.3	2.7	3.8	3.2	4.7	4.5
	ROW	Imp. direct to FC	EU Services	0.5	0.6	0.6	0.6	0.7	0.3	0.8	0.9	1.0	1.1	1.0	1.0	1.1
	ROW	Imp. direct to FC	NonEU Services	0.9	1.0	1.1	1.1	1.2	0.5	1.3	1.4	1.7	1.9	1.7	1.7	1.8
TOTAL UK EMISSIONS INCL IMPORTS & EXPORTS				**680.3**	**685.3**	**691.8**	**737.0**	**720.6**	**712.4**	**749.0**	**712.4**	**750.7**	**808.8**	**801.7**	**854.1**	**851.7**

		1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
EXPORTS	EEE from domestic (UK) sources	131.2	139.4	141.8	145.0	151.0	139.9	143.0	133.9	143.9	143.3	138.7	147.5	148.7
	EEE from imports	48.0	56.9	60.0	77.8	71.4	58.6	73.9	62.5	75.0	85.6	83.6	94.1	93.5
	TOTAL EEE	**179.2**	**196.3**	**201.8**	**222.8**	**222.4**	**198.6**	**216.9**	**196.4**	**218.8**	**228.9**	**222.3**	**241.6**	**242.2**
IMPORTS	EEI OECD Europe	54.2	66.4	68.4	56.4	72.6	83.0	82.0	78.5	83.9	93.0	92.7	81.8	80.0
	EEI non-EU OECD	55.9	59.5	59.8	57.9	68.7	69.9	75.7	68.2	84.0	88.7	88.9	27.9	28.4
	EEI ROW	95.9	101.4	106.7	167.7	111.3	105.7	133.1	116.9	122.8	154.7	161.2	270.5	265.6
	TOTAL EEI	**206.0**	**227.3**	**234.9**	**282.0**	**252.6**	**258.6**	**290.8**	**263.5**	**290.7**	**336.4**	**342.8**	**380.2**	**374.0**

CO2 emissions embedded in imports (EEI) by industry sector

	Year >	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1	Agriculture, hunting and related service activities	2.133	2.174	2.234	2.471	2.395	2.379	2.638	3.086	2.640	3.153	3.412	3.413	3.140
2	Forestry, logging and related service activities	0.017	0.024	0.026	0.036	0.025	0.016	0.028	0.068	0.031	0.033	0.039	0.039	0.033
3	Fishing, operation of fish hatcheries and fish farms; service	0.028	0.026	0.024	0.052	0.026	0.007	0.027	0.033	0.024	0.030	0.035	0.030	0.030
4	Mining of coal and lignite; extraction of peat	0.292	0.264	0.139	0.357	0.156	-0.045	0.127	0.142	0.092	0.223	0.121	0.166	0.333
5	Extraction of crude petroleum and natural gas; service activities	1.335	1.235	0.839	2.890	0.751	0.485	0.449	-0.131	0.617	0.771	0.893	0.638	0.661
6	Mining of metal ores	0.001	0.002	0.002	0.000	0.004	0.003	0.005	0.000	0.002	-0.001	-0.001	-0.000	-0.001
7	Other mining and quarrying	0.010	0.012	0.013	0.005	0.007	0.063	0.172	1.081	0.138	0.055	-0.171	-0.090	0.107
8	Production, processing and preserving of meat and meat	2.614	2.768	2.643	2.989	2.986	2.566	2.816	3.001	2.761	3.147	3.249	3.288	3.079
9	Processing and preserving of fish and fish products; fruit and	2.275	2.309	2.297	2.601	2.578	2.206	2.863	2.841	2.253	2.669	2.721	2.805	2.581
10	Vegetable and animal oils and fats	0.233	0.233	0.231	0.267	0.250	0.115	0.230	0.274	0.203	0.231	0.230	0.230	0.215
11	Dairy products	1.548	1.658	1.621	1.693	1.667	1.645	1.704	2.039	1.698	1.839	1.796	1.746	1.642
12	Grain mill products, starches and starch products	0.280	0.282	0.281	0.347	0.325	0.292	0.330	0.308	0.301	0.371	0.362	0.385	0.336
13	Prepared animal feeds	0.200	0.209	0.218	0.264	0.239	0.229	0.280	0.241	0.277	0.325	0.333	0.349	0.318
14	Bread, rusks and biscuits; manufacture of pastry goods and	0.674	0.719	0.724	0.907	0.792	0.734	0.839	0.830	0.908	1.087	1.152	1.226	1.308
15	Sugar	0.133	0.121	0.107	0.135	0.120	0.034	0.131	0.215	0.071	0.090	0.091	0.078	0.095
16	Cocoa; chocolate and sugar confectionery	0.853	0.858	0.908	0.743	0.831	0.729	0.836	0.719	0.649	0.726	0.754	0.750	0.700
17	Other food products	1.086	1.226	1.228	1.341	1.225	1.024	1.323	1.176	1.085	1.271	1.313	1.303	1.279
18	Alcoholic beverages	0.996	1.133	1.225	1.753	1.408	1.632	1.850	2.099	1.740	1.972	2.024	2.240	2.054
19	Production of mineral waters and soft drinks	0.508	0.501	0.503	0.649	0.604	0.540	0.642	0.539	0.620	0.761	0.759	0.821	0.762
20	Tobacco products	0.377	0.437	0.484	0.389	0.715	0.741	1.167	1.239	0.803	0.939	0.854	0.742	0.676
21	Preparation and spinning of textile fibres	0.011	0.011	0.016	0.020	0.001	0.009	-0.016	0.022	0.005	0.008	0.003	0.015	0.005
22	Textile weaving	0.022	0.020	0.034	0.081	0.035	0.042	0.024	0.067	0.035	0.029	0.028	0.035	0.030
23	Finishing of textiles	0.006	0.005	0.007	0.008	0.006	0.016	0.006	0.007	0.004	0.009	0.013	0.005	0.005
24	Made-up textile articles, except apparel	0.534	0.541	0.599	0.694	0.633	0.634	0.784	0.717	0.788	1.003	1.133	1.106	1.088
25	Carpets and rugs	0.357	0.364	0.379	0.374	0.347	0.340	0.358	0.322	0.325	0.365	0.386	0.365	0.334
26	Other textiles	0.037	0.040	0.050	0.086	0.058	0.023	0.058	0.089	0.065	0.074	0.078	0.095	0.058
27	Knitted and crocheted fabrics and articles	1.418	1.576	1.646	1.808	1.705	1.789	2.081	1.874	1.849	2.279	2.187	2.191	1.987
28	Wearing apparel; dressing and dying of fur	5.841	6.144	6.498	6.891	6.751	7.227	8.232	7.456	7.578	9.262	9.857	9.957	9.231
29	Tanning and dressing of leather; manufacture of luggage,	0.131	0.140	0.149	0.143	0.146	0.114	0.180	0.253	0.164	0.223	0.211	0.233	0.228
30	Footwear	1.032	1.126	1.288	1.307	1.244	1.299	1.379	1.415	1.294	1.718	1.784	1.682	1.529
31	Wood and wood products, except furniture	0.381	0.397	0.416	0.422	0.338	0.336	0.422	0.527	0.418	0.493	0.537	0.571	0.515
32	Pulp, paper and paperboard	0.013	-0.004	0.011	-0.001	-0.015	0.449	0.022	0.008	-0.020	-0.004	-0.008	-0.006	0.000
33	Articles of paper and paperboard	0.356	0.359	0.323	0.377	0.346	0.275	0.334	0.450	0.344	0.385	0.408	0.482	0.475
34	Publishing, printing and reproduction of recorded media	1.273	1.388	1.476	1.779	1.494	1.420	1.622	1.596	1.566	1.726	1.852	2.013	1.838
35	Coke, refined petroleum products and nuclear fuel	6.532	6.788	6.553	4.867	6.597	8.531	6.148	7.981	9.729	12.557	12.151	12.356	15.281
36	Industrial gases, dyes and pigments	0.021	0.026	0.025	0.044	0.021	-0.013	0.032	0.039	0.027	0.026	0.026	0.029	0.037
37	Other inorganic basic chemicals	0.000	0.003	0.002	0.003	0.010	-0.003	0.010	0.000	0.003	-0.006	-0.019	0.003	0.000
38	Other organic basic chemicals	0.664	0.701	0.760	0.013	0.393	0.552	0.389	0.450	0.010	0.002	-0.060	0.014	0.023
39	Fertilisers and nitrogen compounds	0.026	0.062	0.076	0.040	0.095	0.030	0.071	0.157	0.057	0.062	0.071	0.081	0.053
40	Plastics and synthetic rubber in primary forms	0.006	0.003	0.013	0.028	0.002	0.006	0.042	0.000	0.028	0.015	-0.019	0.027	-0.024
41	Pesticides and other agro-chemical products	0.027	0.031	0.032	0.048	0.061	-0.005	0.049	0.061	0.040	0.034	0.112	0.050	0.055
42	Paints, varnishes and similar coatings, printing ink and mastics	0.130	0.133	0.138	0.161	0.143	0.122	0.201	0.235	0.211	0.234	0.184	0.225	0.251
43	Pharmaceuticals, medicinal chemicals and botanical products	0.391	0.516	0.422	0.469	0.558	0.508	0.638	1.131	0.841	1.281	1.374	1.478	1.263
44	Soap and detergents, cleaning and polishing preparations,	0.995	1.171	1.266	1.739	1.375	1.340	1.511	1.420	1.537	1.964	2.250	2.752	2.537
45	Other chemical products	0.587	0.624	0.632	0.951	0.699	0.879	0.861	1.136	1.091	1.173	1.118	1.499	1.500
46	Man-made fibres	-0.007	-0.007	-0.005	-0.006	-0.003	-0.005	-0.000	-0.002	-0.001	-0.006	-0.002	-0.009	-0.001
47	Rubber products	0.397	0.453	0.490	0.750	0.556	0.353	0.708	0.797	0.572	0.646	0.705	0.898	0.830
48	Plastic products	0.726	0.732	0.743	0.880	0.729	1.247	0.956	1.310	0.984	1.200	1.264	1.433	1.376
49	Glass and glass products	0.242	0.258	0.269	0.337	0.283	0.105	0.352	0.459	0.336	0.403	0.404	0.488	0.479
50	Ceramic goods	0.557	0.582	0.713	1.073	0.773	0.774	1.026	1.069	0.959	1.137	1.160	1.321	1.339
51	Bricks, tiles and construction products, baked in clay	0.012	0.011	0.013	0.015	0.016	0.019	0.016	0.035	0.032	0.022	0.026	0.025	0.021
52	Cement, lime and plaster	0.019	0.019	0.019	0.016	0.021	0.018	0.019	0.007	0.025	0.025	0.039	0.030	0.032
53	Articles of concrete, plaster and cement; cutting, shaping and	0.089	0.090	0.092	0.100	0.094	0.048	0.096	0.156	0.135	0.147	0.128	0.168	0.180
54	Basic iron and steel and of ferro-alloys; manufacture of tubes and	0.182	0.213	0.167	0.274	0.055	0.145	0.081	0.277	0.156	0.193	0.195	0.186	0.116
55	Basic precious and non-ferrous metals	0.274	0.251	0.176	0.264	0.277	0.182	1.948	0.569	0.357	0.662	0.506	0.437	0.489
56	Casting of metals	0.000	0.005	0.007	0.011	0.007	0.006	0.001	0.000	0.008	-0.004	-0.002	0.017	0.009
57	Structural metal products	0.930	0.886	0.789	1.173	1.009	1.061	1.334	1.063	1.148	1.342	1.369	1.569	1.439
58	Tanks, reservoirs and containers of metal; manufacture of central	0.269	0.252	0.255	0.500	0.302	0.250	0.326	0.297	0.373	0.409	0.395	0.660	0.671
59	Forging, pressing, stamping and roll forming of metal; powder	0.163	0.102	0.070	0.056	0.028	0.017	0.033	0.022	0.046	0.032	-0.017	-0.006	0.056
60	Cutlery, tools and general hardware	0.570	0.568	0.613	0.732	0.608	1.278	0.816	0.973	0.757	0.942	0.993	1.243	1.184
61	Other fabricated metal products	0.608	0.620	0.593	0.752	0.604	1.060	0.765	0.852	0.700	0.943	0.969	1.207	1.182
62	Machinery for the production and use of mechanical power, except	0.497	0.519	0.518	0.904	0.542	0.746	0.716	0.697	0.643	0.809	0.716	1.036	0.945

63	Other general purpose machinery	1.581	1.642	1.756	2.988	2.306	2.303	2.503	2.152	2.430	2.841	2.645	3.426	3.223
64	Agricultural and forestry machinery	0.375	0.427	0.420	0.539	0.397	0.386	0.331	0.286	0.306	0.389	0.412	0.542	0.527
65	Machine tools	0.512	0.510	0.610	1.155	0.705	1.094	0.911	0.750	0.731	0.788	0.766	0.863	0.787
66	Other special purpose machinery	1.074	1.149	1.243	2.506	1.499	1.841	1.880	1.422	1.429	1.471	1.409	1.918	1.715
67	Weapons and ammunition	-0.054	-0.027	0.032	-0.038	-0.010	-0.033	-0.040	-0.023	-0.015	0.032	0.032	0.035	-0.031
68	Domestic appliances not elsewhere classified	0.895	0.955	0.991	1.320	1.077	1.436	1.181	1.099	1.302	1.662	1.891	2.226	2.127
69	Office machinery and computers	3.406	3.807	4.186	6.452	4.937	6.228	7.259	7.086	6.565	6.544	5.795	6.648	6.097
70	Electric motors, generators and transformers; manufacture of	0.751	0.787	0.971	1.402	1.078	1.122	1.388	1.521	1.423	1.465	1.305	1.619	1.582
71	Insulated wire and cable	0.106	0.245	0.219	0.391	0.260	0.149	0.294	0.286	0.419	0.358	0.299	0.327	0.410
72	Electrical equipment not elsewhere classified	0.529	0.571	0.576	0.808	0.501	0.273	0.559	0.663	0.613	0.502	0.605	0.877	0.930
73	Electronic valves and tubes and other electronic components	0.017	0.044	0.045	0.020	0.009	0.085	0.032	0.028	0.111	0.016	0.004	0.030	0.067
74	Television and radio transmitters and line for telephony and line	0.895	1.025	1.476	1.988	2.173	2.208	2.735	3.208	3.506	3.814	4.928	4.557	4.006
75	Television and radio receivers, sound or video recording or	1.312	1.301	1.443	1.973	1.537	1.396	1.484	1.752	1.896	2.417	2.725	3.569	3.848
76	Medical, precision and optical instruments, watches and clocks	2.213	2.274	2.042	2.577	2.078	2.891	2.552	2.622	2.321	2.518	2.444	3.550	3.360
77	Motor vehicles, trailers and semi-trailers	5.937	6.883	7.394	11.546	8.427	9.756	10.765	9.216	9.032	11.215	11.681	15.001	13.897
78	Building and repairing of ships and boats	0.662	0.512	1.113	0.750	0.638	0.540	0.402	0.421	0.486	0.655	0.657	1.080	0.816
79	Other transport equipment	0.560	0.578	0.808	0.844	0.586	0.597	0.730	0.670	0.777	0.704	0.759	1.001	0.956
80	Aircraft and spacecraft	0.847	1.522	1.999	0.677	1.150	3.028	3.737	3.658	2.189	3.194	4.022	4.894	3.207
81	Furniture	3.802	3.873	4.170	5.414	4.340	4.104	5.475	5.404	6.291	6.794	8.079	9.305	9.327
82	Jewellery and related articles; manufacture of musical	5.760	6.730	7.843	5.989	5.459	7.868	6.746	5.310	4.148	4.103	4.819	5.879	5.182
83	Sports goods, games and toys	8.314	8.821	6.945	7.098	6.145	6.612	7.422	6.756	6.707	6.519	7.435	8.148	7.508
84	Miscellaneous manufacturing not elsewhere classified; recycling	2.283	2.511	2.544	3.435	2.544	1.925	3.014	3.139	2.725	2.776	3.096	3.418	3.036
85	Production and distribution of electricity	3.318	3.837	3.374	3.099	2.997	2.739	2.839	1.443	2.481	2.271	2.121	2.029	2.967
86	Gas; distribution of gaseous fuels through mains; steam and hot	2.962	3.001	2.259	1.965	2.646	3.121	1.858	1.201	2.612	3.013	2.974	2.875	3.667
87	Collection, purification and distribution of water	0.085	0.103	0.106	0.143	0.117	0.126	0.150	0.092	0.118	0.124	0.135	0.157	0.166
88	Construction	7.410	8.099	8.505	11.636	8.451	9.272	10.398	8.598	10.608	13.158	12.998	15.013	15.766
89	Sale, maintenance and repair of motor vehicles, and motor cycles;	1.691	2.056	2.133	3.111	2.458	3.007	3.214	2.439	3.098	3.808	3.664	4.071	4.122
90	Wholesale trade and commission trade, except of motor vehicles	2.712	3.177	3.128	4.282	3.759	4.110	4.385	3.987	4.670	5.416	5.407	5.751	5.673
91	Retail trade, except of motor vehicles and motor cycles; repair	2.236	2.568	2.936	3.842	3.554	3.716	4.360	3.576	4.751	5.713	5.812	6.118	5.914
92	Hotels and restaurants	6.870	7.809	8.041	8.496	8.311	8.569	9.336	8.299	9.423	11.289	12.000	12.278	12.039
93	Transport via railways	0.707	0.796	0.915	1.156	1.275	1.500	1.589	1.748	1.905	2.095	2.090	1.893	1.900
94	Other land transport; transport via pipelines	1.767	1.914	1.939	2.120	2.336	2.708	2.833	0.984	3.356	3.825	3.900	4.043	3.845
95	Water transport	3.558	3.866	3.936	4.046	4.107	6.295	4.825	4.653	4.665	5.509	5.668	5.583	5.806
96	Air Transport	13.096	13.406	14.302	14.043	14.413	18.214	18.822	19.548	22.306	24.190	24.193	22.777	22.627
97	Supporting and auxiliary transport activities; activities of travel	0.249	0.278	0.296	0.353	0.308	0.942	0.355	0.562	0.369	0.462	0.398	0.366	0.384
98	Post and courier activities	0.071	0.091	0.099	0.114	0.111	0.106	0.109	0.086	0.101	0.111	0.110	0.114	0.108
99	Telecommunications	0.803	0.927	0.961	1.233	1.142	0.983	1.386	1.155	1.522	1.902	2.012	2.473	2.406
100	Financial intermediation, except insurance and pension funding	0.252	0.321	0.319	0.402	0.450	0.601	0.553	0.519	0.765	0.852	0.749	0.712	0.692
101	Insurance and pension funding, except compulsory social security	1.510	1.500	1.450	1.683	1.357	1.253	1.881	1.481	2.337	3.094	2.519	2.253	2.111
102	Activities auxiliary to financial intermediation	0.060	0.063	0.077	0.100	0.104	0.000	0.106	0.050	0.076	0.112	0.101	0.117	0.119
103	Real estate activities with own property; letting of own property,	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003
104	Letting of dwellings, including imputed rent	1.435	1.685	1.740	2.254	1.801	1.878	2.121	1.768	2.350	2.804	2.672	2.894	2.779
105	Real estate activities on a fee or contract basis	0.037	0.047	0.051	0.061	0.064	0.079	0.077	0.066	0.085	0.108	0.128	0.130	0.167
106	Renting of machinery and equipment without operator and of	0.681	0.752	0.719	0.855	0.746	0.698	0.753	0.626	0.834	0.896	0.790	0.722	0.629
107	Computer and related activities	0.522	0.607	0.782	1.213	1.049	0.980	1.364	0.982	1.242	1.270	1.160	1.160	1.120
108	Research and development	0.017	0.020	0.021	-0.018	0.023	0.024	0.030	0.073	0.033	0.049	0.057	0.067	0.054
109	Legal activities	0.055	0.061	0.065	0.075	0.069	0.081	0.083	0.069	0.094	0.106	0.135	0.118	0.196
110	Accounting, book-keeping and auditing activities; tax consultancy	0.001	0.002	0.002	0.005	0.003	0.006	0.005	0.009	0.001	0.001	0.004	0.001	0.003
111	Market research and public opinion polling; business and	0.036	0.029	0.020	0.020	0.017	0.016	0.021	0.014	0.015	0.007	0.018	0.012	0.013
112	Architectural and engineering activities and related technical	0.199	0.211	0.228	0.273	0.259	0.268	0.297	0.219	0.239	0.313	0.274	0.291	0.340
113	Advertising	0.005	0.005	0.004	0.006	0.005	0.000	0.005	0.005	0.010	0.000	0.000	0.012	0.006
114	Other business services	0.150	0.165	0.152	0.193	0.178	0.329	0.160	0.111	0.109	0.130	0.148	0.166	0.144
115	Public administration and defence; compulsory social security	9.746	9.802	9.920	10.703	9.889	9.145	12.157	9.728	10.929	12.603	13.938	18.359	17.812
116	Education	2.408	2.623	2.565	3.192	3.161	3.284	3.346	2.504	3.345	3.858	4.025	4.332	4.248
117	Human health and veterinary activities	4.332	4.704	4.954	6.551	5.727	5.154	6.365	5.612	7.339	9.982	10.477	12.554	12.386
118	Social work activities	1.254	1.319	1.315	1.489	1.447	1.395	1.313	1.090	1.311	1.613	1.958	2.434	2.604
119	Sewage and refuse disposal, sanitation and similar activities	0.417	0.511	0.514	0.668	0.542	0.510	0.570	0.450	0.607	0.708	0.756	0.820	0.822
120	Activities of membership organisations not elsewhere	0.206	0.197	0.191	0.228	0.186	0.159	0.185	0.139	0.169	0.198	0.202	0.218	0.207
121	Recreational, cultural and sporting activities	2.710	2.966	3.050	3.660	3.279	3.270	3.560	3.135	3.348	3.770	4.278	4.990	4.946
122	Other service activities	0.785	0.864	0.870	1.067	0.954	0.935	1.054	0.778	0.998	1.123	1.109	1.181	1.101
123	Private households with employed persons	0.006	0.007	0.007	0.006	0.007	0.007	0.008	0.008	0.007	0.008	0.009	0.008	0.008
	Total EEI (Mt of CO2)	**158**	**170**	**175**	**204**	**181**	**200**	**217**	**201**	**216**	**251**	**259**	**286**	**280**
	Year >	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004

CO2 emissions embedded in exports (EEE) by industry sector

123 IO code	Description	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1	Agriculture, hunting and related service activities	1.445	1.145	1.098	1.235	1.248	1.117	1.087	1.111	0.958	0.776	0.814	1.025	0.862
2	Forestry, logging and related service activities	0.024	0.020	0.018	0.019	0.020	0.016	0.021	0.024	0.017	0.014	0.016	0.019	0.026
3	Fishing, operation of fish hatcheries and fish farms; service	0.582	0.392	0.404	0.378	0.417	0.258	0.391	0.300	0.361	0.426	0.368	0.543	0.478
4	Mining of coal and lignite; extraction of peat	0.045	0.058	0.052	0.050	0.066	0.055	0.052	0.043	0.047	0.033	0.029	0.025	0.024
5	Extraction of crude petroleum and natural gas; service activities	7.900	8.868	9.287	9.503	9.971	9.152	7.122	9.635	11.496	12.394	12.308	12.115	11.622
6	Mining of metal ores	0.025	0.021	0.026	0.061	0.025	0.016	0.028	0.009	0.001	0.003	0.034	0.001	0.003
7	Other mining and quarrying	2.262	4.022	3.849	5.577	3.764	3.387	3.309	3.587	6.571	8.018	7.552	8.105	7.036
8	Production, processing and preserving of meat and meat	1.095	1.164	1.412	1.663	1.132	0.904	0.880	0.768	0.709	0.459	0.565	0.622	0.616
9	Processing and preserving of fish and fish products; fruit and	0.400	0.478	0.556	0.599	0.598	0.528	0.588	0.540	0.507	0.516	0.533	0.580	0.547
10	Vegetable and animal oils and fats	0.121	0.145	0.197	0.231	0.240	0.222	0.278	0.231	0.173	0.162	0.254	0.307	0.227
11	Dairy products	0.546	0.616	0.622	0.765	0.637	0.572	0.674	0.679	0.581	0.514	0.501	0.600	0.571
12	Grain mill products, starches and starch products	0.260	0.265	0.278	0.284	0.351	0.314	0.392	0.392	0.367	0.355	0.375	0.365	0.331
13	Prepared animal feeds	0.311	0.287	0.299	0.298	0.301	0.256	0.255	0.214	0.214	0.205	0.215	0.228	0.196
14	Bread, rusks and biscuits; manufacture of pastry goods and	0.297	0.337	0.299	0.322	0.373	0.325	0.323	0.293	0.294	0.312	0.325	0.324	0.255
15	Sugar	0.058	0.071	0.079	0.102	0.078	0.092	0.107	0.101	0.070	0.076	0.057	0.074	0.090
16	Cocoa; chocolate and sugar confectionery	0.431	0.452	0.529	0.530	0.516	0.479	0.462	0.389	0.365	0.314	0.319	0.283	0.233
17	Other food products	0.513	0.565	0.551	0.595	0.640	0.591	0.620	0.586	0.568	0.623	0.621	0.641	0.613
18	Alcoholic beverages	0.213	0.243	0.259	0.269	0.220	0.292	0.190	0.126	0.167	0.134	0.136	0.161	0.117
19	Production of mineral waters and soft drinks	0.151	0.168	0.197	0.246	0.241	0.201	0.202	0.215	0.194	0.203	0.170	0.216	0.189
20	Tobacco products	0.411	0.235	0.331	0.388	0.370	0.369	0.407	0.353	0.340	0.312	0.297	0.245	0.172
21	Preparation and spinning of textile fibres	0.377	0.378	0.438	0.462	0.396	0.267	0.358	0.300	0.339	0.298	0.219	0.208	0.195
22	Textile weaving	0.714	0.907	0.885	0.867	0.785	0.544	0.697	0.534	0.519	0.554	0.531	0.614	0.534
23	Finishing of textiles	-	0.001	0.001	0.002	0.004	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.004
24	Made-up textile articles, except apparel	0.208	0.225	0.213	0.227	0.247	0.217	0.252	0.229	0.202	0.215	0.172	0.196	0.197
25	Carpets and rugs	0.184	0.189	0.200	0.217	0.197	0.164	0.187	0.162	0.167	0.156	0.130	0.125	0.091
26	Other textiles	0.387	0.400	0.401	0.476	0.425	0.385	0.398	0.373	0.449	0.493	0.466	0.540	0.549
27	Knitted and crocheted fabrics and articles	0.623	0.684	0.729	0.742	0.732	0.664	0.656	0.613	0.592	0.539	0.467	0.536	0.512
28	Wearing apparel; dressing and dying of fur	1.557	1.772	1.812	2.062	1.725	1.300	1.708	1.372	1.179	1.071	0.991	1.047	0.882
29	Tanning and dressing of leather; manufacture of luggage,	0.254	0.282	0.374	0.380	0.362	0.294	0.262	0.202	0.251	0.234	0.229	0.206	0.187
30	Footwear	0.318	0.351	0.348	0.385	0.363	0.249	0.263	0.142	0.200	0.190	0.168	0.131	0.073
31	Wood and wood products, except furniture	0.183	0.188	0.280	0.309	0.358	0.371	0.346	0.369	0.340	0.356	0.326	0.403	0.320
32	Pulp, paper and paperboard	3.810	3.240	3.002	2.801	2.571	2.319	2.555	2.048	2.423	2.402	2.413	2.923	2.620
33	Articles of paper and paperboard	0.351	0.422	0.519	0.638	0.602	0.683	0.552	0.392	0.400	0.412	0.398	0.481	0.378
34	Publishing, printing and reproduction of recorded media	0.759	0.950	1.108	1.232	1.260	1.176	1.178	1.043	1.060	1.176	1.242	1.447	1.359
35	Coke, refined petroleum products and nuclear fuel	12.070	14.250	11.662	10.862	13.546	15.130	11.176	9.570	14.817	13.577	14.790	16.797	18.670
36	Industrial gases, dyes and pigments	1.490	1.608	1.537	1.338	1.227	0.806	1.214	0.787	0.899	1.075	0.915	0.997	0.827
37	Other inorganic basic chemicals	0.666	0.882	0.748	0.891	0.693	0.507	0.574	0.386	1.102	1.108	0.574	0.615	0.633
38	Other organic basic chemicals	6.505	7.565	7.987	7.435	7.518	5.622	8.053	7.793	6.704	6.995	7.539	7.813	6.951
39	Fertilisers and nitrogen compounds	0.272	0.282	0.290	0.407	0.386	0.279	0.343	0.313	0.429	0.416	0.334	0.348	0.313
40	Plastics and synthetic rubber in primary forms	2.324	2.556	2.674	2.170	2.142	1.412	2.093	1.966	2.217	2.555	2.823	2.897	2.846
41	Pesticides and other agro-chemical products	0.580	0.774	0.755	0.489	0.693	0.639	0.748	0.629	0.505	0.510	0.642	0.575	0.551
42	Paints, varnishes and similar coatings, printing ink and mastics	0.406	0.442	0.524	0.514	0.447	0.396	0.323	0.254	0.289	0.308	0.422	0.460	0.417
43	Pharmaceuticals, medicinal chemicals and botanical products	1.993	2.569	2.760	3.239	3.046	2.791	3.160	2.506	3.008	4.159	4.576	5.723	5.296
44	Soap and detergents, cleaning and polishing preparations,	1.155	1.368	1.578	1.480	1.661	1.636	1.662	1.363	1.363	1.389	1.429	2.109	1.831
45	Other chemical products	3.729	4.234	4.254	4.112	4.159	3.758	3.631	2.990	2.901	3.219	3.213	3.753	3.196
46	Man-made fibres	1.429	1.245	1.153	1.097	1.135	1.226	1.092	0.958	1.136	1.475	0.883	1.127	0.992
47	Rubber products	0.971	1.026	1.114	1.256	1.261	1.275	1.193	1.035	1.380	1.065	0.933	0.916	0.840
48	Plastic products	2.317	2.288	2.542	2.899	2.837	2.523	2.510	2.253	2.357	2.546	2.508	2.975	2.772
49	Glass and glass products	0.863	0.846	0.888	0.870	0.807	0.761	0.837	0.644	0.805	0.782	0.738	0.910	0.903
50	Ceramic goods	0.709	0.709	0.744	0.924	0.884	0.743	0.729	0.583	0.611	0.567	0.444	0.408	0.365
51	Bricks, tiles and construction products, baked in clay	0.022	0.019	0.029	0.040	0.067	0.040	0.046	0.038	0.055	0.041	0.036	0.037	0.033
52	Cement, lime and plaster	0.273	0.341	0.326	0.412	0.624	0.707	0.776	0.690	0.458	0.422	0.386	0.336	0.366
53	Articles of concrete, plaster and cement; cutting, shaping and	0.650	0.733	0.780	0.848	0.913	0.949	1.032	0.960	0.914	0.858	0.679	0.773	0.790
54	Basic iron and steel and of ferro-alloys; manufacture of tubes and	15.376	17.440	17.881	18.944	17.436	6.136	15.118	12.448	12.899	12.962	13.404	17.219	19.087
55	Basic precious and non-ferrous metals	5.051	5.453	5.963	8.154	6.422	2.392	6.143	5.028	7.464	7.523	6.211	7.160	8.123
56	Casting of metals	-	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
57	Structural metal products	0.417	0.480	0.521	0.704	0.596	0.669	0.645	0.587	0.397	0.471	0.385	0.606	0.595
58	Tanks, reservoirs and containers of metal; manufacture of central	0.177	0.210	0.239	0.213	0.303	0.402	0.261	0.198	0.141	0.153	0.115	0.142	0.146
59	Forging, pressing, stamping and roll forming of metal; powder	-	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60	Cutlery, tools and general hardware	0.774	0.722	0.756	0.881	0.936	0.791	0.893	0.900	1.016	1.092	0.934	0.946	0.826
61	Other fabricated metal products	1.591	1.384	1.701	2.153	1.993	1.776	1.914	1.492	1.393	1.483	1.329	1.389	1.577
62	Machinery for the production and use of mechanical power, except	3.082	3.406	3.321	3.943	3.929	3.550	3.391	2.971	3.340	3.472	3.301	3.670	3.529

63	Other general purpose machinery	2.416	2.531	2.604	3.565	3.589	3.610	3.143	2.757	2.696	2.963	2.502	2.892	2.961
64	Agricultural and forestry machinery	0.531	0.551	0.668	0.822	0.905	1.011	0.910	0.748	0.589	0.525	0.470	0.515	0.400
65	Machine tools	0.667	0.680	0.901	1.025	1.078	1.105	1.072	0.886	0.884	0.852	0.609	0.551	0.480
66	Other special purpose machinery	2.639	2.826	2.922	3.665	3.619	3.530	4.018	3.156	2.882	3.122	2.854	3.379	3.127
67	Weapons and ammunition	0.314	0.590	0.382	0.624	0.605	0.664	0.707	0.257	0.347	0.228	0.220	0.146	0.190
68	Domestic appliances not elsewhere classified	0.506	0.549	0.598	0.749	0.678	0.709	0.646	0.497	0.462	0.442	0.409	0.447	0.366
69	Office machinery and computers	3.393	4.827	5.615	8.149	6.880	6.778	7.662	6.733	7.335	7.385	5.870	5.371	4.279
70	Electric motors, generators and transformers; manufacture of	1.539	1.678	1.725	2.001	2.047	1.996	2.111	1.782	1.936	2.055	1.965	2.209	1.949
71	Insulated wire and cable	0.332	0.342	0.409	0.561	0.494	0.407	0.474	0.346	0.465	0.485	0.314	0.397	0.336
72	Electrical equipment not elsewhere classified	1.147	1.419	1.593	1.736	1.863	1.556	1.903	1.375	1.646	1.722	1.577	1.574	1.463
73	Electronic valves and tubes and other electronic components	1.250	2.330	2.711	4.028	3.117	2.050	2.424	2.555	3.855	4.386	4.579	3.106	3.106
74	Television and radio transmitters and line for telephony and line	0.414	0.611	1.223	1.883	1.930	2.131	2.737	2.261	3.786	4.297	3.051	2.686	1.994
75	Television and radio receivers, sound or video recording or	0.992	1.409	1.616	1.947	1.906	1.466	1.679	1.053	1.127	1.093	0.785	0.834	0.778
76	Medical, precision and optical instruments, watches and clocks	2.599	2.676	2.644	3.019	3.036	2.776	2.967	2.276	2.832	3.269	2.890	2.947	2.875
77	Motor vehicles, trailers and semi-trailers	8.803	7.995	8.956	11.676	12.362	12.000	12.342	10.797	12.463	10.790	12.117	14.192	13.364
78	Building and repairing of ships and boats	0.781	0.526	0.603	0.639	0.648	1.398	0.486	0.534	0.430	0.436	0.465	0.571	0.648
79	Other transport equipment	0.213	0.214	0.500	0.282	0.240	0.198	0.250	0.202	0.173	0.212	0.187	0.265	0.233
80	Aircraft and spacecraft	6.591	5.951	5.173	5.737	6.566	7.907	8.827	7.831	8.040	8.502	6.893	9.480	8.365
81	Furniture	0.661	0.616	0.670	0.801	0.823	0.791	0.817	0.799	0.751	0.788	0.648	0.636	0.670
82	Jewellery and related articles; manufacture of musical	1.167	1.602	2.186	1.846	2.255	2.265	2.376	1.863	1.624	1.943	1.951	2.240	2.143
83	Sports goods, games and toys	0.563	0.617	0.800	0.811	0.727	0.433	0.422	0.339	0.500	0.536	0.541	0.590	0.457
84	Miscellaneous manufacturing not elsewhere classified; recycling	0.891	0.876	0.917	0.792	0.752	0.743	0.776	0.511	0.486	0.519	0.509	0.562	0.493
85	Production and distribution of electricity	0.255	0.269	0.253	0.317	0.286	0.261	0.272	0.312	0.305	0.264	1.032	1.623	1.452
86	Gas; distribution of gaseous fuels through mains; steam and hot	0.022	0.024	0.025	0.029	0.029	0.035	0.042	0.058	0.072	0.079	0.089	0.096	0.106
87	Collection, purification and distribution of water	0.003	0.003	0.003	0.003	0.003	0.002	0.004	0.004	0.004	0.004	0.003	0.004	0.003
88	Construction	0.085	0.094	0.110	0.127	0.142	0.193	0.230	0.183	0.142	0.116	0.118	0.141	0.160
89	Sale, maintenance and repair of motor vehicles, and motor cycles;	0.679	0.715	0.704	0.848	0.827	0.263	1.132	1.059	0.999	1.120	0.965	1.031	1.035
90	Wholesale trade and commission trade, except of motor vehicles	7.941	8.351	8.075	9.005	8.880	9.650	9.359	10.011	8.776	9.215	8.637	8.216	8.007
91	Retail trade, except of motor vehicles and motor cycles; repair	0.064	0.066	0.071	0.077	0.082	0.088	0.095	0.092	0.095	0.105	0.102	0.101	0.103
92	Hotels and restaurants	2.981	3.460	3.469	4.052	4.064	3.851	3.792	3.376	3.365	3.156	3.105	3.080	3.156
93	Transport via railways	0.133	0.131	0.138	0.187	0.221	0.240	0.222	0.224	0.215	0.217	0.190	0.186	0.206
94	Other land transport; transport via pipelines	1.373	1.513	1.593	1.741	1.642	1.519	1.734	1.552	1.709	1.676	1.868	1.962	2.135
95	Water transport	13.747	14.159	14.350	14.328	15.672	15.941	14.509	12.081	13.489	16.587	17.113	19.693	26.849
96	Air Transport	11.794	12.851	12.750	13.173	14.211	12.717	14.772	15.357	16.757	16.450	15.569	13.994	13.905
97	Supporting and auxiliary transport activities; activities of travel	0.466	0.528	0.518	0.500	0.531	0.533	0.638	0.614	0.664	0.727	0.617	0.596	0.575
98	Post and courier activities	0.040	0.063	0.071	0.096	0.091	0.085	0.088	0.102	0.101	0.114	0.115	0.145	0.150
99	Telecommunications	0.404	0.450	0.423	0.443	0.467	0.494	0.553	0.544	0.615	0.732	0.771	0.900	1.010
100	Financial intermediation, except insurance and pension funding	0.461	0.486	0.429	0.758	0.893	1.101	1.121	1.253	1.406	1.562	1.335	1.342	1.317
101	Insurance and pension funding, except compulsory social security	0.087	0.312	0.336	0.525	0.641	0.817	0.754	0.826	0.659	1.186	1.537	1.321	1.154
102	Activities auxiliary to financial intermediation	1.583	1.670	2.042	1.882	2.417	2.499	2.759	2.710	3.145	3.512	2.936	2.933	3.329
103	Real estate activities with own property; letting of own property,	0.008	0.007	0.007	0.007	0.007	0.011	0.006	0.007	0.006	0.005	0.003	0.016	0.012
104	Letting of dwellings, including imputed rent	0.035	0.038	0.036	0.040	0.033	0.032	0.031	0.029	0.030	0.027	0.024	0.024	0.024
105	Real estate activities on a fee or contract basis	0.002	0.002	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
106	Renting of machinery and equipment without operator and of	0.266	0.278	0.221	0.224	0.180	0.149	0.147	0.128	0.131	0.120	0.114	0.116	0.116
107	Computer and related activities	0.466	0.523	0.620	0.667	0.563	0.758	0.836	0.940	1.069	1.087	1.187	1.393	1.608
108	Research and development	0.323	0.357	0.405	0.418	0.532	0.712	1.112	1.167	1.051	1.391	1.424	1.659	1.787
109	Legal activities	0.119	0.114	0.122	0.118	0.148	0.169	0.213	0.197	0.247	0.293	0.317	0.303	0.290
110	Accounting, book-keeping and auditing activities; tax consultancy	0.026	0.029	0.031	0.032	0.034	0.048	0.096	0.113	0.122	0.121	0.132	0.120	0.142
111	Market research and public opinion polling; business and	0.226	0.245	0.254	0.262	0.250	0.330	0.386	0.381	0.383	0.391	0.405	0.393	0.344
112	Architectural and engineering activities and related technical	0.542	0.577	0.629	0.692	0.718	0.720	0.848	0.690	0.618	0.832	0.725	0.779	0.744
113	Advertising	0.330	0.363	0.372	0.382	0.319	0.300	0.467	0.466	0.572	0.612	0.596	0.734	0.611
114	Other business services	2.465	2.544	2.837	3.011	3.262	2.816	3.567	3.835	4.007	4.203	4.587	4.489	4.117
115	Public administration and defence; compulsory social security	0.409	0.400	0.333	0.371	0.308	0.261	0.276	0.242	0.254	0.400	0.386	0.462	0.455
116	Education	0.237	0.268	0.265	0.280	0.343	0.318	0.334	0.316	0.296	0.297	0.425	0.418	0.394
117	Human health and veterinary activities	0.040	0.044	0.046	0.059	0.062	0.057	0.060	0.054	0.055	0.055	0.051	0.053	0.054
118	Social work activities	0.001	0.001	0.001	0.002	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.002
119	Sewage and refuse disposal, sanitation and similar activities	0.026	0.034	0.023	0.022	0.022	0.013	0.013	0.010	0.012	0.012	0.011	0.014	0.015
120	Activities of membership organisations not elsewhere	-	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
121	Recreational, cultural and sporting activities	1.382	1.431	1.383	1.469	1.438	1.283	1.279	1.112	1.362	1.469	1.508	1.507	1.539
122	Other service activities	0.037	0.043	0.045	0.055	0.054	0.049	0.052	0.047	0.047	0.052	0.049	0.054	0.052
123	Private households with employed persons	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.000
	Total EEE (Mt of CO2)	**179**	**196**	**202**	**223**	**222**	**199**	**217**	**196**	**219**	**229**	**222**	**242**	**242**
	Year >	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004

9 Appendix B: Glossary

AT	Analytical Table
BEET	Balance of emissions embedded in trade
CO_2-e	Carbon dioxide equivalents
CPI	Consumer price index
CRAS	Conflicting RAS (matrix balancing procedure)
Defra	Department For Environment, Food And Rural Affairs
EEE	Emissions embedded in exports
EEI	Emissions embedded in imports
EET	Emissions embedded in trade
FC	Final consumption
FD	Final demand
GHG	Greenhouse gas
GTAP	Global Trade Analysis Project
GWP	Global warming potential
IEA	International Energy Agency
IO	Input-output
IPCC	Intergovernmental Panel on Climate Change
MFA	Material flow analysis
MRIO	Multi-region input-output
OECD	Organisation for Economic Co-operation and Development
ONS	Office for National Statistics
PPP	Purchasing power parity
RAS	Synonym for a matrix balancing approach used mainly to update input-output tables, developed by Richard A. Stone in 1961[23] and named after the typical sequence of matrices in the procedure.
ROW	Rest of the world
SAM	Social accounting matrix
SCP	Sustainable consumption and production
SIOT	Symmetric input-output table
SRIO	Single region input-output
SUT	Supply and Use Table
UK-MRIO 1	Multi-region input-output model with global coverage, including the United Kingdom as one of the trading partners (also acronym for the model developed in this project with the '1' meaning that this is the first stage of model development).
UNFCCC	United Nations Framework Convention on Climate Change

[23] (Eurostat 2008; United Nations 1999).

10 Appendix C: References

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