DEVELOPMENT OF AN EMBEDDED CARBON EMISSIONS INDICATOR

A research report to the Department for Environment, Food and Rural Affairs by the Stockholm Environment Institute and the University of Sydney

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DEVELOPMENT OF AN EMBEDDED CARBON EMISSIONS INDICATOR

Producing a Time Series of Input-Output Tables and Embedded Carbon Dioxide Emissions for the UK by Using a MRIO Data Optimisation System

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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[1] 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

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

1 Project Context

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. 2006a)[2]. 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

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[2] 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

Sustainable Development, it was recognised that the adoption of such a consumption-based perspective – in addition to the territorial estimation and accounting of emissions that is a legal reporting requirement under the United Nations Framework Convention on Climate Change – 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 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.[3] 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 emissions between 1990 and 2003.

As a follow-up to our previous work, the current work[4] 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 assimilate 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

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[3] 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.

[4] 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

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[5] at the University of York has collaborated with The Centre for Integrated Sustainability Analysis (ISA) at the University of Sydney[6] in this project to develop the required data and model basis.

Aim of this 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 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[7] 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 (see Appendix C: Data Sources and Data Preparation on page 41).

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.

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

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

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

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

A literature review was undertaken in the course of the 'Resource Flows' project[2] on models and approaches that are capable of estimating emission embodiments in international trade. Since the conclusion of the project and the publication of its findings (Wiedmann et al. 2007a; Wiedmann et al. 2006a), new research has been published. We have updated this literature review and the results are presented in Appendix B: Review of Literature on EET models on page 37 of this report.

The main finding from the review is that in 2007 alone 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.

2 Methodological Approach

Data handling protocol

For a successful implementation of the UK-MRIO 1 model it is important to define the system correctly and in full generality with all components, valuations and other transactions and transitions that could arise. This ensures consistency in the implementation process and will avoid having to re-design parts of the system later on.

The implementation and application of a full multi-regional input-output framework poses three basic challenges: data availability, data reconciliation and computability. These issues and possible practical solutions are discussed in detail in (Wiedmann et al. 2006a). In the following we focus on the important issue of data handling in a MRIO model.

Compiling the required data, estimating missing data and balancing conflicting data in the right way is the most crucial part of a MRIO framework. Most resources have been devoted to this part of the work since good handling of data ensures consistency, robustness and repeatability of the whole approach. The data system is now able to

- include data in different classifications,
- handle conflicting data consistently,

- cope with suppressed data,
- estimate missing data,
- accommodate different years for the analysis of time series.

A generic framework that satisfies these requirements is depicted in the diagram below. In essence, this data framework employs optimisation techniques that balance data according to constraints which are defined by existing/available data. The essential elements are:

- Concordance matrices that match data from different classifications.
- Data templates that automatically translate between existing/available data and balanced data sheets. These templates are the central part of the system and required to assemble all the data used in the model. They are coded in a way that allows the entry of data in different formats or prices as well as blank or suppressed data points. They include the initial data estimates as well as a list of constraints required for optimisation.
- A set of balanced data sheets containing all required information, generated through reliable optimisation techniques.

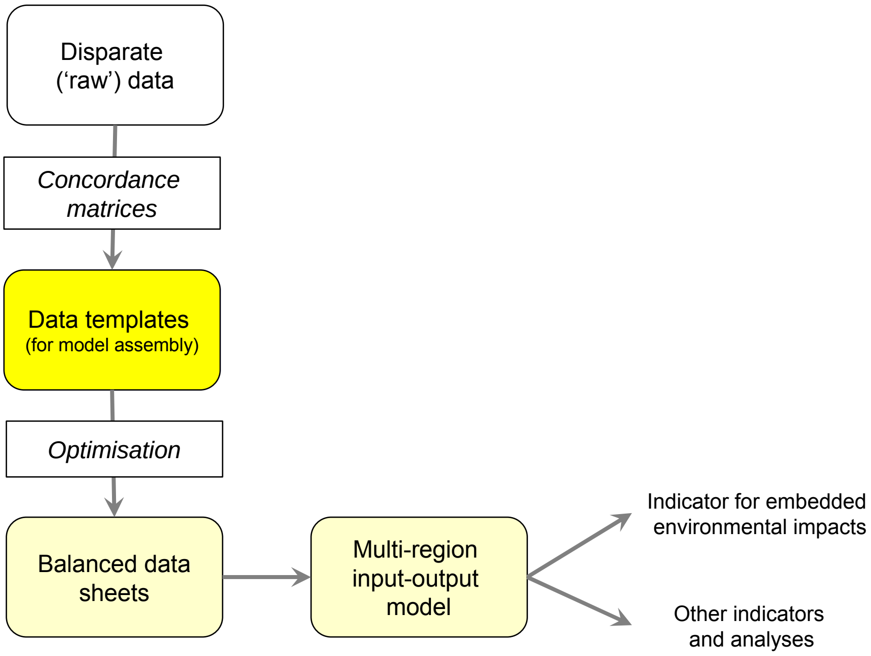

Figure 1: Data handling protocol for a multi-region input-output model

Such a data framework is very flexible and easily expandable. The outcome of this data protocol is a code that allows for more data to be added at any time, including additional trading partners (regions, countries), additional environmental impact data or additional years of data. These additions do not change the basic framework so that annual and time series data can be reproduced reliably. Estimates of uncertainties can also be performed as an intrinsic part of the model.

It is not a necessary condition to have analytical (symmetric) input-output tables for an environmental input-output model. Under certain assumptions and with some caveats (see Section 4), supply and use matrices can be used instead as described in (Lenzen et al. 2004) and (Wiedmann et al. 2006b). This is a big advantage as supply and use tables are often available annually while analytical or symmetric IO tables are usually not (for the situation in the UK see e.g. (Mahajan 2007a). It also allows using more up-to-date information as the time delay for publishing supply and use tables is shorter than for analytical tables (in the region of two to three years as opposed to more than five years for analytical tables). This is important because changes in the structure of domestic and foreign economies can be picked up more accurately if up-to-date input-output information is used.

The superiority of using detailed supply and use tables is reinforced when the level of detail available is considered. (Dalgaard and Gysting 2004b) write: “In the product dimension they range from 123 products and industries in the UK, over 500 products and 90 industries in France, 800 products and 200 industries in the Netherlands to 980 products and 178 industries in Norway and [about 2750 products] in Denmark, all compiled on a yearly basis. The benchmark input-output tables in the United States are based on supply and use tables containing about 715 industries and 2281 products.” However, it has to be noted that not all the countries mentioned use exactly the same conceptual and definitional basis for their National Accounts.

Without doubt, Analytical Tables (ATs) produced by the ONS would have best met the needs of environmental IO models because they would have been built by using original and detailed information on the production of by-products and auxiliary production. Also, the consumption of imports of goods and services and UK-produced goods and services is shown separately and ATs are valued in basic prices. The need to strip out imports, taxes (less subsidies) on products and distributors' trading margins is key to get to the true factors of production. However, the ONS plans for annual IO Analytical Tables (Beadle 2007; Mahajan 2007a) could not be realised yet. Because of the current data situation in the UK, the annual supply and use tables had to form the backbone of the MRIO model for the UK (see also Section 4).

As figures for imports and margin flows are not available in the supply and use tables, a two stage process has been employed, with initial estimates obtained from published analytical tables, subsequently updated for the year under investigation by utilising constrained optimisation with the import and margin totals by product. The procedures involved are described in the following Sections and Appendices. First, however, we describe the general structure of the UK-MRIO 1 model.

Definition of the UK-MRIO 1 model using a SUT data framework

The basic layout of the model framework is depicted in Table 1. For the purpose of this project, which is to implement the model in principle with only a small number of trading partners at this stage, we choose to consider UK trade with three world regions, OECD Europe (Region e), OECD non-Europe (Region o) and non-OECD countries (Region w).[8]

The UK is represented with its full input-output data in supply and use format whereas the three world regions are represented by their domestic and imports transaction matrices. Imports to the UK are distinguished by region and by destination to intermediate ($\mathbf{U}^{ru}$) and final demand ($\mathbf{y}^{ru}$). At this stage of model development, we only consider trade between the UK and the regions (uni-directional) but not between the regions themselves and we only include CO_2 as environmental load ($\mathbf{E}^{r}$).

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[8] This decision was driven by data availability (see Appendix C: Data Sources and Data Preparation, page 44) and practical considerations.

Table 1: Multi-region input-output (MRIO) system employed in this work

		Intermediate demand								Final demand				Total output
		UK(u)		*Region e*		*Region o*		*Region w*		*UK(u)*	*Region e*	*Region o*	*Region w*	
		prod	ind	prod	ind	prod	ind	prod	ind					
UK(u)	prod		$\mathbf{U}^{uu}$							$\mathbf{y}^{uu}$	------ $\mathbf{y}^{ur}$ ------			$\mathbf{q}^{u}$
	ind	$\mathbf{V}^{uu}$												$\mathbf{g}^{u}$
Region e	prod		$\mathbf{U}^{eu}$		$\mathbf{U}^{ee}$					$\mathbf{y}^{eu}$	$\mathbf{y}^{ee}$	------ $\mathbf{y}^{er}$ ------		$\mathbf{q}^{e}$
	ind			$\hat{\mathbf{q}}^{e}$										$\mathbf{g}^{e}$
Region o	prod		$\mathbf{U}^{ou}$				$\mathbf{U}^{oo}$			$\mathbf{y}^{ou}$	- $\mathbf{y}^{or}$ ----	$\mathbf{y}^{oo}$	---- $\mathbf{y}^{or}$ -	$\mathbf{q}^{o}$
	ind					$\hat{\mathbf{q}}^{o}$								$\mathbf{g}^{o}$
Region w	prod		$\mathbf{U}^{wu}$						$\mathbf{U}^{ww}$	$\mathbf{y}^{wu}$	------ $\mathbf{y}^{wr}$ ------		$\mathbf{y}^{ww}$	$\mathbf{q}^{w}$
	ind							$\hat{\mathbf{q}}^{w}$						$\mathbf{g}^{w}$
Primary inputs			$\mathbf{w}^{u}$		$\mathbf{w}^{e}$		$\mathbf{w}^{o}$		$\mathbf{w}^{w}$					
Total inputs		$\mathbf{q}^{u'}$	$\mathbf{g}^{u'}$	$\mathbf{q}^{e'}$	$\mathbf{g}^{e'}$	$\mathbf{q}^{o'}$	$\mathbf{g}^{o'}$	$\mathbf{q}^{w'}$	$\mathbf{g}^{w'}$					
Factor inputs (environmental loads)			$\mathbf{E}^{u}$		$\mathbf{E}^{e}$		$\mathbf{E}^{o}$		$\mathbf{E}^{w}$					

Legend to Table 1:

- UK United Kingdom (superscript u)
- Region e OECD Europe countries (superscript e)[9]
- Region o OECD non-Europe countries (superscript o)[10]
- Region w non-OECD countries = rest of the world (superscript w)
- prod products
- ind industries
- r index for any region / country (u, e, o, w).
- $\mathbf{U}^{uu}$ Domestic use matrix of the UK with elements u_{ij}^{uu} indicating the input of commodity *i* into industry *j*
- $\mathbf{U}^{ru}$ Matrix of imports from region *r* into UK industries with u_{ij}^{ru} indicating the input of commodity *i* from region *r* into UK industry *j*
- $\mathbf{V}^{uu}$ Domestic supply matrix of the UK with element v_{ij}^{uu} indicating the output of commodity *j* by industry *i*
- $\mathbf{U}^{rr}$ Domestic use matrix of region r
- $\mathbf{g}^{r}$ Vector of total output of industries in country/region *r* (the prime symbol ' denotes transposition)
- $\mathbf{q}^{r}$ Vector of total output of commodities in country/region *r* (the prime symbol ' denotes transposition; the hat symbol ^ denotes diagonalisation, i.e. the vector is transformed into a matrix with diagonal elements only)
- $\mathbf{y}^{uu}$ Column vectors of total final domestic demand on UK production[11]
- $\mathbf{y}^{ur}$ Column vectors of final export demand on UK production (exports of goods and services)[12]
- $\mathbf{y}^{ru}$ Column vectors of total final demand in the UK on production imported from region *r*
- $\mathbf{y}^{rr}$ Column vectors of total final domestic demand on production in region r
- $\mathbf{y}^{sr}$ Column vectors of final export demand on production in country s

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[9] Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom

[10] Canada, Mexico, United States, Australia, Japan, Korea, New Zealand

[11] Including demand of households, non-profit institutions serving households (NPISH), central government, local government, gross fixed capital formation, valuables and changes in inventories (cf. ONS 2007c).

[12] Including exports of goods and export of services to European and non-European Union countries (cf. ONS 2007c).

- **w**^{r} Row vectors of primary inputs (income, surplus) into industries (note that **w**^{r} contains only value added items and no imports, taxes or margins, because the latter are contained in the **U**^{ru} matrices; for more details see section 'UK input-output data' on page 41).
- **E**^{r} Row vector of (CO_2) emissions by industry in country/region *r*
- \- - - Hyphens mean that data for this cell is implicitly included in data from other cells, i.e. total exports are aggregated in **y**^{ur}, **y**^{er}, **y**^{or} and **y**^{wr}

The next step is to derive (relative) coefficient matrices from the (absolute) transaction matrices. Defining input coefficient matrices **A**^{rs} with $a_{ij}^{rs} = u_{ij}^{rs} / g_j^s$ and output coefficient matrix **B**^{rs} with $b_{ij}^{rs} = v_{ij}^{rs} / q_j^s$ the grey-shaded parts of Table 1 can be transformed into a compound direct requirements matrix:

Eq. 1
$$\mathbf{A^*} = \begin{pmatrix} 0 & \mathbf{A}^{uu} & 0 & 0 & 0 & 0 & 0 & 0 \\ \mathbf{B}^{uu} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{A}^{eu} & 0 & \mathbf{A}^{ee} & 0 & 0 & 0 & 0 \\ 0 & 0 & \mathbf{B}^{ee} & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{A}^{ou} & 0 & 0 & 0 & \mathbf{A}^{oo} & 0 & 0 \\ 0 & 0 & 0 & 0 & \mathbf{B}^{oo} & 0 & 0 & 0 \\ 0 & \mathbf{A}^{wu} & 0 & 0 & 0 & 0 & 0 & \mathbf{A}^{ww} \\ 0 & 0 & 0 & 0 & 0 & 0 & \mathbf{B}^{ww} & 0 \end{pmatrix}$$

Eq. 2
$$\text{Setting } \mathbf{y^*} = \begin{pmatrix} \mathbf{y}^{u} \\ 0 \\ \mathbf{y}^{eu} \\ 0 \\ \mathbf{y}^{ou} \\ 0 \\ \mathbf{y}^{wu} \\ 0 \end{pmatrix}, \qquad \mathbf{g^*} = \begin{pmatrix} \mathbf{q}^{u} \\ \mathbf{g}^{u} \\ \mathbf{q}^{e} \\ \mathbf{g}^{e} \\ \mathbf{q}^{o} \\ \mathbf{g}^{o} \\ \mathbf{q}^{w} \\ \mathbf{g}^{w} \end{pmatrix},$$

with **y**^{u} = **y**^{uu} + **y**^{ur} = total final demand for the UK allows to calculate **A*** which satisfies the basic input-output relationship

Eq. 3
$$\mathbf{A^*\,g^* + y^* = g^*} \;\Leftrightarrow\; \mathbf{g^* = (I\text{-}A^*)^{-1}\,y^*}\,,$$

where **I** is a suitable unity matrix. The compound Leontief inverse $\mathbf{(I\text{-}A^*)^{-1}}$ contains compound total multipliers of intermediate demand and trade.[13]

Data sources and preparation

A detailed description of all data sources and of how the data were prepared is provided in Section 10 (Appendix C: Data Sources and Data Preparation, page 41). We have used publicly available input-output data from the UK Office for National Statistics (ONS)[14,15] 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.

Balancing data by using the CRAS method

A common problem in compiling and updating Social Accounting Matrices (SAM) or input-output tables is that of incomplete or inconsistent data. Missing or conflicting matrix elements may be due to a variety of reasons such as costly and therefore incomplete industry surveys, the suppression of confidential information and inconsistencies when sectors have to be disaggregated. The latter two are specific problems in the compilation of the UK-MRIO 1 model (see also Druckman et al. 2007, pp11).

External data points can be used to formulate a system of equations that constrain the unknown matrix elements. Constraints in this context are ‘fixed’ data values, i.e. any data points in the system that are known with sufficient accuracy. Any available and reliable data can serve as constraints. In order to constrain the preliminary estimate of IO tables, it is important to incorporate as many sources of superior data as possible. However, unknowns usually

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[13] Note: Imports matrices by world region can be separated into place of origin, i.e. it is possible to fill all cells in the grey shaded area in Table 1 by using export information from the UK and from the three regions. This can be done by estimating the imports matrix into region a from region b by first assuming imports from regions b, c and d have the same structure as the global imports into region a (of which data is available), and then balancing against the known exports of regions b, c and d. Due to the initial paucity of data on other regions imports matrices, and the limited effect it has on UK emissions, this has not been included in this version of the UK-MRIO 1 model, but may be included in later versions and will enable the estimation of flows of emissions between the various other regions of the world.

[14] 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 (see page 41 and following).

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

outnumber external constraints, resulting in the system being underdetermined, that is exhibiting too many degrees of freedom to be solved analytically.[16] The two most prominent numerical approaches for reconciling such an underdetermined system are probably the RAS method, and constrained optimisation.

During the past 40 years, both approaches have successfully tackled a number of challenges, leading to a number of useful features[17]: Ideally, the technique should

- incorporate constraints on arbitrarily sized and shaped subsets of matrix elements, instead of only fixing row and column sums;
- allow considering the reliability of the initial estimate;
- allow considering the reliability of external constraints;
- be able to handle negative values and to preserve the sign of matrix elements if required;
- be able to handle conflicting external data.

While all criteria have been addressed by constrained optimisation methods, there is currently no RAS-type technique that satisfies the last criterion. In particular the inability of RAS to deal with conflicting external data represents a considerable drawback for practice, because for most statistical agencies such data are often rather the norm than the exception.

The most simple case of conflicting data is probably a situation in which two data sources are located that prescribe two different values for the same matrix entry, resulting in inconsistent constraints. When faced with such constraints, existing RAS variants adjust the respective matrix element in turn to both directly conflicting values, and thus enter into oscillations without ever converging to a satisfactory solution.

More generally, sets of external data can be conflicting indirectly amongst each other. In practice, indirect conflict might present itself for example when on one hand, data on final demand and output of iron ore suggest a certain intermediate demand of iron ore, however on the other hand this intermediate demand is too large to be absorbed by the iron and steel manufacturing sector. Further examples involving conflicting external information are GDP

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[16] A sensitivity analysis based on Monte-Carlo simulation will be carried out in 2008 to test the stability of the results.

[17] (Lahr and de Mesnard 2004) provide a recent overview of extensions to the classic RAS technique.

measures[18], and multi-national and regional input-output systems. In practice, such inconsistencies are often traced and adjusted manually by statisticians.[19]

In this work we use a new RAS variant that is able to handle conflicting external data and inconsistent constraints. We achieve this capability by introducing standard error estimates for external data. We build on previous RAS variants that satisfy the remaining criteria, and thus arrive at a RAS-type method that matches the capabilities of constrained optimisation. We will refer to this method as CRAS (Conflicting RAS). The detailed CRAS procedures are described in Appendix D: Matrix Balancing with CRAS on page 60.

3 Results

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.[20] 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 (for methodological details see Section 12, Appendix E: Production of Symmetric Input-Output Tables on page 68). We have also estimated imports

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[18] (Barker et al. 1984, p.475) write: "… we observed that the income, expenditure, production and financial estimates of data are typically inconsistent. The presence of such accounting inconsistencies emphasises the unreliable nature of economic data." See also (Smith et al. 1998).

[19] (Barker et al. 1984, p.475) remark that "…trading off the relative degrees of uncertainty of the various data items in the system in order to adjust the prior data to fit the accounting identities […] is essentially what national income accountants do during the last stages of compiling the accounts when faced mith major discrepancies between data from different sources". (Dalgaard and Gysting 2004a) (p. 170) from Statistik Denmark report that many analysts responsible for compiling input-output tables favour manual adjustment, because "based on the experience that many errors in primary statistics are spotted in the course of a balancing process that is predominantly manual, compilers are typically convinced that a (mainly) manual balancing process yields results of higher quality than those emanating from a purely automatic balancing of the accounts. From that point of view, the resources involved in manual balancing are justified as a very efficient consistency check on the accounts."

[20] 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, see footnote 52.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.

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.[21] 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 2007a).

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

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[21] 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.

country (e.g. the UK) wherever these are consumed (either in the UK or exported). This report refers to these emissions as the '**UNFCCC Inventory'**

Although the national totals submitted to the UNFCCC do not, by international agreement, include emissions from international aviation and shipping, an estimate of these can be included in order to calculate the total emissions produced by a country's activities[22]. This report refers to these estimates as '**producer emissions (PE)**' – also sometimes referred to as '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 three approaches serve different purposes, have different applications and complement each other. The UK's UNFCCC Inventory is a legal reporting requirement. Its coverage corresponds to UK political jurisdiction and therefore the area over which policies introduced by the UK Government have direct effect. The UNFCCC is the international treaty that provides the framework for agreeing targets for emissions reduction. Parties to the UNFCCC and the Kyoto Protocol (which is a Protocol to the UNFCCC) have recognised the need for deep cuts in global emissions and the need for nationally appropriate action by developed and developing countries and are aiming to reach agreement on future action in 2009.

The PE indicator 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. The CE indicator can help to identify the driving forces behind changes in the worldwide impact of emissions from UK consumption patterns. The UNFCCC national total and the PE and CE 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 UNFCCC and associated legal instruments, and the world trade regime.

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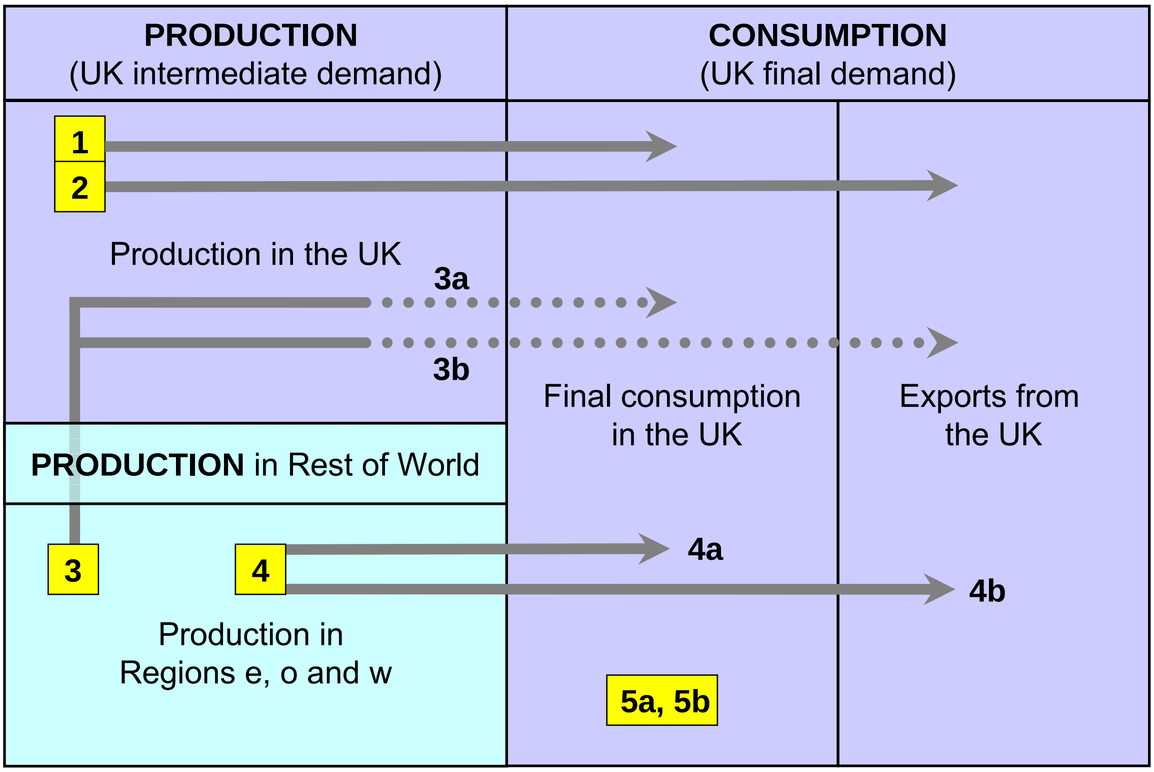
[22] Estimates of emissions produced by UK residents are provided each year as part of the Environmental Accounts published by the ONS (ONS 2007b). They are based upon the UK's Greenhouse Gas Emissions Inventory with adjustments for emissions from UK operators of international aviation and shipping (DEFRA 2007). See also Table 2 which shows the bridging between the different GHG accounts. The UNFCCC Inventory contains estimates of emissions due to fuel loaded in the UK onto international shipping and aircraft, but only as an information item; these emissions are not, by international agreement, included in national totals submitted to the UNFCCC.

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 2.



Arrows should be read as **"Emissions generated by** [*beginning of arrow*] **attributed to** [*end of arrow*]**"**

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

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

Figure 2: Depiction of emissions occurring through UK economic activity, including trade, and different principles of emissions accounting (Region e = OECD Europe, Region o = OECD non-Europe, Region w = non-OECD countries)

Legend to Figure 2:

1 UK production emissions, including international aviation and shipping provided by UK operators, attributable to UK final consumption,

2 UK production emissions attributable to exports

3a Imported emissions through intermediate consumption of UK industry attributable to UK final consumption

3b Imported emissions through intermediate consumption of UK industry attributable to UK exports

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

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

5a UK emissions generated by households not from private motoring (e.g. housing)

5b UK emissions generated by households from private motoring

Producer Emissions (PE): A production-based indicator (emissions accounting based on the producer principle) adds together all emissions that are generated by UK resident units, including international aviation and shipping emissions from UK registered operators, i.e. **1 + 2 + 5a + 5b** (blue shaded areas in Figure 2; for data sources see the section on 'Carbon dioxide emissions and intensities' on page 57).

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 2), i.e. **1 + 3a + 4a + 5a + 5b**.

UNFCCC national total: This is calculated as the emissions occurring within the territory of the UK, including aviation and shipping between UK destinations. The UNFCCC national total is reconcilable with PE by means of the bridging data shown in Table 2.

Emissions Embedded[23] *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 (final demand from the rest of the world) and occur mostly on 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**.

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

The method of allocation for CE and PE is driven by consumption, as all emissions are ultimately allocated to final demand (all arrows in the figure end in the UK final demand box). The UNFCCC national total is driven by territorial definition.

Table 2 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 emissions or the UNFCCC national total (in 2004, CE are 132 Mt or 21% higher than PE and over 200 Mt or 37% higher than the national total reported to the UNFCCC, including overseas territories, see also Figure 3).
- Consumer emissions have risen steadily over the period and are now 18% higher than in 1992, while the national total emissions reported to the UNFCCC have declined by 5%.
- 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. This is also depicted in Figure 4.
- EEI from the Rest of the World were about half the total in 1992 and have increased markedly in recent years (see Table 5 and text below).

Table 2: 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

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
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 not due to travel (e.g. housing) (5a) [24]	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 due to travel (5b) [24]	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
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**

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[24] 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 57 and following.

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
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 (-) [25]	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
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 the emissions reported to the UNFCCC; see Figure 3.

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[25] 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.

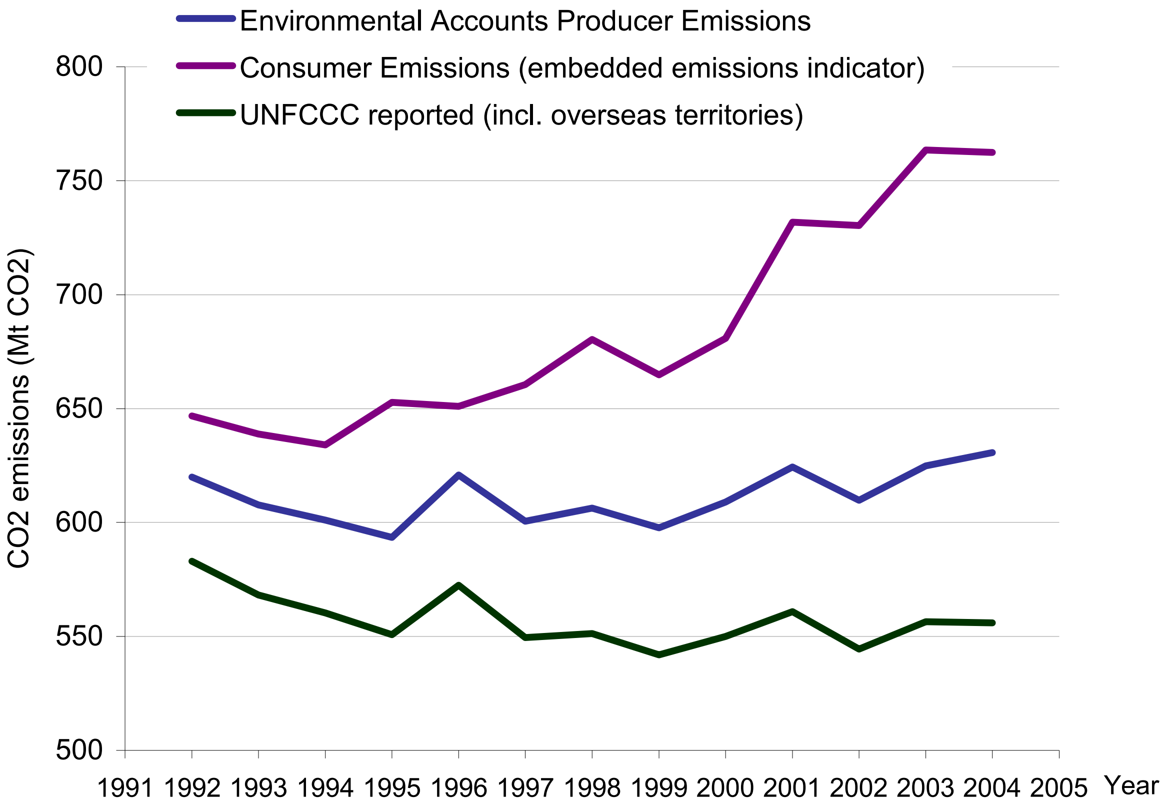

Figure 3: Development of UK CO_2 emissions from 1992 to 2004 according to different accounting principles
(note that the vertical scale doesn't start at zero).

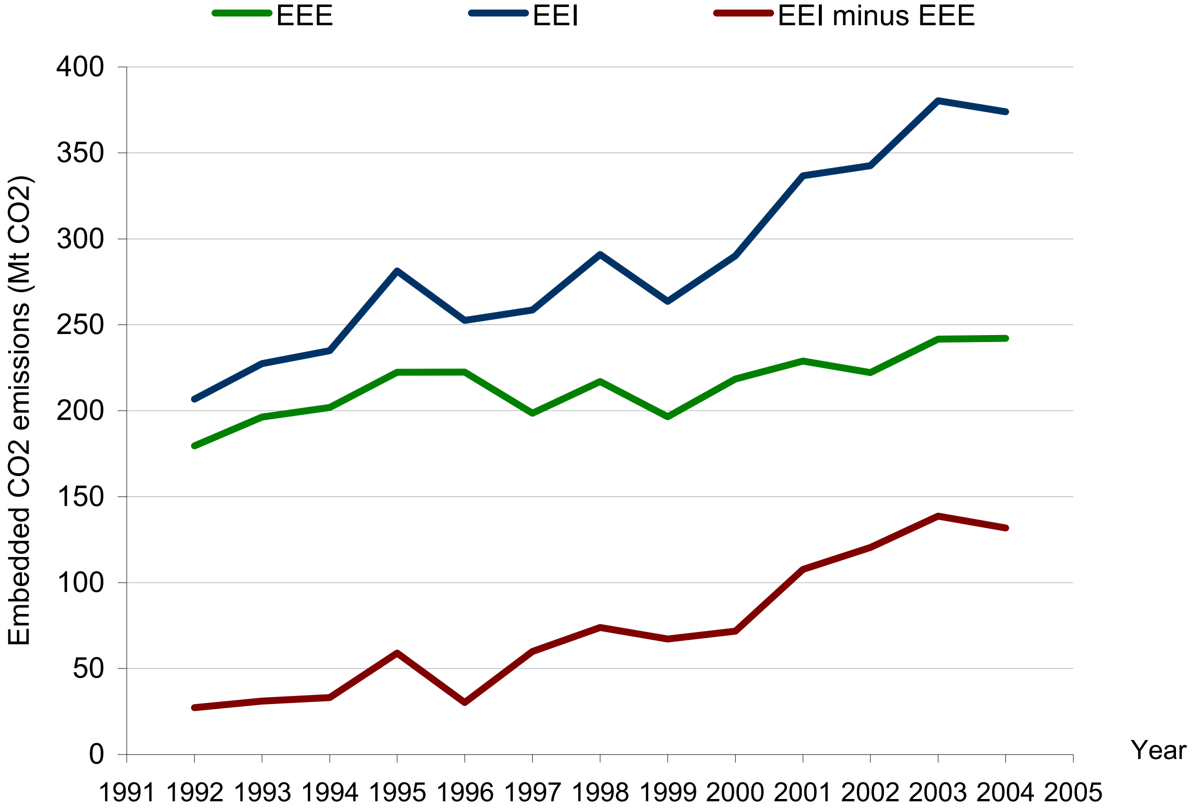

Figure 4: **CO_2 emissions embedded in total UK imports (EEI), total UK exports (EEE) and the difference EEI-EEE** (equal to –BEET) **from 1992 to 2004**

The increase of embedded emissions over time can be compared with a general increase in the trade of goods and services, see Figures 5. 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 (Figure 4) 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 F: Detailed Results for CO2 Emissions Embedded in UK Trade on page 72.

Figures 5: **Volume of UK trade in goods and services from 1995 to 2005 (lines) and balance of trade (columns) (ONS 2006a)**

Table 2 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.[26] However, this task was beyond the scope of the project.

Figure 6 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

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[26] 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.

partners such as Japan and the US towards newly emerging economies like China and Eastern European countries. This is described in more detail in the Appendix on page 53 (Change of trade in goods between 2002 and 2003).

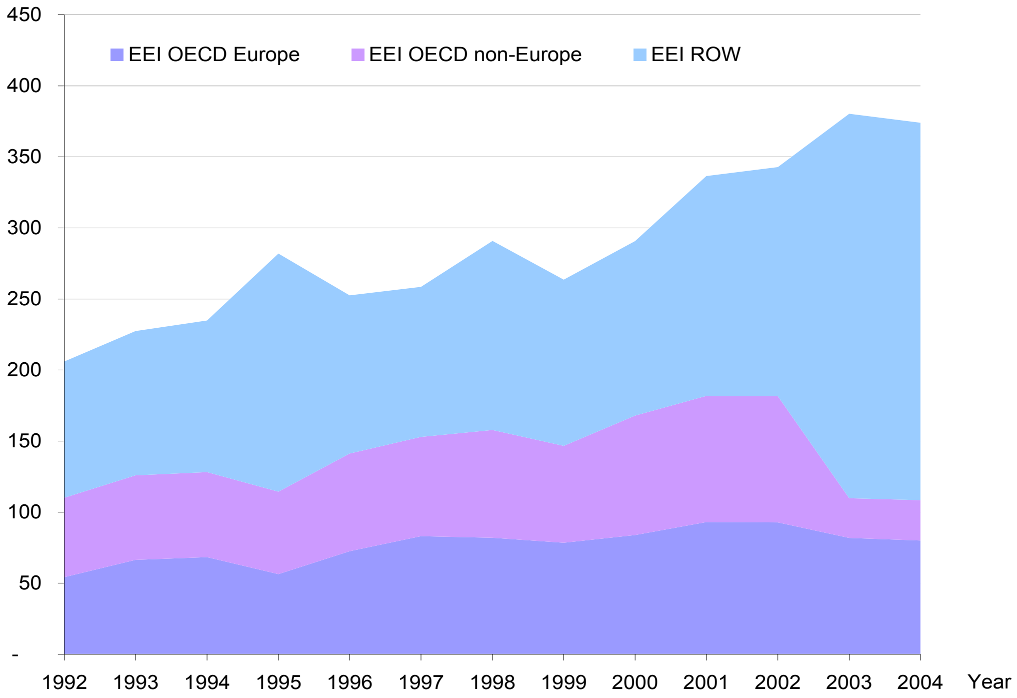

Figure 6: Origin of CO_2 emissions embedded in imports to the UK (in Mt of CO_2)

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 3).

Table 3: 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. 2008).

4 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 (only one column of imports matrices is needed in Eq. 1). 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 (see Appendix C: Data Sources and Data Preparation: Carbon dioxide emissions and intensities, page 57).

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 (see Section 'Carbon dioxide emissions and intensities' on page 57).

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 Section 10 (Appendix C: Data Sources and Data Preparation).

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.

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. 2006a, 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.

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).

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[27], thus providing much better sector specifity of CO_2 emissions and other environmental load factors. Once available, data from the European EXIOPOL project[28] can be used to make the data and modelling basis for European countries more consistent and accurate. For world regions,

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

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

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 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).

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).

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[29]. With

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[29] https://www.gtap.agecon.purdue.edu/databases/v6/v6_sectors.asp

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.

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 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.

Publications

Last but not least, we suggest that the results from the current UK-MRIO 1 model be published in two ways. First, academic publications in peer-reviewed, scientific journals should be sanctioned and supported in order to get critical feedback on the methodology from the wider scientific community. Second, 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.

The original project requirements were surpassed with the calculation of a complete time series of trade embedded CO_2 emissions from 1992 to 2004. The UK-MRIO 1 model produces results that are in line with those from other models and research groups and further research is recommended to make the model even more robust and relevant for UK (environmental) policy.

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.

7 Acknowledgements

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Three coefficient matrices for OECD Europe, OECD non-Europe and non-OECD countries were kindly provided by The Netherlands Environmental Assessment Agency (MNP) for the years 1997 and 2001 (Wilting 2007).

8 Appendix A: Research Contacts

For an effective exchange of information on current MRIO modelling research worldwide, the project team has established personal contacts with other major institutes and researchers involved in this type of research, including

- Norwegian University of Science and Technology (NTNU), Trondheim, Norway: Dr Glen Peters
- Netherlands Environmental Assessment Agency (MNP), AH Bilthoven, The Netherlands: Dr Harry Wilting
- Sustainable Europe Research Institute (SERI), Vienna, Austria: Dr Stefan Giljum
- TNO, Delft, The Netherlands: Mr Arnold Tukker
- Geneva International Academic Network, University of Geneva (Unige): Mr Damien Friot
- Rütter + Partner, Rüschlikon, Switzerland: Dr. Carsten Nathani

9 Appendix B: Review of Literature on EET models

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. 2006a).

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.

(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' [30]. 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 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)[32]. 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.

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

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

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

10 Appendix C: Data Sources and Data Preparation

UK input-output data

One important part of the work involves the provision of meaningful initial data. The closer these initial estimates are to the 'real' data, the more accurate the balanced results will become. The starting basis for our calculations in this project were the currently available input-output data from ONS in the form of Supply and Use Tables.[33] Additional information such as the transition matrix from basic to purchaser's prices in the Analytical Tables 1995 form other crucial information about the structure of imports and other data.

In the UK, input-output data are collated and published regularly by the Office for National Statistics as part of the National Accounting framework (ONS 2006b), (Mahajan 2006).[34] The data are presented in various formats of which those with the highest numbers of sectors and detailed inter-industry transactions including those with foreign countries are most relevant for this project.[35] For the years from 1992 to 2004 the following tables are currently publicly available (ONS 2007c) (numbers in brackets show the numbers of sectors or headings in the tables; excluding totals and sub-totals):

- ONS Table 1: Domestic output at basic prices (123)
- ONS Table 2: Supply of products in basic and purchasers' prices, including trading margins and taxes less subsidies on products (123)

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[33] Input-Output (IO) Analytical Tables (ATs) are derived from annual IO Supply and Use Tables (SUTs). The SUTs provide a picture of the flows of products and services in the economy for a single year. They show the composition of uses and resources across institutional sectors and the inter-dependence of industries. ATs are, in essence, a combination of the separate Supply and Use Tables into a symmetric matrix, showing separately the consumption of domestically produced and imported goods and services (Ruiz and Mahajan 2002). The ATs are extended from 123 to 138 groups by separating components of the non-market output produced by Government and NPISHs (Non-Profit Institutions Serving Households) from the output produced by the market sectors, in order to show their different input structures. The ATs from ONS also provide further analytical information such as the Matrix of Coefficients and the Leontief Inverse.

[34] See http://www.statistics.gov.uk/inputoutput.

[35] http://www.statistics.gov.uk/about/methodology_by_theme/inputoutput/latestdata.asp. Due to an ongoing major programme of modernisation of the UK National Accounts, the annual updating of the accounts in the *Blue Book 2007* through the existing supply and use tables is not taking place in 2007 and the latest annual benchmark data will not be incorporated until 2008. In 2007 ONS is not producing Input-Output Annual Supply and Use Tables or Input-Output Analyses for the year 2005 (Beadle 2007).

- ONS Table 3a: Demand for products - The 'Combined Use' matrix - Intermediate demand (123 x 124) (all intermediate consumption at purchasers' prices, except of Gross Value Added and Total Output which are at basic prices)
- ONS Table 3b: Demand for products - The 'Combined Use' matrix - Final demand (123 x 11) (all at purchasers' prices)
- ONS Table 8: Summary analysis of domestic output at basic prices (supply matrix, 30 x 30)

Additional IO analyses (not relevant for the current project):

- ONS Table 4: Household final consumption expenditure by functional heading (123 x 43)
- ONS Table 5: General government final consumption by type of service (123 x 8)
- ONS Table 6: Gross fixed capital formation (123 x 39)
- ONS Table 7: Production accounts by sector and for the whole economy (summary table)

Expanding supply tables

For the purpose of this project it is advantageous to have initial estimates of supply tables in 123 sector breakdown. Published data however show complete supply tables by 30 industries only (ONS Table 8) and much of the data even at this level of aggregation is considered disclosive. A request to ONS to provide supply tables at 123 industries by 123 products was not granted on the grounds that this would be contrary to current statistics legislation[36], even on the proviso that they are not published (Gazley 2007).

We have therefore reverted to Eurostat which also publishes these tables (Eurostat 2007). The IO data from ONS is consistent with the European System of Accounts (ESA 95) and is regularly submitted to Eurostat. However, the Eurostat publications show supply tables in a 59 sector resolution and thus in a more detailed format than the 30 sector supply tables published by ONS. These 59x59 supply tables are available for the year 1995 to 2004 and have been expanded to 123x123 tables by using the following procedure.

Suppressed (confidential) data points were estimated and filled in manually in the original 59x59 Eurostat supply tables in such a way that industry and commodity totals would change less than 1% and that the highest value in any one row or column would always be at the crossing of industry and corresponding commodity (diagonal of primary products). These tables were

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[36] This policy is outlined on page 301 of the UK Input-Output publication (ONS 2006b).

then expanded to 123x123 sectors by using total output of industries and commodities as given in ONS Table 2. Vertical expansion from 59 to 123 sectors was done by applying the proportions of total domestic supply of 123 products to all rows of the supply matrix. Accordingly, horizontal expansion was performed by applying the proportions of total output of 123 industries to all columns of the supply matrix. Information on the principal product as a percentage of total industry output and of total commodity output (i.e. the proportion of diagonal vs non-diagonal elements, provided in ONS Table 2) was then used as a constraint for balancing the supply tables.

Creating domestic use tables in basic prices

Combined use tables for intermediate and final demand are provided by ONS in 123 sector format (ONS Tables 3a and 3b; (ONS 2006b). Two modifications need to be made before these tables can be used in the MRIO model; they need be converted from purchasers' prices to basic prices and imports need to be subtracted in order to obtain the domestic use tables for intermediate and final demand ($\mathbf{U}^{uu}$ and $\mathbf{y}^{u}$ in Table 1). The 'Transition matrix' published by ONS in the 'UK Input-Output Analytical Tables 1995' achieves both steps in one go by combining imports, trading margins and taxes less subsidies in one table (Ruiz and Mahajan 2002). We use this Transition matrix from 1995 for two purposes, a) to create the initial estimates of the imports matrices $\mathbf{U}^{eu}$, $\mathbf{y}^{eu}$, $\mathbf{U}^{ou}$, $\mathbf{y}^{ou}$, $\mathbf{U}^{wu}$, $\mathbf{y}^{wu}$, and b) to derive a domestic use matrix in basic prices for each year 1992 to 2004. More specific information, such as transition and/or imports matrices for years other than 1995 – which would have made our initial estimates more accurate – was not available from ONS (Mahajan 2007b), (see also Druckman et al. 2007, pp11).

Whilst the Use and Transition tables are provided in product by industry form, the published Imports table is in product by product form, which according to (Ruiz and Mahajan 2002) was calculated by applying RAS to known product column totals of a product by industry table. As a first step, hence, the imports table was necessarily re-engineered into a product by industry table by re-applying RAS to the published industry column totals. The resulting product by industry Imports table was then subtracted from the published product by industry Transition matrix to obtain a Transition matrix that referred only to Distributors' trading margins and Taxes less subsidies on products. Finally, the domestic Use table in basic prices was obtained by subtracting the Transition and Imports tables from the original Use table.

All UK input-output tables were left in current years prices.

The lack of structural data on imports and margins for any year other than 1995 necessitated the assumption that there had been no change in the relative amount consumers pay/receive in imports, taxes/subsidies and distribution margins from 1995 to other years.[37] The total amount of imports, taxes/subsidies and margins of each product, is, however, known, and included as a constraint on the data.

The method to split up the total imports matrix into contributions from the three world regions is described on pp51 (Trade data).

Non-UK (Rest of the World) input-output data

There are only a few databases worldwide that hold input-output tables for the whole or large regions of the world economy. The most important are OECD, GTAP, IDE-JETRO and Eurostat.[38] In the following we examine the suitability of those databases for our ROW approximation.

The OECD Input-Output Database has recently been updated with the 2006 edition (Ahmad et al. 2006; Wixted et al. 2006; Yamano and Ahmad 2006). The first edition of this collection of IO tables dates back to 1995 and covered 10 OECD countries spanning the period 1968 to 1990. The first update to this was the 2002 edition of the database, which increased the country coverage to 18 OECD and 2 large non-OECD countries, spanning the period 1992 to 1997. The 2006 edition has continued this expansion and includes 37 countries (28 OECD and 9 non-OECD) further strengthening the ability of the database to allow the analysis of global issues. These latest tables are based around the year 2000 for most countries, though for some, more recent years are provided (for example, 2003 for Mexico). Figure 7 shows the coverage of global GDP of the respective editions of OECD IO tables. For a broad overview of potential uses of 'harmonised' Input-Output tables see (Wixted et al. 2006).

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[37] Note that this problem (the difficulty of converting Use tables from purchasers' to basic prices and from combined to domestic layout because of lack of published data due to confidentiality guidelines being followed by ONS) is also well documented by (Druckman et al. 2007).

[38] Compare with the summary on databases of international input-output transactions from (Wixted et al. 2006: 12-14).

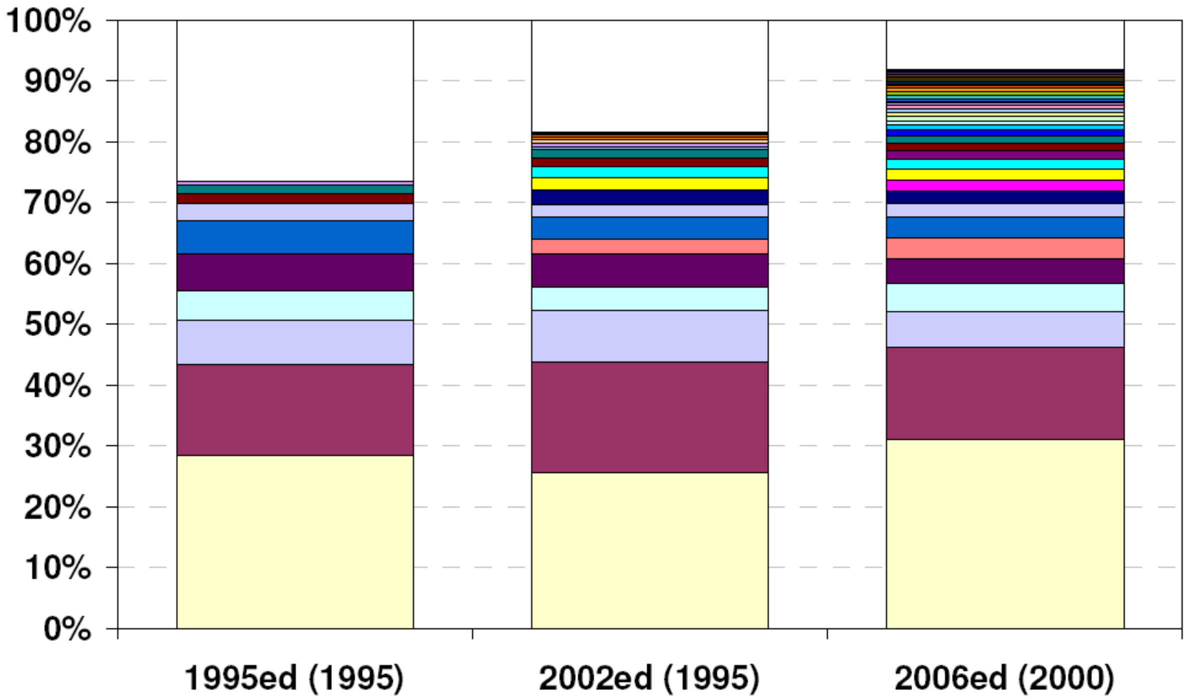

Figure 7: **OECD IO Database of global GDP by edition (from (Ahmad et al. 2006; Yamano and Ahmad 2006).**

The OECD database however does not offer aggregated IO tables for world regions or even the whole world economy. For this purpose, individual tables would have to be aggregated separately.

The Institute of Developing Economies (IDE-JETRO, http://www.ide.go.jp) offers a database of international input-output tables for Asia and the US for the years 1985, 1990, 1995 and 2000. The general layout is depicted in Table 4 (the most detailed industrial classification comprises 76 sectors.). The tables also include import and export matrices for Hong Kong, the EU and the “Rest of the World" but obviously this is not the same as technology matrices. Basically, IDE-JETRO define the ROW matrix as a residual of import matrices from the national IO tables after separating out all the import matrices from the member countries[39], and treat it as exogenous data to the Leontief inverse system. Henceforth, an A matrix for the ROW is not estimated (Inomata 2007).

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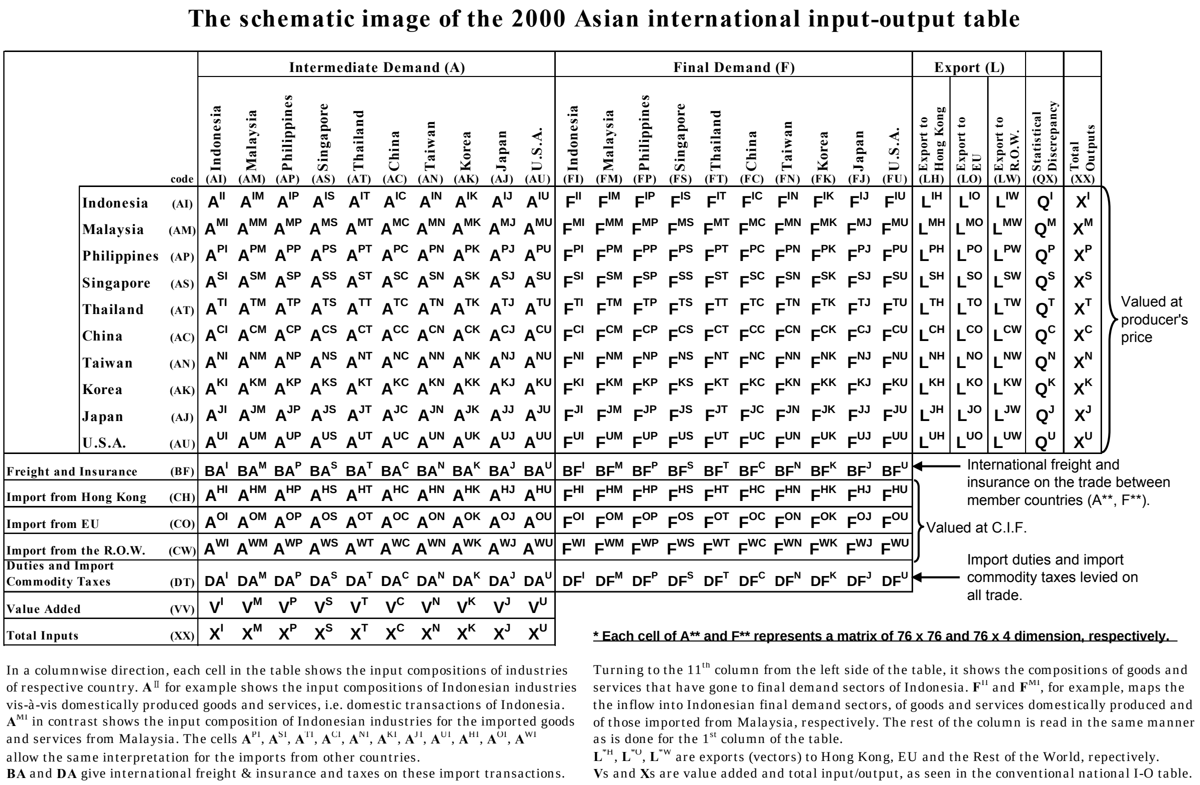
[39] Japan, USA, China (mainland), Korea, Taiwan, Indonesia, Malaysia, Thailand, the Philippines, Singapore, Hong Kong, and EU.

Table 4: Schematic illustration of the 2000 Asian international input-output table from IDE-JETRO (Inomata 2007).



The schematic image of the 2000 Asian international input-output table

		Intermediate Demand (A)										Final Demand (F)										Export (L)				
	code	Indonesia (AI)	Malaysia (AM)	Philippines (AP)	Singapore (AS)	Thailand (AT)	China (AC)	Taiwan (AN)	Korea (AK)	Japan (AJ)	U.S.A. (AU)	Indonesia (FI)	Malaysia (FM)	Philippines (FP)	Singapore (FS)	Thailand (FT)	China (FC)	Taiwan (FN)	Korea (FK)	Japan (FJ)	U.S.A. (FU)	Export to Hong Kong (LH)	Export to EU (LO)	Export to R.O.W. (LW)	Statistical Discrepancy (QX)	Total Outputs (XX)
Indonesia	(AI)	A^{II}	A^{IM}	A^{IP}	A^{IS}	A^{IT}	A^{IC}	A^{IN}	A^{IK}	A^{IJ}	A^{IU}	F^{II}	F^{IM}	F^{IP}	F^{IS}	F^{IT}	F^{IC}	F^{IN}	F^{IK}	F^{IJ}	F^{IU}	L^{IH}	L^{IO}	L^{IW}	Q^{I}	X^{I}
Malaysia	(AM)	A^{MI}	A^{MM}	A^{MP}	A^{MS}	A^{MT}	A^{MC}	A^{MN}	A^{MK}	A^{MJ}	A^{MU}	F^{MI}	F^{MM}	F^{MP}	F^{MS}	F^{MT}	F^{MC}	F^{MN}	F^{MK}	F^{MJ}	F^{MU}	L^{MH}	L^{MO}	L^{MW}	Q^{M}	X^{M}
Philippines	(AP)	A^{PI}	A^{PM}	A^{PP}	A^{PS}	A^{PT}	A^{PC}	A^{PN}	A^{PK}	A^{PJ}	A^{PU}	F^{PI}	F^{PM}	F^{PP}	F^{PS}	F^{PT}	F^{PC}	F^{PN}	F^{PK}	F^{PJ}	F^{PU}	L^{PH}	L^{PO}	L^{PW}	Q^{P}	X^{P}
Singapore	(AS)	A^{SI}	A^{SM}	A^{SP}	A^{SS}	A^{ST}	A^{SC}	A^{SN}	A^{SK}	A^{SJ}	A^{SU}	F^{SI}	F^{SM}	F^{SP}	F^{SS}	F^{ST}	F^{SC}	F^{SN}	F^{SK}	F^{SJ}	F^{SU}	L^{SH}	L^{SO}	L^{SW}	Q^{S}	X^{S}
Thailand	(AT)	A^{TI}	A^{TM}	A^{TP}	A^{TS}	A^{TT}	A^{TC}	A^{TN}	A^{TK}	A^{TJ}	A^{TU}	F^{TI}	F^{TM}	F^{TP}	F^{TS}	F^{TT}	F^{TC}	F^{TN}	F^{TK}	F^{TJ}	F^{TU}	L^{TH}	L^{TO}	L^{TW}	Q^{T}	X^{T}
China	(AC)	A^{CI}	A^{CM}	A^{CP}	A^{CS}	A^{CT}	A^{CC}	A^{CN}	A^{CK}	A^{CJ}	A^{CU}	F^{CI}	F^{CM}	F^{CP}	F^{CS}	F^{CT}	F^{CC}	F^{CN}	F^{CK}	F^{CJ}	F^{CU}	L^{CH}	L^{CO}	L^{CW}	Q^{C}	X^{C}
Taiwan	(AN)	A^{NI}	A^{NM}	A^{NP}	A^{NS}	A^{NT}	A^{NC}	A^{NN}	A^{NK}	A^{NJ}	A^{NU}	F^{NI}	F^{NM}	F^{NP}	F^{NS}	F^{NT}	F^{NC}	F^{NN}	F^{NK}	F^{NJ}	F^{NU}	L^{NH}	L^{NO}	L^{NW}	Q^{N}	X^{N}
Korea	(AK)	A^{KI}	A^{KM}	A^{KP}	A^{KS}	A^{KT}	A^{KC}	A^{KN}	A^{KK}	A^{KJ}	A^{KU}	F^{KI}	F^{KM}	F^{KP}	F^{KS}	F^{KT}	F^{KC}	F^{KN}	F^{KK}	F^{KJ}	F^{KU}	L^{KH}	L^{KO}	L^{KW}	Q^{K}	X^{K}
Japan	(AJ)	A^{JI}	A^{JM}	A^{JP}	A^{JS}	A^{JT}	A^{JC}	A^{JN}	A^{JK}	A^{JJ}	A^{JU}	F^{JI}	F^{JM}	F^{JP}	F^{JS}	F^{JT}	F^{JC}	F^{JN}	F^{JK}	F^{JJ}	F^{JU}	L^{JH}	L^{JO}	L^{JW}	Q^{J}	X^{J}
U.S.A.	(AU)	A^{UI}	A^{UM}	A^{UP}	A^{US}	A^{UT}	A^{UC}	A^{UN}	A^{UK}	A^{UJ}	A^{UU}	F^{UI}	F^{UM}	F^{UP}	F^{US}	F^{UT}	F^{UC}	F^{UN}	F^{UK}	F^{UJ}	F^{UU}	L^{UH}	L^{UO}	L^{UW}	Q^{U}	X^{U}
Freight and Insurance	(BF)	BA^{I}	BA^{M}	BA^{P}	BA^{S}	BA^{T}	BA^{C}	BA^{N}	BA^{K}	BA^{J}	BA^{U}	BF^{I}	BF^{M}	BF^{P}	BF^{S}	BF^{T}	BF^{C}	BF^{N}	BF^{K}	BF^{J}	BF^{U}					
Import from Hong Kong	(CH)	A^{HI}	A^{HM}	A^{HP}	A^{HS}	A^{HT}	A^{HC}	A^{HN}	A^{HK}	A^{HJ}	A^{HU}	F^{HI}	F^{HM}	F^{HP}	F^{HS}	F^{HT}	F^{HC}	F^{HN}	F^{HK}	F^{HJ}	F^{HU}					
Import from EU	(CO)	A^{OI}	A^{OM}	A^{OP}	A^{OS}	A^{OT}	A^{OC}	A^{ON}	A^{OK}	A^{OJ}	A^{OU}	F^{OI}	F^{OM}	F^{OP}	F^{OS}	F^{OT}	F^{OC}	F^{ON}	F^{OK}	F^{OJ}	F^{OU}					
Import from the R.O.W.	(CW)	A^{WI}	A^{WM}	A^{WP}	A^{WS}	A^{WT}	A^{WC}	A^{WN}	A^{WK}	A^{WJ}	A^{WU}	F^{WI}	F^{WM}	F^{WP}	F^{WS}	F^{WT}	F^{WC}	F^{WN}	F^{WK}	F^{WJ}	F^{WU}					
Duties and Import Commodity Taxes	(DT)	DA^{I}	DA^{M}	DA^{P}	DA^{S}	DA^{T}	DA^{C}	DA^{N}	DA^{K}	DA^{J}	DA^{U}	DF^{I}	DF^{M}	DF^{P}	DF^{S}	DF^{T}	DF^{C}	DF^{N}	DF^{K}	DF^{J}	DF^{U}					
Value Added	(VV)	V^{I}	V^{M}	V^{P}	V^{S}	V^{T}	V^{C}	V^{N}	V^{K}	V^{J}	V^{U}															
Total Inputs	(XX)	X^{I}	X^{M}	X^{P}	X^{S}	X^{T}	X^{C}	X^{N}	X^{K}	X^{J}	X^{U}															

Valued at producer's price

International freight and insurance on the trade between member countries (A**, F**).

Valued at C.I.F.

Import duties and import commodity taxes levied on all trade.

*** Each cell of A** and F** represents a matrix of 76 x 76 and 76 x 4 dimension, respectively.**

In a columnwise direction, each cell in the table shows the input compositions of industries of respective country. $\mathbf{A}^{II}$ for example shows the input compositions of Indonesian industries vis-à-vis domestically produced goods and services, i.e. domestic transactions of Indonesia. $\mathbf{A}^{MI}$ in contrast shows the input composition of Indonesian industries for the imported goods and services from Malaysia. The cells $\mathbf{A}^{PI}$, $\mathbf{A}^{SI}$, $\mathbf{A}^{TI}$, $\mathbf{A}^{CI}$, $\mathbf{A}^{NI}$, $\mathbf{A}^{KI}$, $\mathbf{A}^{JI}$, $\mathbf{A}^{UI}$, $\mathbf{A}^{HI}$, $\mathbf{A}^{OI}$, $\mathbf{A}^{WI}$ allow the same interpretation for the imports from other countries.
BA and **DA** give international freight & insurance and taxes on these import transactions.

Turning to the 11th column from the left side of the table, it shows the compositions of goods and services that have gone to final demand sectors of Indonesia. $\mathbf{F}^{II}$ and $\mathbf{F}^{MI}$, for example, maps the the inflow into Indonesian final demand sectors, of goods and services domestically produced and of those imported from Malaysia, respectively. The rest of the column is read in the same manner as is done for the 1st column of the table.
$\mathbf{L}^{*H}$, $\mathbf{L}^{*O}$, $\mathbf{L}^{*W}$ are exports (vectors) to Hong Kong, EU and the Rest of the World, repectively.
Vs and **X**s are value added and total input/output, as seen in the conventional national I-O table.

The European System of Accounts ESA 95 has established a compulsory transmission of tables of the input-output framework by the European Member States. In detail this concerns annual supply- and use-tables, five-yearly symmetric input-output tables, symmetric input-output tables of domestic production and symmetric input-output tables of imports. All these tables cover the period from 1995 onwards and are harmonised by Eurostat's standardised questionnaire, which distinguishes 60 products (classification CPA P60) and 60 industries (NACE Rev.1 A60). Currently, IO data are available for 24 European Member States and Norway.[40] However, there are no aggregated IO tables for parts or the whole of Europe.[41] See also (Huppes et al., 2006) for a critique of the IO data situation in Europe.

A linked IO model with world coverage is described by (Shimpo and Okamura 2006). According to this source, Keio University is compiling an inventory of IO

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[40] http://epp.eurostat.ec.europa.eu/pls/portal/url/page/PGP_DS_ESA_IOT/PGE_DS_ESA_01

[41] The Regional Economics Department at the University of Groningen offers some EU inter-country input-output tables for download (www.regroningen.nl/index_en.html), the most recent one from 1985 featuring six interlinked EU countries.

tables from more than 60 countries by sending questionnaires to national statistical offices in the world and conducting surveys on website. However, no more information could be retrieved from the website.

GTAP (Global Trade Analysis Project) is a global network of researchers and policy makers conducting quantitative analysis of international policy issues and is coordinated by the Center for Global Trade Analysis, Purdue University, USA (http://www.gtap.agecon.purdue.edu). Products from GTAP include data, models, and utilities for multi-region, applied general equilibrium analysis of global economic issues. The GTAP 6 data base (Dimaranan 2006) describes bilateral trade patterns, production, consumption and intermediate use of commodities and services of the global economy in 2001. The data is disaggregated to 57 sectors and 87 countries/regions and thus the data base is able to capture details of interactions between domestic sectors as well as international trading partners. Aggregated data (e.g. one large IO table of the world economy) is not available for GTAP 6, although two aggregations of the GTAP 5 data base can be purchased (10 sectors x 66 regions and 57 sectors x 10 regions). For a critical discussion of the quality and usefulness of GTAP data for MRIO modelling see (Peters 2007).

GTAP data are used in several studies with MRIO models for the calculation of impacts embedded in trade (Peters 2007; Wiedmann et al. 2007a). Whereas (Chung, 2005) aggregates the data into nine regions of the world, Nijdam and colleagues (Nijdam et al. 2005) construct technological matrices for three world regions from the GTAP input-output tables, representing OECD Europe, OECD non-Europe and non-OECD countries.[42]

The Netherlands Environmental Assessment Agency (MNP) (Wilting 2007) courteously provided us with the technical coefficient matrices for 1997 used in the study by (Nijdam et al. 2005) which are based on the GTAP 5 database as well as with a similar dataset for the year 2001 (based on the GTAP 6 database). These six technological matrices were derived from GTAP coefficient 'cost structure of firms' and distinguish 30 economic sectors. The coefficients include both domestic as imported inputs. By using these coefficients it is assumed that the imports of a certain region are produced with the technology of that region (Nijdam et al. 2005, p151).

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[42] A number of multi-region input-output models with world coverage using the GTAP database and results for environmental impacts embedded in trade have been presented very recently at the 16th International Input-Output Conference 2007 in Istanbul (http://www.io2007.itu.edu.tr). Full papers from this conference are not available yet at the time of completion of this draft final report.

Table 5: Country coverage of three world regions in the UK-MRIO 1 model as adopted from (Nijdam et al. 2005)

Region e	Region o	Region w
OECD Europe	**OECD non-Europe**	**non_OECD**
Austria	Canada	All other countries
Belgium	Mexico	
Czech Republic	United States	*(Note that this region includes the large economies of Russia, China, India etc as well as all countries that joined the European Union in 2004 and are not in the OECD, i.e. Cyprus, Estonia, Latvia, Lithuania, Malta and Slovenia)*
Denmark	Australia	
Finland	Japan	
France	Korea	
Germany	New Zealand	
Greece		
Hungary		
Iceland		
Ireland		
Italy		
Luxembourg		
Norway		
Poland		
Portugal		
Slovak Republic		
Spain		
Sweden		
Switzerland		
Turkey		
United Kingdom*)		

*) Due to the original model purpose of (Nijdam et al. 2005) the A matrix from Region e includes technical coefficients from the UK and excludes those from the Netherlands. However, CO_2 emissions were compiled differently in order to be more in line with the purpose of the UK-MRIO 1 model and thus include CO_2 emissions for the Netherlands and exclude those for the UK (see page 57).

We use the six tables to apply constraints to the MRIO for the three non-UK regions. Due to the lack of data for any years but 1997 and 2001, static technical coefficients are assumed for three time periods: 1997 and earlier (using 1997 technical coefficients); 1998-2000 (using average coefficients); and 2001 and later (using 2001 technical coefficient).

In terms of price conversions / adaptations we applied the following procedure:

- all UK input-output tables were left in current prices
- the tables for the three world regions were converted from current US$ to current £ by using purchasing power parity (PPP) data from OECD for the two years 1997 and 2001.
- for the other years (1992 to 1996, 1998 to 2000, 2002 to 2004) we used consumer price index (CPI) data from the OECD to correct for inflation. CPI data is available for the OECD EU, for total OECD, which was approximated to Non-EU OECD in this project, and for four major Non-

OECD trading partners, of which the average was used to estimate CPI data for the rest of the world in this project. Note that we don't use input-output data for years other than 1997 and 2001 but just correct the emissions intensities along the full time series.

Table 6: Concordance matrix between 123 sectors (ONS/IO data) and 30 sectors (world-region IO tables)

		1 Agriculture (arable farming)	2 Horticulture	3 Livestocks	4 Forestry, hunting and other agriculture	5 Fishery	6 Oil and gas extraction	7 Minerals extraction	8 Food production, from animals	9 Food production, non-animal	10 Beverages and tobacco	11 Textiles and clothes	12 Leather products	13 Wood and wood products	14 Paper, paperboard and publishing	15 Petroleum products
1	Agriculture, hunting and related service activities	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
2	Forestry, logging and related service activities	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
3	Fishing, operation of fish hatcheries and fish farm	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
4	Mining of coal and lignite; extraction of peat	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
5	Extraction of crude petroleum and natural gas; se	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
6	Mining of metal ores	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
7	Other mining and quarrying	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
8	Production, processing and preserving of meat an	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
9	Processing and preserving of fish and fish produc	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
10	Vegetable and animal oils and fats	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
11	Dairy products	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
12	Grain mill products, starches and starch products	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
13	Prepared animal feeds	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
14	Bread, rusks and biscuits; manufacture of pastry	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
15	Sugar	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
16	Cocoa; chocolate and sugar confectionery	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
17	Other food products	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
18	Alcoholic beverages	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
19	Production of mineral waters and soft drinks	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
20	Tobacco products	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
21	Preparation and spinning of textile fibres	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
22	Textile weaving	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
23	Finishing of textiles	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
24	Made-up textile articles, except apparel	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
25	Carpets and rugs	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
26	Other textiles	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
27	Knitted and crocheted fabrics and articles	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
28	Wearing apparel; dressing and dying of fur	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
29	Tanning and dressing of leather; manufacture of l	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
30	Footwear	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
31	Wood and wood products, except furniture	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
32	Pulp, paper and paperboard	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
33	Articles of paper and paperboard	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
34	Publishing, printing and reproduction of recorded	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
35	Coke, refined petroleum products and nuclear fue	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
36	Industrial gases, dyes and pigments	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	Other inorganic basic chemicals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	Other organic basic chemicals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	Fertilisers and nitrogen compounds	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	Plastics and synthetic rubber in primary forms	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		16 Chemicals, rubber and plastic products	17 Construction materials and mineral products n.e.c.	18 Ferrous and non-ferrous metals	19 Metal products	20 Machinery and electrotechnical appliances and equipment	21 Motor vehicles and other transport equipment	22 Furniture and other manufacturing industry	23 Electricity supply	24 Gas supply	25 Water extraction and supply	26 Construction and building installation	27 Trade	28 Transport	29 Business services	30 Government and public services
32	Pulp, paper and paperboard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	Articles of paper and paperboard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	Publishing, printing and reproduction of recorded	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	Coke, refined petroleum products and nuclear fue	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	Industrial gases, dyes and pigments	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	Other inorganic basic chemicals	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	Other organic basic chemicals	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	Fertilisers and nitrogen compounds	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	Plastics and synthetic rubber in primary forms	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	Pesticides and other agro-chemical products	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	Paints, varnishes and similar coatings, printing ink	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	Pharmaceuticals, medicinal chemicals and botani	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	Soap and detergents, cleaning and polishing prep	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	Other chemical products	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	Man-made fibres	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47	Rubber products	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	Plastic products	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	Glass and glass products	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
50	Ceramic goods	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
51	Bricks, tiles and construction products, baked in cl	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
52	Cement, lime and plaster	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
53	Articles of concrete, plaster and cement; cutting, s	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
54	Basic iron and steel and of ferro-alloys; manufactu	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
55	Basic precious and non-ferrous metals	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
56	Casting of metals	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
57	Structural metal products	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
58	Tanks, reservoirs and containers of metal; manufa	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
59	Forging, pressing, stamping and roll forming of me	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
60	Cutlery, tools and general hardware	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
61	Other fabricated metal products	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
62	Machinery for the production and use of mechani	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
63	Other general purpose machinery	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
64	Agricultural and forestry machinery	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
65	Machine tools	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
66	Other special purpose machinery	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
67	Weapons and ammunition	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
68	Domestic appliances not elsewhere classified	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
69	Office machinery and computers	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
70	Electric motors, generators and transformers; ma	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
71	Insulated wire and cable	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
72	Electrical equipment not elsewhere classified	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
73	Electronic valves and tubes and other electronic c	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
74	Television and radio transmitters and line for tele	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
75	Television and radio receivers, sound or video rec	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
76	Medical, precision and optical instruments, watch	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
77	Motor vehicles, trailers and semi-trailers	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
78	Building and repairing of ships and boats	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
79	Other transport equipment	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
80	Aircraft and spacecraft	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
81	Furniture	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
82	Jewellery and related articles; manufacture of mu	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
83	Sports goods, games and toys	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
84	Miscellaneous manufacturing not elsewhere class	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
85	Production and distribution of electricity	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
86	Gas; distribution of gaseous fuels through mains;	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
87	Collection, purification and distribution of water	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
88	Construction	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
89	Sale, maintenance and repair of motor vehicles, a	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
90	Wholesale trade and commission trade, except of	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
91	Retail trade, except of motor vehicles and motor c	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
92	Hotels and restaurants	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
93	Transport via railways	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
94	Other land transport; transport via pipelines	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
95	Water transport	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
96	Air Transport	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
97	Supporting and auxiliary transport activities; activi	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
98	Post and courier activities	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
99	Telecommunications	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
100	Financial intermediation, except insurance and pe	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
101	Insurance and pension funding, except compulso	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
102	Activities auxiliary to financial intermediation	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
103	Real estate activities with own property; letting of	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
104	Letting of dwellings, including imputed rent	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
105	Real estate activities on a fee or contract basis	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
106	Renting of machinery and equipment without oper	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
107	Computer and related activities	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
108	Research and development	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
109	Legal activities	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
110	Accounting, book-keeping and auditing activities;	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
111	Market research and public opinion polling; busine	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
112	Architectural and engineering activities and relate	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
113	Advertising	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
114	Other business services	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
115	Public administration and defence; compulsory so	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
116	Education	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
117	Human health and veterinary activities	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
118	Social work activities	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
119	Sewage and refuse disposal, sanitation and simila	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
120	Activities of membership organisations not elsewh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
121	Recreational, cultural and sporting activities	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
122	Other service activities	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
123	Private households with employed persons	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Trade data

International trade data are available from a variety of sources including ONS, Eurostat, OECD and UN statistics. In addition, and especially for the years 1999 to 2004, UK specific trade data are also available from HM Revenue & Customs, 'Statistics and Analysis of Trade Unit' (HMRC 2007) which formed the main data source for trade data used in this project.

However, when compiling the trade data we encountered major problems, e.g.

- trade in services is not included in the standard databases
- concordance matrices had to be constructed in order to convert the data to a 123 sector format
- data for the years 1996 to 1998 from HMRC was in a different classification than the data available from www.uktradeinfo.com (and had to be purchased).
- data for the years 1992 to 1995 were not available at all.

Trade in goods

We obtained data of *trade in goods* in 5 digits SITC (Standard International Trade Code) format from HM Revenue & Customs for the years of 1999-2004 (www.uktradeinfo.com). The dataset for each year is available for 240 countries on approximately 2,500 different products. According to the requirements for this project, we needed to compile the trade dataset in the format of three world regions by 123 economic sectors. A country concordance matrix was used to compile the 240 countries into the three regions – European OECD countries, Non-European OECD countries and the rest of the world (see Table 5). A commodity concordance matrix was used to convert the 2,500 products in SITC format into 123 input-output categories in terms of the "Classification of 123 Input-Output industry/product groups by Standard Industrial Classification (SIC) 2003 and NACE Revision 1.1" as provided in "UK input-output analysis – edition 2006"[43], and the concordance matrix between SITC and SIC 2003 as provided by Eurostat[44].

For the years of 1996-1998, data of *trade in goods* in 4 digits SITC format had to be purchased from HM Revenue & Customs. The dataset only provides the data (imports or exports) between the UK and the other countries which have

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[43] ONS website http://www.statistics.gov.uk/downloads/theme_economy/Input_Output_Analyses_2006_edition.pdf

[44] Eurostat website http://ec.europa.eu/eurostat/ramon/relations/index.cfm?TargetUrl=LST_REL&StrLanguageCode= EN&IntCurrentPage=2

trade transactions in particular commodities, but no data entry is made if there is no transaction (not even 'zero'). This results in an inconsistency of the country list in every product. For example, under the category of “growing of cereals and other crops”, the dataset provides the trade data for both France and Austria since the two countries have transactions with the UK for cereals products in a particular year. However, under the category of “farming of cattle, sheep, goats, horses, asses, mules and hinnies; dairy farming”, the dataset only shows the data for France but not Austria since Austria did not have trade transactions with the UK for this particular product. Therefore, the number of European countries which had the trade transaction with the UK for the category of “growing of cereals and other crops” is 9, but the number changes to 5 for the category of “farming of cattle, sheep, goats, horses, asses, mules and hinnies; dairy farming”. In order to compile the data to the standard format of three regions with 123 input-output sectors, we had to take five steps to achieve this. Firstly we sorted the dataset by country alphabetically and separated the trade data between EU OECD countries, Non-EU OECD countries and the rest of world in three different files. Secondly we sorted the data in each file by SITC category; and then run the subtotal for each SITC category; extracted and saved the subtotals to a new file for each region. Each subtotal contains the information of summation of each SITC product in all countries in each region. Thirdly we compared the SITC lists between the three regions (three different files); there are 1034 products categories in the list of EU OECD countries, 1030 categories in Non-EU OECD countries and 1028 categories in the rest of world. In order to make the lists consistent, we manually assigned “zeros” to the missing categories in Non-EU OECD countries and the rest of world lists to make a consistent list of SITC categories of 1034 for all regions. Fourthly we created a concordance matrix between the 4-digits SITC format (1034 sectors) with 123 IO sectors. At last, we distinguished between EU OECD countries, Non-EU OECD countries and the rest of world.

For the early years (1992-1995) there was no trade data available at all. Enquiries with professional data providers suggested by HMRC resulted in no response. Due to this unavailability of trade data on country level for these years we used a linear trendline from the year 1996 to 2004 and projected backwards the figures for each input-output sector between 1992 and 1995.

As a last step, we compared our dataset of *trade in goods* with the totals for imports in goods from the supply and use tables provided by ONS. The summation of the three regional trade data in each IO sector matches with the ONS totals for imports in the region of ±20% or better. In order to be consistent with IO data, we derived the percentage breakdown of each IO sector for the three regions for each year by using the compiled dataset of *trade in goods*;

then multiplied the percentage breakdown with the sectoral ONS total for imports in goods to generate the compiled *trade in goods* dataset in the format of three world regions by 123 sectors.

Change of trade in goods between 2002 and 2003

When looking at the origin of CO_2 emissions embedded in imports (EEI) to the UK over time (Figure 6 on page 26), a sudden change between the years 2002 and 2003 becomes apparent. EEI from non-European OECD countries dropped from 89 Mt CO_2 to 28 Mt CO_2, while EEI from ROW countries went up from 161 to 270 Mt CO_2 at the same time.

This phenomenon was investigated in detail and we found that the sudden change can be explained with a rapid shift in trade patterns. After excluding possible data artefacts such as suppressed data, missing data or a mismatch in classification concordance over time, we found a significant shift of trade from non-European OECD countries to non-OECD countries (ROW). Table 7 shows the imports of goods in £million on a SITC 2-digit level. The most significant changes have been highlighted in blue. Some of the products are associated with high values of embedded energy and carbon, like for example petroleum products, some chemical products, machinery and (transport) equipment.

Table 7: Imports of goods to the UK in 2002 and 2003 by region of origin (HMRC 2007) (important changes have been highlighted in blue)

Description SITC 2-digit level	**Imports in 2002**			**£million**	**Imports in 2003**			**£million**
	EU OECD	Non-EU OECD	Rest of world	**Total**	EU OECD	Non-EU OECD	Rest of world	**Total**
00: LIVE ANIMALS OTHER THAN ANIMALS OF DIVISION 03	151	92	106	**349**	184	16	148	**348**
01: MEAT & MEAT PREPARATIONS	2,247	257	387	**2,891**	2,679	46	641	**3,366**
02: DAIRY PRODUCTS & BIRDS' EGGS	1,218	97	10	**1,325**	1,460	30	48	**1,538**
03: FISH,CRUSTACEANS,MOLLUSCS & AQ.INVERTS & PREPS THE	351	487	601	**1,439**	343	65	1,031	**1,439**
04: CEREALS & CEREAL PREPARATIONS	1,069	128	113	**1,310**	1,149	81	161	**1,391**
05: VEGETABLES & FRUIT	2,937	450	1,141	**4,528**	3,233	103	1,595	**4,931**
06: SUGAR, SUGAR PREPARATIONS & HONEY	292	55	445	**792**	332	23	503	**858**
07: COFFEE, TEA, COCOA, SPICES & MANUFACTURES THEREOF	627	70	472	**1,169**	652	51	492	**1,195**
08: FEEDING STUFF FOR ANIMALS (NOT INC.UNMILLED CEREAL	347	171	239	**757**	407	9	486	**902**
09: MISCELLANEOUS EDIBLE PRODUCTS & PREPARATIONS	27	2	-	**29**	27	-	4	**31**
11: BEVERAGES	1,995	832	292	**3,119**	2,134	509	681	**3,324**
12: TOBACCO & TOBACCO MANUFACTURES	251	26	173	**450**	247	8	139	**394**
21: HIDES, SKINS & FURSKINS, RAW	35	14	12	**61**	38	5	18	**61**
22: OIL SEEDS & OLEAGINOUS FRUITS	66	86	136	**288**	51	14	204	**269**
23: CRUDE RUBBER (INCLUDING SYNTHETIC & RECLAIMED)	103	54	57	**214**	89	2	139	**230**
24: CORK & WOOD	692	168	461	**1,321**	766	59	635	**1,460**
25: PULP & WASTE PAPER	175	235	139	**549**	186	100	263	**549**
26: TEXTILE FIBRES NOT MANUFACTURED & THEIR WASTE ETC	167	113	118	**398**	151	16	207	**374**
27: CRUDE FERTILIZERS & CRUDE MINERALS (EXC FUELS ETC)	184	77	106	**367**	181	19	172	**372**
28: METALLIFEROUS ORES & METAL SCRAP	388	835	398	**1,621**	411	493	707	**1,611**
29: CRUDE ANIMAL & VEGETABLE MATERIALS N.E.S.	914	62	134	**1,110**	936	12	185	**1,133**
32: COAL, COKE & BRIQUETTES	54	312	537	**903**	53	223	748	**1,024**
33: PETROLEUM, PETROLEUM PRODUCTS & RELATED MATERIALS	1,444	3,961	2,726	**8,131**	1,667	7	8,065	**9,739**
34: GAS, NATURAL & MANUFACTURED	281	73	2	**356**	172	-	53	**225**
35: ELECTRIC CURRENT	189	-	-	**189**	171	-	-	**171**
41: ANIMAL OILS & FATS	33	24	3	**60**	37	3	26	**66**
42: FIXED VEGETABLE FATS & OILS, CRUDE,REFINED,FRACTIO	244	15	153	**412**	304	2	176	**482**
43: ANIMAL OR VEGETABLE FATS & OILS, PROCESSED, & WAXE	70	20	22	**112**	74	2	44	**120**
51: ORGANIC CHEMICALS	4,057	1,056	790	**5,903**	3,723	200	2,418	**6,341**
52: INORGANIC CHEMICALS	596	323	204	**1,123**	618	62	459	**1,139**
53: DYEING, TANNING & COLOURING MATERIALS	706	218	62	**986**	755	66	211	**1,032**
54: MEDICINAL & PHARMACEUTICAL PRODUCTS	5,211	1,715	633	**7,559**	5,967	528	1,883	**8,378**
55: ESSENTIAL OILS & PERFUME MATERIALS; TOILET PREPS E	1,889	525	170	**2,584**	2,104	134	583	**2,821**
56: FERTILIZERS (OTHER THAN THOSE OF GROUP 272)	120	44	95	**259**	150	5	186	**341**
57: PLASTICS IN PRIMARY FORMS	2,027	363	110	**2,500**	2,232	49	435	**2,716**
58: PLASTICS IN NON-PRIMARY FORMS	1,329	272	67	**1,668**	1,438	56	304	**1,798**
59: CHEMICAL MATERIALS & PRODUCTS N.E.S.	1,489	649	142	**2,280**	1,636	66	649	**2,351**
61: LEATHER, LEATHER MANUFACTURES N.E.S & DRESSED FURS	160	20	63	**243**	149	6	89	**244**
62: RUBBER MANUFACTURES N.E.S.	1,019	408	200	**1,627**	1,088	39	621	**1,748**
63: CORK & WOOD MANUFACTURES (EXCLUDING FURNITURE)	803	183	513	**1,499**	840	42	631	**1,513**
64: PAPER, PAPERBOARD & MANUFACTURES THEREOF	3,820	680	301	**4,801**	4,009	155	773	**4,937**
65: TEXTILE YARN, FABRICS, MADE UP ARTICLES ETC	2,455	657	1,226	**4,338**	2,428	275	1,563	**4,266**
66: NON-METALLIC MINERAL MANUFACTURES N.E.S.	1,793	1,479	3,015	**6,287**	1,815	1,038	3,664	**6,517**
67: IRON & STEEL	2,270	507	412	**3,189**	2,476	56	840	**3,372**
68: NON-FERROUS METALS	1,571	979	812	**3,362**	1,651	273	1,540	**3,464**
69: MANUFACTURES OF METAL N.E.S.	2,509	1,071	1,139	**4,719**	2,769	141	2,068	**4,978**
71: POWER GENERATING MACHINERY & EQUIPMENT	2,844	3,627	1,328	**7,799**	2,795	588	4,110	**7,493**
72: MACHINERY SPECIALIZED FOR PARTICULAR INDUSTRIES	2,550	1,317	243	**4,110**	2,674	192	1,298	**4,164**
73: METALWORKING MACHINERY	407	434	55	**896**	456	68	300	**824**
74: GENERAL INDUSTRIAL MACHINERY & EQP. & MACHINE PT.N	4,586	2,230	682	**7,498**	4,979	319	2,565	**7,863**
75: OFFICE MACHINES & ADP MACHINES	7,357	3,965	3,562	**14,884**	7,837	250	6,679	**14,766**
76: TELECOMMS & SOUND RECORDING & REPRODUCING APP. & E	4,642	3,453	2,410	**10,505**	5,025	285	6,018	**11,328**
77: ELE MACHINERY, APP & APPLIANCES & ELE PT THEREOF N	5,963	4,467	3,401	**13,831**	5,893	330	7,596	**13,819**
78: ROAD VEHICLES (INCLUDING AIR CUSHION VEHICLES)	24,395	3,960	949	**29,304**	25,345	237	5,111	**30,693**
79: OTHER TRANSPORT EQUIPMENT	1,831	6,773	650	**9,254**	1,573	1,222	5,201	**7,996**
81: P/FAB BUILDINGS;SANIT.,PLUMBING,HEATING &LIGHTING	671	155	310	**1,136**	818	25	531	**1,374**
82: FURNITURE & PARTS THEREOF; BEDDING, MATTRESSES ETC	1,514	500	1,071	**3,085**	1,729	76	1,714	**3,519**
83: TRAVEL GOODS, HANDBAGS & SIMILAR CONTAINERS	172	41	473	**686**	200	15	527	**742**
84: ARTICLES OF APPAREL & CLOTHING ACCESSORIES	2,488	1,475	6,129	**10,092**	2,684	268	7,656	**10,608**
85: FOOTWEAR	1,287	52	1,077	**2,416**	1,215	18	1,191	**2,424**
87: PROFESSIONAL, SCIENTIFIC & CONTROLLING INS & APP N	2,087	2,388	615	**5,090**	2,252	281	2,611	**5,144**
88: PHOTOGRAPHIC & OPTICAL GOODS, N.E.S.; WATCHES & CL	944	877	415	**2,236**	961	257	969	**2,187**
89: MISCELLANEOUS MANUFACTURED ARTICLES N.E.S.	5,152	4,646	3,490	**13,288**	5,261	969	7,091	**13,321**
90: COMMODITIES/TRANSACTIONS NOT CLASS'D ELSEWHERE IN	120	393	783	**1,296**	226	64	1,081	**1,371**
Total	119,385	60,618	46,580	**226,583**	125,905	10,553	98,737	**235,195**

Total imports increased about 4% between 2002 and 2003. On a country basis, total imports from the US and Australia (non-EU OECD) dropped 10% and 3%, respectively, whereas total imports from China increased by 23%, from India by 15%, and from Eastern European countries by 18% (the latter are classified as ROW countries, see Table 5). In conclusion, there seems to be a real shift in trade away from non-European OECD countries such as Japan and the US towards countries like China and Eastern European countries who were to become full EU member states in 2004.

Trade in Services

Data on the UK *trade in services* is available from the 'Pink Book' published annually by ONS (ONS 2006a). By courtesy of ONS we obtained Excel tables of trade in services data for the years of 1997 to 2004 (Lowes 2007). The trade in services data has 11 categories with distinction between 31 regions and countries. Similarly to the process of compiling the data of *trade in goods*, we firstly aggregated the data into three regions. For the category of EU OECD countries, the data is available for 1997-2003, which is represented as “EU 15” in the original dataset. The “EU 15” is replaced by “EU 25” in 2004 dataset, we assumed that the new 10 EU countries have same trade pattern to “Philippines”. Therefore to generate EU OECD in 2004, we used the EU 25 figures minus ten times the Philippine’s services imports to the UK. For the category of Non OECD countries, most of individual countries data are available except Norway, Czech Republic and Poland. We assumed that the three countries have the same trade pattern as South Korea. Therefore, we add all available Non EU OECD countries data plus three times the figures of South Korea. To generate the figures of the rest of world, we deducted the EU OECD and Non EU OECD from the world totals.

Finally, we assigned the 11 services categories to the 57 IO services sectors by generating the percentage breakdowns for the 11 services categories between the three world regions, and then multiplying with the ONS totals for imports in services. This results in trade in services data for the three world regions by 57 IO services sectors which are consistent with the total imports figures provided in the annual supply and use Tables. Again, for the early years 1992 to 1996, where no trade in services data is available, we used the trend for the year 1997 to 2004 for each sector and projected backwards.

Imports matrices by world region

A very important component of the MRIO system is separate matrices for imports to (UK) intermediate and final demand for each of the three world regions. These are not part of the annual ONS publications and a total imports matrix has only been published once as part of the 1995 Analytical Tables ("Imports Use matrix at basic prices, Product by Product", (Ruiz and Mahajan 2002). We have described above (page 43: Creating domestic use tables in basic prices) how we made use of this information to derive imports matrices for all years of the time series. In the following we describe the method to split up the total imports matrix into contributions from the three world regions, i.e. to create $\mathbf{U}^{eu}$, $\mathbf{y}^{eu}$, $\mathbf{U}^{ou}$, $\mathbf{y}^{ou}$, $\mathbf{U}^{wu}$, and $\mathbf{y}^{wu}$ in Table 1.

There is a range of international trade statistics that specify trade volumes in both f.o.b. and c.i.f. valuation. However, these statistics only detail the amounts of commodities traded between countries but not their usage by industries (elements U_{ij}^{ru} flow matrices). In other words, it is in general not possible to find information on the spatial origin of every intermediate and final import, disaggregated according to the consuming sector in the country of destination (see also (Boomsma et al. 1991, pp.7-8). This is mainly because of the considerable cost, time and resources that are associated with conducting international industry surveys (Round 1978a, b).

One solution to the generation of an initial (pre-balancing) estimate of off-diagonal trade flow matrices is to use *trade coefficients* (a non-survey approach)

Eq. 4 $$c_i^{rs} = \frac{u_i^{rs}}{\sum_r u_i^{rs}} \quad \text{with} \quad \sum_r c_i^{rs} = 1 ,$$

describing the percentage of imports of commodity *i* into country *s* (here the UK) that come from country *r*. These trade coefficients can then be applied to an entire row of the national imports matrices (M_{ij}^{s}) and imported final demand vectors (f_i^{s}) in order to yield breakdown according to country of origin:

Eq. 5 $$U_{ij}^{rs} = c_i^{rs} M_{ij}^{s} \quad \text{and} \quad y_i^{rs} = c_i^{rs} f_i^{s} .$$

This procedure assumes that the trade coefficients are identical for all entries along a row of the imports matrix, that is for all using domestic industries. Additionally, for years without separate import matrices (which is the case for the UK), an initial estimation of import coefficients can be made by assuming the relative importance of the usage of commodity by industry is constant over time.

Carbon dioxide emissions and intensities

Sectoral carbon dioxide emissions estimates for the UK economy can be found in the national Environmental Accounts, which are published bi-annually by the Office for National Statistics (ONS 2007b). The data distinguishes emissions from 91 production and two household activities (travel and non-travel) and is available for the full time period from 1992 to 2004 covered by the multi-regional model. These total 'Producer Emissions' (PE) include the emissions from international marine transport and aviation ("bunker emissions")[45] , biomass burning and cross-boundary transport, but exclude land use change and forestry emissions (see Bridging Tables from Environmental Accounts, ONS 2007b). The PE from Environmental Accounts are therefore different from those in the tables used for reporting to UNFCCC (IPCC) and UNECE (Goodwin 2007). For a full explanation of all differences between the different greenhouse gas accounting tables see (ONS 2007a, page 28 and Table 2.4).

For the years 2000, 2001, 2003 and 2004 CO_2 emissions were allocated from sector “Mining of metal ores” (SIC92: 13) to sector “Other mining and quarrying” (SIC92: 14) (minor in size), because no economic activities were recorded for these years (industry output = £0). To retain as much detail as possible in the UK-MRIO 1 model, the carbon dioxide emissions data were further disaggregated to the 123 sector level of the supply and use tables. In the absence of better information, CO_2 emissions were broken down proportionally to total industry output. For example, emissions of sector e_j can be broken down into two sub-sectors e_{j1} and e_{j2} given available information on total industry output g_{j1} and g_{j2} by

Eq. 6
$$e_j = e_{j1} + e_{j2} = \frac{g_{j1}}{g_j} e_j + \frac{g_{j2}}{g_j} e_j$$
$$with\ g_j = g_{j1} + g_{j2}$$

As a direct consequence, CO_2 intensities d_{j1} and d_{j2} in these sub-sectors will be equal to the CO_2 intensity in the aggregate sector d_j, that is

Eq. 7
$$d_{j1} = \frac{e_{j1}}{g_{j1}} = \frac{e_j}{g_j} = d_j = \frac{e_{j2}}{g_{j2}} = d_{j2}$$

As the 91 production sectors of the Environmental Accounts could not be directly mapped onto the 123 sectors of the SUT publication without further

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[45] More precisely these are the emissions from international flights and shipping transport run by UK operators.

aggregation, only 76 different UK-specific CO_2 intensities are distinguished in the multi-regional model across the 123 production sectors (see also Wiedmann et al. 2006b).

CO_2 emission data for the rest of the world were taken from the database provided by the International Energy Agency (IEA 2006). The data is restricted to CO_2 emissions from fuel combustion. The data is consistent with the IPCC's sectoral approach (see IEA, 2006: chapter 5). However, in order to gain a more complete picture of CO_2 emissions embedded in products imported to the UK, emissions from international marine bunkers and international aviation were included as well (as was in the UK data). CO_2 emissions in 140 countries as distinguished in the IEA database were aggregated into the three world regions (OECD-Europe, OECD non-Europe, non-OECD) of the MRIO model. Equally, 31 sectors of the IEA data were mapped into the 30 sectors distinguished in the MRIO model for non-UK regions. In this context it was assumed that all CO_2 emissions from energy production arise in the energy sector even if it was auto-generated by another sector.

CO_2 intensities for non-UK regions were derived by dividing sectoral CO_2 emissions of a particular region by total sector industry outputs. However, while monetary data for the UK is provided in British pounds (£), non-UK regions are recorded in US dollar (£). In general, to deal with differences in currencies in multi-regional models two approaches are available: adopt a mixed units approach, such that the national production and demand data is kept in the national currency, and trade matrices are recorded in mixed units, where units are constant across any one row of the MRIO table, but not across any column. The second option is to convert the output data of all regions to a single currency. Due to the uni-directional nature of the multi-regional model developed here, total industry output vectors for the non-UK regions were converted from US dollars into British pounds (£) using purchasing power parities (PPP)[46] provided by the Organisation for Economic Co-operation and Development (OECD, 2007). Due to differences in classification between the input-output and the IEA data, 18 different CO_2 intensities could finally be derived for the 30 sectors distinguished for the non-UK regions in the model.

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[46] Purchasing Power Parities (PPPs) are currency conversion rates that both convert to a common currency and equalise the purchasing power of different currencies. In other words, they eliminate the differences in price levels between countries in the process of conversion.

Table 8: Concordance matrix between 18 sectors (IEA data) and 30 sectors (world-region IO tables)

	1 Agriculture (arable farming)	2 Horticulture	3 Livestocks	4 Forestry, hunting and other agriculture	5 Fishery	6 Oil and gas extraction	7 Minerals extraction	8 Food production, from animals	9 Food production, non-animal	10 Beverages and tobacco	11 Textiles and clothes	12 Leather products	13 Wood and wood products	14 Paper, paperboard and publishing	15 Petroleum products
1 Agriculture & forestry	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
2 Fishing	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
3 Extraction of oil and gas, petroleum products	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
4 Extraction of other minerals	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
5 Food and beverages	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
6 Clothing and leather	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
7 Manufacture of wood products	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
8 Paper, paperboard and publishing	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
9 Chemical rubber and plastic products	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10 Mineral products	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 Ferrous and non-ferrous metals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12 Metal products, Machinery and electrotechnica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13 Motor vehicles and transport equipment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14 Furniture and industry n.e.c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15 Electricity and gas supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16 Construction and building installation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17 Transport	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18 Commercial and Public Services	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	16 Chemicals, rubber and plastic products	17 Construction materials and mineral products n.e.c.	18 Ferrous and non-ferrous metals	19 Metal products	20 Machinery and electrotechnical appliances and equipment	21 Motor vehicles and other transport equipment	22 Furniture and other manufacturing industry	23 Electricity supply	24 Gas supply	25 Water extraction and supply	26 Construction and building installation	27 Trade	28 Transport	29 Business services	30 Government and public services
1 Agriculture & forestry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2 Fishing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 Extraction of oil and gas, petroleum products	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 Extraction of other minerals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 Food and beverages	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 Clothing and leather	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7 Manufacture of wood products	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 Paper, paperboard and publishing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9 Chemical rubber and plastic products	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10 Mineral products	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
11 Ferrous and non-ferrous metals	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
12 Metal products, Machinery and electrotechnica	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
13 Motor vehicles and transport equipment	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
14 Furniture and industry n.e.c	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
15 Electricity and gas supply	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
16 Construction and building installation	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
17 Transport	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
18 Commercial and Public Services	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1

The CO_2 intensities were calculated for all years from 1992 and 2004. While the absolute emissions are available from the IEA database for all years, it was more difficult to estimate the total (monetary) industry output per sector and region over the whole time period. We used GDP per economic sector data from UN statistics (United Nations 2007) to derive this information. GDP data from individual countries were compiled into the three world regions first. In a second step we applied the growth rates of these sectors to the corresponding GTAP sectors to derive new total output estimates for all years other than 1997 and 2001. Again, total output in current US$ were converted to current £ by using PPP. By doing so we made two implicit assumptions: firstly, total output and GDP grow proportionally and secondly, growth within each of the seven economic sectors distinguished in the UN database is homogenous.

11 Appendix D: Matrix Balancing with CRAS

Constraints on arbitrarily sized and shaped subsets of matrix elements

The RAS method – in its basic form – bi-proportionally scales a matrix $\mathbf{A}_0$ of unbalanced preliminary estimates of an unknown real matrix **A**, using **A**'s known row and column sums. The balancing process is usually aborted when the discrepancy between the row and column sums of $\mathbf{A}_0$ and **A** is less than a previously fixed threshold. (Bacharach 1970) has analysed the bi-proportional constrained matrix problem in great detail, in particular in regard to the economic meaning of bi-proportional change[47], the existence and uniqueness of the iterative RAS solution, its properties of minimisation of distance metric[48], and uncertainty associated with errors in row and column sum data and with the assumption of bi-proportionality. The origins of the method go back several decades (Deming and Stephan 1940). (Stone and Brown 1962), (Bacharach 1970), and (Polenske 1997) provide a historical background.

A special situation arises when some of the matrix elements of **A** are known in addition to its row and column sums, for example from an industry survey. The 'modified RAS' (MRAS) approach (Allen 1974; Lecomber 1975a; Paelinck and Walbroeck 1963) deals with this partial information as follows: the preliminary estimate $\mathbf{A}_0$ has to be "netted", that is the known elements are subtracted, and $\mathbf{A}_0$ contains 0 at the corresponding positions. The net $\mathbf{A}_0$ is then subjected to the standard RAS procedure, and the known elements are added back on after balancing.

In practice, situations can arise where, in addition to certain elements of **A**, some aggregates of elements of **A** are known. For example, a published table $\mathbf{A}^G$ of national aggregates may constitute partial information when constructing

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[47] When applied to the forecasting of monetary input-output matrices, bi-proportional changes have been interpreted as productivity, substitution or fabrication effects (Leontief 1941); (Stone and Brown 1962) affecting industries over time. (Miernyk 1976) view however is that the RAS method "substitutes computational tractability for economic logic", and that the production interpretation loses its meaning when the entire input-output table is balanced, and not only inter-industry transactions (see also (Giarratani 1975).

[48] The RAS, Linear Programming and minimum information gain algorithms yield a balanced matrix estimate that is – in terms of some measure of multidimensional 'distance' – closest to the unbalanced preliminary estimate. When applied to temporal forecasting, this property is explained as a conservative hypothesis of attributing inertia to inter-industrial relations (Bacharach 1970), p. 26). While the classic RAS method is aimed at maintaining the value structure of the balanced matrix, the closely related Cross-Entropy methods (Robinson et al. 2001) are aimed at maintaining the coefficient structure.

a multi-regional input-output system, or a more disaggregated national table. Accordingly, (Oosterhaven et al. 1986) add a “national cell constraint” to the standard row and column sum constraints. Similarly, (Jackson and Comer 1993) use partition coefficients for groups of cells of a disaggregated base year matrix to disaggregate cells in an updated but aggregated matrix. (Batten and Martellato 1985) (p. 52-55) discuss further constraints structures, involving intermediate and final demand data. (Gilchrist and St Louis 1999, 2004) propose a three-stage “TRAS” for the case when aggregation rules exist under which the partial aggregated information $\mathbf{A}^G$ can be constructed from its disaggregated form **A**. Subjecting an input-output matrix to random censoring, these authors demonstrate that the inclusion of partial aggregated information into the TRAS procedure leads to superior outcomes than applying the standard RAS method. (Cole 1992) describes the general TRAS type that accepts constrained subsets of any size or shape. However, no TRAS variant deals with uncertainties, or handles negative matrix elements and conflicting external information.

Reliability of the initial estimate and external information

Another variant of the MRAS method takes into account the uncertainty of the preliminary estimates, and contains the occurrence of perfectly known elements as a special case (Lecomber 1975a, b), with case studies in (Allen 1974) and (Allen and Lecomber 1975). This is accomplished by introducing a matrix **E** containing “reliability information” about the elements in $\mathbf{A}_0$. **E** instead of $\mathbf{A}_0$ is then balanced in order to take up the difference between the preliminary and true totals:

Eq. 8 $$\mathbf{A^*} = \left(\mathbf{A}_0 - \mathbf{E}\right) + \hat{\mathbf{r}}\mathbf{E}\hat{\mathbf{s}}$$

A* is the balanced estimate, and $\hat{\mathbf{r}}$ and $\hat{\mathbf{s}}$ are diagonal scaling matrices, as in the conventional RAS algorithm. Where E_{ij} = 0, A_{ij} remains unchanged during balancing. (Lecomber 1975a, b) also investigates the influence of errors in the “true” totals.

A shortcoming of Lecomber’s approach is that the elements of **E** cannot be interpreted as standard deviations. If we follow Lecomber in maintaining 0 ≤ E_{ij} ≤ A_{0ij}, and consider that RAS preserves the positive signs in **E**, then $A^*_{ij} \geq A_{oij} - E_{ij} \forall i, j$. In other words if E_{ij} were the standard deviations of A_{0ij}, then the balanced estimate **A*** could never go more than one standard deviation below the initial estimate $\mathbf{A}_0$. An upper limit for **A*** does not exist however. Thus, as Lecomber points out, the elements of **E** must be sufficiently large to ensure the controlling vectors are non-negative – but there is no method to ensure this, whilst still interpreting the elements of **E** as standard errors. Thus considering that conflicting external information may well diverge by more than one standard deviation, it follows that MRAS will not reach a solution under sufficiently inconsistent constraints, unless more (unspecified) information on errors is obtained.

(Lahr 2001) takes into account the uncertainties of external constraints in treating the tolerances of the RAS termination criteria as functions of the varying reliabilities of row and column sums. (Dalgaard and Gysting 2004a) incorporate information about the reliability of external constraints (again row and column totals) into the balancing process as “confidence factors” λ, and successively adjust the target totals $\mathbf{u}_n$ of the *n*th iteration as a weighted sum $u_{n,j} = \lambda_j^{n-1} u_{0,j} + \left(1 - \lambda_j^{n-1}\right) u_{n-1,j}$ of the initial unbalanced totals $u_{0,j}$ and the totals $u_{n-1,j}$ of the previous iteration. With subsequent iterations, the confidence factors 0 ≤ λ_j^n ≤ 1 become smaller and smaller, thus gradually converging away from the unbalanced initial totals $\mathbf{u}_0$, towards the balanced totals $\mathbf{u}_\infty$. The innovation is that totals with high confidence (λ_j ≤ 1) get adjusted away from the initial totals much slower than those totals with low confidence (λ_j ≥ 0).

While both approaches consider the varying reliability of totals, they cannot deal with inconsistent totals. In applying conventional RAS scaling factors, Lahr’s algorithm would always end up balancing matrix elements to satisfy only one of a number of conflicting external constraints. Similarly, for large enough *n*, Dalgaard and Gysting’s algorithm would oscillate around those inconsistent totals $u_{n-1,j}$ with non-zero confidence.[49]

Negative elements

(Junius and Oosterhaven 2003) derive a generalised RAS (“GRAS”) algorithm that can balance negative elements, by splitting the matrix **A** into positive and negative parts **P** and **N**, and balancing **A** = **P** – **N** according to

Eq. 9
$$\begin{array}{l} \left(\hat{\mathbf{r}}\mathbf{P}\hat{\mathbf{s}} - \hat{\mathbf{r}}^{-1}\mathbf{N}\hat{\mathbf{s}}^{-1}\right)\mathbf{i} = \mathbf{u}^* \\ \mathbf{i}\left(\hat{\mathbf{r}}\mathbf{P}\hat{\mathbf{s}} - \hat{\mathbf{r}}^{-1}\mathbf{N}\hat{\mathbf{s}}^{-1}\right) = \mathbf{v}^* \end{array},$$

---

[49] (Dalgaard and Gysting 2004a) do describe balancing matrices with “unequal net row and column sum” and “macro differences between supply and use”. However, rather than inconsistencies in external information, this means correct differences in the sum over supply by *industry* and use by *product*, which naturally occur in asymmetric commodity-by-industry supply and use tables.

where **i** is the summation vector. Note that in order to minimise information gain, the balanced matrix $\hat{\mathbf{r}}\mathbf{P}\hat{\mathbf{s}} - \hat{\mathbf{r}}^{-1}\mathbf{N}\hat{\mathbf{s}}^{-1}$ conform to totals $\mathbf{u}^* = e\,\mathbf{u}$, $\mathbf{v}^* = e\,\mathbf{v}$, and $\mathbf{i}\,\mathbf{u}^* = \mathbf{i}\,\mathbf{v}^*$, where $e = 2.718\ldots$ is the base of the exponential function, and **u** and **v** are the prescribed row and column sum vectors, respectively, of **A** (Oosterhaven 2005). The results (A_{ij}) of GRAS have to be scaled down by e in order to satisfy the initially prescribed totals **u** and **v**.

In its basic formulation by (Junius and Oosterhaven 2003), GRAS neither incorporates constraints on subsets, nor does it deal with uncertainty and data conflict.

Constrained optimisation

Already (Bacharach 1970) has shown that the conventional RAS technique is equivalent to the constrained minimisation of an information gain function $f = \Sigma_{ij} A_{ij} \ln(A_{ij}/A_{0ij})$. Naturally, this circumstance leads to the parallel developments of both RAS and constrained optimisation techniques for the purpose of balancing input-output tables or SAMs. It is interesting to see that researchers working on either technique have faced almost the same challenges.

The basic structure of a constrained optimisation problem applied to SAMs is

Eq. 10 $$\text{Minimise } f(\mathbf{A}, \mathbf{A}_0)\text{, subject to } \Sigma_i A_{ij} = x_j \text{ and } \Sigma_j A_{ij} = x_i\ ,$$

where f is the objective function, and x_i and x_j are row and column totals. (Morrison and Thumann 1980) minimise a weighted sum of squares of deviations $f = \Sigma_{ij} (A_{ij} - A_{0ij})^2 / w_{ij},$ where the w_{ij} are the weights. They also explicitly describe the incorporation of external information referring to general subsets of matrix elements, into a Lagrange multiplier approach. Using a vectorised representation of $\mathbf{A} = (a_i)_{i=1,N\times N}$, a system of N_C constraints of any shape and size on $N\times N$ variables (including row and column totals) can be conveniently described in matrix notation:

Eq. 11 $$\mathbf{G\,a} = \mathbf{c}\ ,$$

Where the "aggregator matrix" **G** ($N_C \times N$) holds the coefficients linking the N variables a_i with the external data c_i on the N_C constraints.

(Byron 1978) incorporates variances Σ for the initial estimate $\mathbf{a}_0$ into a quadratic Lagrange function $f = (\mathbf{a} - \mathbf{a}_0)'\ \Sigma^{-1} (\mathbf{a} - \mathbf{a}_0) + \lambda'(\mathbf{Ga} - \mathbf{c})$, and uses the first-order conditions to solve for the Lagrange multipliers and the balanced SAM:

Eq. 12 $$\lambda = (\mathbf{G}\Sigma\mathbf{G}')^{-1}(\mathbf{Ga}_0 - \mathbf{c})\ ,$$

Eq. 13 $\mathbf{a} = \mathbf{a}_0 - \Sigma\mathbf{G}\lambda$.

(van der Ploeg 1982, 1984, 1988) elegantly extends Byron's formulation by a) adding disturbances ε to the external constraint information **c**, so that $\mathbf{G}\ \mathbf{a} = \mathbf{c} + \varepsilon$, and b) extending the unknown vector **a** with the unknown disturbances ε, to a compound vector **p**, distributed as

Eq. 14 $$\mathbf{p} = \begin{pmatrix} \mathbf{a} \\ \boldsymbol{\varepsilon} \end{pmatrix} \sim \mathrm{D}\left[\begin{pmatrix} \mathbf{a}_0 \\ 0 \end{pmatrix}, \begin{pmatrix} \boldsymbol{\Sigma}_\mathbf{a} \\ \boldsymbol{\Sigma}_\mathbf{c} \end{pmatrix}\right] = \mathrm{D}[\mathbf{p}_0, \boldsymbol{\Sigma}]$$

with means $\mathbf{a}_0$ and 0, and variances Σ_a and Σ_c. Exactly known constraints are a special case with the corresponding element of Σ_c being zero. Extending $\mathbf{C} = (\mathbf{G}, -\mathbf{I})$, where **I** is the unity matrix, the generalised problem becomes

Eq. 15 Minimise $f = (\mathbf{p} - \mathbf{p}_0)' \Sigma^{-1} (\mathbf{p} - \mathbf{p}_0)$, subject to $\mathbf{C}\ \mathbf{p} = \mathbf{c}$,

with solutions analog to Eq. 12 and Eq. 13. Since the solution for the Lagrange multipliers involves the inversion of $\mathbf{C}\Sigma\mathbf{C}'$, computing times are strongly influenced by the sizes N and N_C of the SAM and constraint system. Both Byron and van der Ploeg go to great lengths in exploiting the sparse structure of the coefficients matrix, and in devising efficient algorithms in order to be able to solve large SAMs. In effect, it is the introduction of ε and Σ_c that enables handling conflicting external data (van der Ploeg calls it "constraint violation"), because the disturbances ε in Eq. 14 and Eq. 15 allows the adjusted constraint value **G a** to deviate from its prescribed value **c**.

(Lecomber 1975a), (Morrison and Thumann 1980), and (Harrigan and Buchanan 1984) explicitly note that the conventional Langrange multiplier procedure in Eq. 10 does not guarantee non-negative solutions. This is undesirable because negative matrix entries can present problems in input-output analysis (ten Raa and Van der Ploeg 1989).

With the requirement of non-negativity, the constrained optimisation problem essentially becomes a *bounded* constrained optimisation. In general, one asks that the unknown SAM elements are within lower and upper bounds $l_i \leq a_i \leq u_i$. The mixing of equality and inequality conditions requires quadratic programming methods, which renders the solution of the optimisation problem considerably more complicated, as the expositions of (Harrigan and Buchanan 1984), (Zenios et al. 1989), and (Nagurney and Robinson 1992) may testify.

(Tarancon and Del Rio 2005) present an interesting variant of the bounded optimisation problem, by deriving lower and upper bounds from criteria for the stable structural evolution of input-output coefficients, and introducing supplementary variables to take up the slack between the bounds and the matrix entries. If the model turns out to be inconsistent because some constraints cannot be met within those bounds, then the analyst manually chosen certain constraints to be relaxed, until no variable exceeds the bounds.

Table 9: Recent extensions to RAS and optimisation techniques for balancing SAMs and input-output tables.

Criterion	RAS-type technique	Constrained optimisation
a)	(Gilchrist and St Louis 1999)	(Morrison and Thumann 1980)
b)	(Lecomber 1975a, b)	(Stone et al. 1942); (Byron 1978)
c)	(Lecomber 1975a, b); (Lahr 2001); (Dalgaard and Gysting 2004a)	(van der Ploeg 1982)
d)	(Junius and Oosterhaven 2003)	(Harrigan and Buchanan 1984)
e)	This work	(van der Ploeg 1982)

CRAS – Conflicting RAS

(Tarancon and Del Rio 2005) explicitly state that (p. 2) "… the RAS process cannot be developed with interval estimates of the margins. Hence, point estimates are used, which may carry an implicit error." On the other hand, compared to constrained optimisation techniques, RAS has enjoyed higher popularity, which is probably due to ease of programming. Considering that the use of RAS in statistical agencies requires the manual and therefore often tedious removal of inconsistencies in the constraint system, it would be desirable to have a RAS technique that deals with such common occurrences in a systematic and automated way. The description of such a RAS variant is the topic of this Section. We will base our derivation strongly on the GRAS notation of (Junius and Oosterhaven 2003).

In the standard GRAS method, the preliminary estimate $\mathbf{A}_0 = \mathbf{P}_0 - \mathbf{N}_0$ is alternately row- and column-scaled using diagonal matrices $\hat{\mathbf{r}}$ and $\hat{\mathbf{s}}$, so that after the *n*-th round of balancing, $\mathbf{A}_n = \hat{\mathbf{r}}_{n-1}\mathbf{P}_{n-1}\hat{\mathbf{s}}_{n-1} - \hat{\mathbf{r}}_{n-1}^{-1}\mathbf{N}_{n-1}\hat{\mathbf{s}}_{n-1}^{-1}$. $\mathbf{A}_n$ is then subjected to the next scaling operation. GRAS uses scalers

Eq. 16

$$r_{n,i} = \frac{u_i^* + \sqrt{u_i^{*2} + 4\sum_j P_{n,ij} \sum_j N_{n,ij}}}{2\sum_j P_{n,ij}}\text{, with}$$

$$P_{n,ij} = P_{n-1,ij} s_{n-1,j}\,, N_{n,ij} = N_{n-1,ij} s_{n-1,j}^{-1}\text{ , and}$$

$$s_{n-1,j} = \frac{v_j^* + \sqrt{v_j^{*2} + 4\sum_i P_{n-1,ij} \sum_i N_{n-1,ij}}}{2\sum_i P_{n-1,ij}}\ .$$

The algorithm converges if

Eq. 17

$$\begin{array}{l} \left\| \left(\hat{\mathbf{r}}\mathbf{P}\hat{\mathbf{s}} - \hat{\mathbf{r}}^{-1}\mathbf{N}\hat{\mathbf{s}}^{-1} \right)\mathbf{i} - \mathbf{u}^* \right\| < \delta \left\| \mathbf{u}^* \right\| \\ \left\| \mathbf{i}\left(\hat{\mathbf{r}}\mathbf{P}\hat{\mathbf{s}} - \hat{\mathbf{r}}^{-1}\mathbf{N}\hat{\mathbf{s}}^{-1} \right) - \mathbf{v}^* \right\| < \delta \left\| \mathbf{v}^* \right\| \end{array} ,$$

for a sufficiently small δ.

Incorporating constraints on arbitrary subsets of matrix elements

Consider now a generalised formulation of constraints as in **G a** = **c** (Eq. 11). Such a formulation includes constrained row and column sums, constraint single elements, constrained subsets, and negative elements as special cases. Constraints can include any number of elements, which may be fully, partly or non-adjacent.[50] Constraints may also exclude some of the row and column totals (compare (Thissen and Löfgren 1998), p. 1994). Let **G** = **G**$^+$ – **G**$^-$ be a decomposition of the constraint coefficients matrix, analog to the decomposition **A** = **P** – **N** of **A**. Let there be N_C constraints, and let **c*** = *e* **c**. Eq. 15 can then be generalised to

Eq. 18

$$r_n = \frac{c_i^* + \sqrt{c_i^{*2} + 4\sum_j G_{ij}^+ a_{n-1,j} \sum_j G_{ij}^- a_{n-1,j}}}{2\sum_j G_{ij}^+ a_{n-1,j}} \quad \text{and}$$

$$a_{n,j} = a_{n-1,j} r_n^{\mathrm{Sgn}\left(G_{ij}\right)}, \qquad \text{with } i = n - \left\lfloor \frac{n}{N_C} \right\rfloor N_C\,.$$

In Eq. 18, the negative elements in Eq. 15 have been replaced with negative coefficients on positive elements, but otherwise the formulation is exactly the same. There is only one scaler r_i for each constraint *i*, and these scalers are

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[50] Single-element constraints need not be part of the scaling procedure, but could be "netted out" using the "modified RAS" method.

applied consecutively for all i =1,…,N_C.[51] The r_i and a_j are calculated alternately. The GRAS feature of scaling negative elements by the inverse of the positive scaler is evident in the exponent Sgn(G_{ij}) in Eq. 18. The algorithm converges if

Eq. 19 $$\left\|\mathbf{Ga}-\mathbf{c}^*\right\| < \delta \left\|\mathbf{c}^*\right\| ,$$

for a sufficiently small δ.

Incorporating reliability and conflict of external data

In cases of inconsistent constraints brought about by conflicting external data, the termination condition (11) may never be met, and GRAS has to be terminated if the distance function between the constraints **c** and their realisations **G a** does not improve anymore, that is if for two subsequent iterations n – 1 and n

Eq. 20 $$\left\|\mathbf{Ga}-\mathbf{c}^*\right\|_n - \left\|\mathbf{Ga}-\mathbf{c}^*\right\|_{n-1} < \delta ,$$

for a sufficiently small δ. Following this termination, we propose a GRAS-type algorithm that modifies the constraints **c*** as well:

Eq. 21
$$r_n = \frac{c^*_{n,i} + \sqrt{c^{*2}_{n,i} + 4\sum_j G^+_{ij} a_{n-1,j} \sum_j G^-_{ij} a_{n-1,j}}}{2\sum_j G^+_{ij} a_{n-1,j}},$$
$$c^*_{n,i} = c^*_{n-1,i} - \mathrm{Sgn}\left(c^*_{n-1,i} - \sum_j G_{ij} a_{n-1,j}\right) \times \mathrm{Min}\left(\left|c^*_{n-1,i} - \sum_j G_{ij} a_{n-1,j}\right|, \alpha\sigma_i\right)$$
$$\text{with } c^*_{0,i} = c^*_i \,,\ a_{n,j} = a_{n-1,j} r_n^{\mathrm{Sgn}(G_{ij})} ,\ \text{and } i = n\text{-}\left\lfloor \frac{n}{N_C} \right\rfloor N_C \,,$$

where 0 ≤ α ≤ 1 and σ_i is the standard error of c_i. We refer to this algorithm as CRAS (‘Conflicting RAS’). The essence of this idea is that once GRAS terminates in oscillations without reaching convergence, the original external constraints c_i can clearly not all be satisfied simultaneously, and either some of them or all of them must be erroneous. In order to achieve convergence, the c_i must be modified “towards” their realisations $(\mathbf{Ga})_i$. Since each constraint is known to a higher or lower degree of accuracy. Therefore, an amount $\alpha\sigma_i$ is

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[51] The symbol $\lfloor\ \rfloor$ in equation 10 is the floor function and refers to the largest integer smaller than the number inside.

added or subtracted from each $c^{*}_{n-1,i}$, depending on the sign Sgn($c^{*}_{n-1,i} - \sum_{j} G_{ij} a_{n-1,j}$). The constant α can be chosen freely: The higher its value, the more rapid the adjustment process, but also the more inaccurate the adjustment. Note that in order to prevent overshoot in situations where the realisation (**Ga**)$_i$ is closer to the c_i than σ_i, the maximum adjustment allowed is $|c^{*}_{n-1,i} - \sum_{j} G_{ij} a_{n-1,j}|$. With constraint values modified as in Eq. 21, the termination criterion of CRAS is equal to that in Eq. 19.

12 Appendix E: Production of Symmetric Input-Output Tables

Technology assumptions in a supply-use representation

The deliverable of this project is a time series of balanced (monetary) input-output tables for the UK (“Analytical IO Tables”, “Leontief Inverses”, “Symmetric Input-Output Tables”) for the years 1992 to 2004, based on the initial estimates and constraints compiled for each. Such a time series is very useful when carrying out a number of analyses, including long-term Structural Decomposition Analysis (SDA) (Dietzenbacher and Stage 2006; Lenzen 2006; Llop 2007) and trend analyses. Such analyses allow the identification of driving factors that contribute most strongly to growing environmental pressure and unsustainability.

This section addresses the question of technology assumptions in a supply-use representation as used in the UK-MRIO 1 model.

The United Nations Handbook on input-output table compilation (United Nations 1999) distinguishes two basic technology assumptions: In the industry technology assumption[52], the production recipe is unique to an industry, while

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[52] This assumption could also be called *“assumption of fixed product sales structures”* according to (Thage 2005) and (Yamano and Ahmad 2006). Both publications argue in favour of the compilation of industry-by-industry tables based on this assumption and present a number of advantages. (Yamano and Ahmad 2006 p.22) write "…the conversion merely assumes that the proportion of domestically produced commodity A bought by industry B from industry C is proportional to industry C’s share of the total (domestic) economy production of commodity A. Put this way, it is clear that this is a far less demanding assumption than that implied by the equivalent, but differently named, 'industry technology' assumption".

products' input recipes are a weighted sum over industries' production recipes. In the commodity technology assumption, the input recipe is unique to a product, while industries' production recipes are a weighted sum over their primary and joint products.

In the UN Handbook, technology assumptions are dealt with for symmetric input-output coefficients tables (SIOT). However, both industry and commodity technology assumption can be represented using supply-use formulations without the need for producing a SIOT. In the following we will use the standard United Nations notation (United Nations 1999), except for the supply matrix, which we will call **V** instead of M signifying the older term "make matrix". Let a single-region supply-use transaction block **T** be represented by

Eq. 22 $$\mathbf{T} = \begin{bmatrix} 0 & \mathbf{U} \\ \mathbf{V} & 0 \end{bmatrix} ,$$

with **U** being a product-by-industry use matrix, showing the input U_{ij} of commodity i into industry j, and **V** being a industry-by-product supply matrix, with V_{ij} showing the output by industry i of commodity j. This block formulation is well known in the input-output literature (Gigantes 1970; Schinnar 1978).

Let **T** satisfy the national accounting identity

Eq. 23 $$\begin{bmatrix} 0 & \mathbf{U} \\ \mathbf{V} & 0 \end{bmatrix} \begin{bmatrix} \mathbf{1} \\ \mathbf{1} \end{bmatrix} + \begin{bmatrix} \mathbf{y}_c \\ 0 \end{bmatrix} = \begin{bmatrix} \mathbf{q} \\ \mathbf{g} \end{bmatrix} ,$$

where $[\ \mathbf{1}\ \mathbf{1}\ ]^t$ is the row summation vector, $\mathbf{y}_c$ is a vector of final demand of products, and **q** and **g** are vectors of gross output of products and industries, respectively. Let

Eq. 24 $$\begin{bmatrix} 0 & \mathbf{B} \\ \mathbf{D} & 0 \end{bmatrix} = \begin{bmatrix} 0 & \mathbf{U} \\ \mathbf{V} & 0 \end{bmatrix} \begin{bmatrix} \hat{\mathbf{q}}^{-1} & 0 \\ 0 & \hat{\mathbf{g}}^{-1} \end{bmatrix}$$

be a supply-use coefficients block, where the hat symbol ("^") denotes a diagonalised vector. **B** is called the (product-by-industry) use coefficients matrix, and **D** is called the (industry-by-product) market share matrix.

Industry technology assumption

Industry technology assumes an input recipe that is characteristic for an industry; this is in essence the use matrix **U**. Therefore, the supply-use blocks in Eq. 12 basically assume industry technology. The UN input-output handbook

(United Nations 1999, Eqs. 4.4 and 4.12), provides instructions for combining use coefficients and market shares into either a symmetric industry-by-industry input-output coefficients matrix

Eq. 25 $$\mathbf{A}_{\mathrm{I,ii}} = \mathbf{DB} \ ,$$

or a symmetric product-by-product input-output coefficients matrix

Eq. 26 $$\mathbf{A}_{\mathrm{I,cc}} = \mathbf{BD} \ .$$

These matrices are used in either the industry-by-industry input-output model (United Nations 1999, Eq. 4.10)

Eq. 27 $$(\mathbf{I} - \mathbf{DB})\mathbf{g} = \mathbf{D}\mathbf{y}_{\mathrm{c}} \ ,$$

or in the product-by-product input-output model, (United Nations 1999, Eq. 4.9)

Eq. 28 $$(\mathbf{I} - \mathbf{BD})\mathbf{q} = \mathbf{y}_{\mathrm{c}} \ .$$

Using the compound supply-use-block formulation as in Eq. 24, a compound Leontief Inverse can be written as

Eq. 29 $$\mathbf{L}_{\mathrm{I}}^{*} = \begin{bmatrix} \mathbf{I} & -\mathbf{B} \\ -\mathbf{D} & \mathbf{I} \end{bmatrix}^{-1} \ .$$

Using the partitioned inverse of (Miyazawa 1968), Eq. 29 can be written as

Eq. 30 $$\mathbf{L}_{\mathrm{I}}^{*} = \begin{bmatrix} \mathbf{I} + \mathbf{B}\mathbf{L}_{\mathrm{I,ii}}\mathbf{D} & \mathbf{B}\mathbf{L}_{\mathrm{I,ii}} \\ \mathbf{L}_{\mathrm{I,ii}}\mathbf{D} & \mathbf{L}_{\mathrm{I,ii}} \end{bmatrix} \ ,$$

where $\mathbf{L}_{\mathrm{I,ii}} = (\mathbf{I} - \mathbf{DB})^{-1}$ is the Leontief Inverse of the industry-by-industry input-output model. Considering the series expansion $\mathbf{B}\mathbf{L}_{\mathrm{I,ii}}\mathbf{D} = \mathbf{B}\left(\mathbf{I} + \mathbf{DB} + (\mathbf{DB})^{2} + \mathbf{...}\right)\mathbf{D}$, Eq. 30 can be simplified to

Eq. 31 $$\mathbf{L}_{\mathrm{I}}^{*} = \begin{bmatrix} \mathbf{L}_{\mathrm{I,cc}} & \mathbf{B}\mathbf{L}_{\mathrm{I,ii}} \\ \mathbf{L}_{\mathrm{I,ii}}\mathbf{D} & \mathbf{L}_{\mathrm{I,ii}} \end{bmatrix} \ ,$$

with $\mathbf{L}_{\mathrm{I,cc}} = (\mathbf{I} - \mathbf{BD})^{-1}$ being the Leontief Inverse of the product-by-product input-output model (see Eq. 28).

Hence, when supply and use matrices are handled in integrated blocks, the compound Leontief inverse elegantly reproduces both product-by-product and industry-by-industry models in one formulation.

Commodity technology assumption

Commodity technology assumes an input recipe that is characteristic for a product. Once again, the UN (United Nations 1999, Eq. 4.17) provides instructions for combining use coefficients and the supply matrix into a symmetric product-by-product input-output coefficients matrix:

Eq. 32 $$\mathbf{A}_{\mathrm{C,cc}} = \mathbf{U}\mathbf{V}^{-1} \ .$$

In essence, $\mathbf{A}_{\mathrm{C,cc}}$ holds the input recipe for products produced by industries. The corresponding product-by-product input-output model is

Eq. 33 $$(\mathbf{I} - \mathbf{A}_{\mathrm{C,cc}})\mathbf{q} = \mathbf{y}_{\mathrm{c}} \ .$$

In the context of the commodity technology assumption, the supply-use block assumes a different shape; the coefficients matrix is now

Eq. 34 $$\begin{bmatrix} \mathbf{A}_{\mathrm{C,cc}} & 0 \\ \mathbf{D} & 0 \end{bmatrix} = \begin{bmatrix} 0 & \mathbf{U} \\ \mathbf{V} & 0 \end{bmatrix} \begin{bmatrix} \hat{\mathbf{q}}^{-1} & 0 \\ \mathbf{V}^{-1} & 0 \end{bmatrix} .$$

The compound Leontief Inverse can then be written as

Eq. 35 $$\mathbf{L}_{\mathrm{C}}^{*} = \begin{bmatrix} \mathbf{I} - \mathbf{A}_{\mathrm{C,cc}} & 0 \\ -\mathbf{D} & \mathbf{I} \end{bmatrix}^{-1} = \begin{bmatrix} \mathbf{L}_{\mathrm{C,cc}} & 0 \\ \mathbf{D}\mathbf{L}_{\mathrm{C,cc}} & \mathbf{I} \end{bmatrix} ,$$

where $\mathbf{L}_{\mathrm{C,cc}} = (\mathbf{I} - \mathbf{A}_{\mathrm{C,cc}})^{-1}$ is the Leontief Inverse of the product-by-product input-output model (see Eq. 33).

Once again, when supply and use matrices are handled in integrated blocks, the compound Leontief Inverse elegantly reproduces both product-by-product and industry-by-industry models in one formulation.

Further information on the treatment of industry technology and commodity technology in a make-use framework can be found in this literature e.g.: (ten Raa and Van der Ploeg 1989; Thage 2005; United Nations 1999; Yamano and Ahmad 2006).

13 Appendix F: 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.

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**

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 (Mt)

123	Year >	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1	Agriculture, hunting and related service activities	2.377	2.388	2.443	2.743	2.649	2.643	2.851	3.218	2.842	3.340	3.608	3.678	3.363
2	Forestry, logging and related service activities	0.021	0.028	0.029	0.040	0.029	0.019	0.032	0.084	0.034	0.036	0.042	0.044	0.039
3	Fishing, operation of fish hatcheries and fish farms; service	0.083	0.067	0.070	0.100	0.078	0.042	0.076	0.171	0.077	0.105	0.104	0.117	0.115
4	Mining of coal and lignite; extraction of peat	0.299	0.275	0.149	0.368	0.170	- 0.034	0.138	0.175	0.102	0.232	0.129	0.174	0.341
5	Extraction of crude petroleum and natural gas; service activities	2.084	2.105	1.677	3.734	1.627	1.243	0.953	1.637	1.826	2.262	2.344	2.026	2.186
6	Mining of metal ores	0.013	0.022	0.017	0.062	0.023	0.014	0.029	0.007	0.003	0.000	0.000	0.000	0.000
7	Other mining and quarrying	0.975	1.561	1.408	3.647	1.511	1.093	1.656	4.364	3.956	5.233	3.893	4.274	4.155
8	Production, processing and preserving of meat and meat	2.854	3.059	3.003	3.461	3.292	2.828	3.059	3.418	2.955	3.291	3.428	3.487	3.274
9	Processing and preserving of fish and fish products; fruit and	2.369	2.435	2.445	2.775	2.741	2.357	3.032	3.050	2.393	2.828	2.889	2.990	2.756
10	Vegetable and animal oils and fats	0.265	0.277	0.291	0.340	0.327	0.203	0.312	0.334	0.253	0.278	0.300	0.331	0.295
11	Dairy products	1.679	1.827	1.800	1.917	1.857	1.815	1.913	2.300	1.880	2.023	1.980	1.969	1.854
12	Grain mill products, starches and starch products	0.334	0.345	0.349	0.426	0.418	0.380	0.438	0.433	0.400	0.481	0.477	0.501	0.439
13	Prepared animal feeds	0.267	0.277	0.290	0.359	0.315	0.296	0.346	0.293	0.335	0.392	0.402	0.428	0.386
14	Bread, rusks and biscuits; manufacture of pastry goods and	0.730	0.793	0.791	0.997	0.881	0.814	0.918	0.898	0.975	1.168	1.237	1.316	1.374
15	Sugar	0.150	0.144	0.133	0.169	0.148	0.069	0.170	0.234	0.095	0.120	0.112	0.105	0.127
16	Cocoa; chocolate and sugar confectionery	0.966	0.991	1.065	0.906	0.985	0.879	0.980	0.794	0.753	0.828	0.856	0.844	0.776
17	Other food products	1.222	1.399	1.399	1.540	1.416	1.203	1.512	1.293	1.248	1.469	1.513	1.516	1.482
18	Alcoholic beverages	1.042	1.194	1.291	1.827	1.467	1.707	1.902	2.117	1.785	2.013	2.066	2.293	2.094
19	Production of mineral waters and soft drinks	0.547	0.554	0.564	0.740	0.681	0.603	0.707	0.593	0.677	0.828	0.815	0.898	0.829
20	Tobacco products	0.480	0.505	0.580	0.513	0.827	0.852	1.302	1.334	0.910	1.056	0.969	0.842	0.745
21	Preparation and spinning of textile fibres	0.105	0.118	0.143	0.195	0.128	0.088	0.089	0.086	0.083	0.075	0.060	0.072	0.055
22	Textile weaving	0.213	0.282	0.311	0.427	0.307	0.235	0.281	0.218	0.195	0.205	0.195	0.238	0.181
23	Finishing of textiles	0.006	0.005	0.007	0.008	0.006	0.017	0.007	0.008	0.005	0.009	0.014	0.006	0.006
24	Made-up textile articles, except apparel	0.586	0.604	0.665	0.778	0.709	0.699	0.862	0.767	0.835	1.056	1.179	1.158	1.137
25	Carpets and rugs	0.404	0.415	0.438	0.447	0.405	0.385	0.410	0.357	0.362	0.404	0.420	0.397	0.358
26	Other textiles	0.146	0.157	0.180	0.275	0.194	0.145	0.182	0.176	0.183	0.208	0.213	0.250	0.206
27	Knitted and crocheted fabrics and articles	1.563	1.743	1.846	2.041	1.906	1.979	2.263	1.998	1.991	2.419	2.308	2.331	2.119
28	Wearing apparel; dressing and dying of fur	6.490	6.892	7.296	7.916	7.557	7.800	9.069	7.975	8.073	9.757	10.322	10.452	9.633
29	Tanning and dressing of leather; manufacture of luggage,	0.197	0.227	0.262	0.284	0.274	0.230	0.282	0.340	0.261	0.326	0.319	0.331	0.315
30	Footwear	1.129	1.248	1.415	1.467	1.391	1.404	1.508	1.481	1.392	1.818	1.876	1.752	1.566
31	Wood and wood products, except furniture	0.418	0.438	0.469	0.489	0.403	0.398	0.489	0.587	0.486	0.574	0.623	0.680	0.605
32	Pulp, paper and paperboard	0.357	0.359	0.427	0.512	0.365	0.787	0.423	0.274	0.331	0.385	0.347	0.428	0.455
33	Articles of paper and paperboard	0.447	0.484	0.480	0.635	0.549	0.454	0.532	0.587	0.487	0.536	0.553	0.644	0.612
34	Publishing, printing and reproduction of recorded media	1.538	1.730	1.860	2.299	1.932	1.748	2.047	1.892	1.931	2.128	2.301	2.553	2.305
35	Coke, refined petroleum products and nuclear fuel	8.906	9.662	8.557	6.508	9.018	10.983	7.548	9.060	13.242	16.290	16.191	16.847	21.469
36	Industrial gases, dyes and pigments	0.188	0.239	0.212	0.309	0.202	0.128	0.200	0.143	0.173	0.192	0.224	0.268	0.242
37	Other inorganic basic chemicals	0.072	0.106	0.076	0.138	0.092	0.068	0.078	0.045	0.149	0.169	0.104	0.148	0.146
38	Other organic basic chemicals	4.571	4.904	5.202	1.497	6.268	5.508	6.685	5.920	1.280	1.728	2.429	3.068	2.770
39	Fertilisers and nitrogen compounds	0.050	0.090	0.103	0.086	0.130	0.065	0.100	0.191	0.095	0.109	0.113	0.132	0.099
40	Plastics and synthetic rubber in primary forms	0.353	0.429	0.463	0.712	0.423	0.305	0.461	0.324	0.599	0.665	0.999	1.245	1.165
41	Pesticides and other agro-chemical products	0.112	0.151	0.143	0.246	0.194	0.130	0.184	0.160	0.197	0.214	0.412	0.322	0.289
42	Paints, varnishes and similar coatings, printing ink and mastics	0.222	0.244	0.261	0.354	0.267	0.244	0.296	0.301	0.319	0.346	0.369	0.445	0.446
43	Pharmaceuticals, medicinal chemicals and botanical products	0.867	1.199	1.152	1.716	1.544	1.320	1.677	1.829	2.011	2.966	3.463	4.315	3.865
44	Soap and detergents, cleaning and polishing preparations,	1.260	1.510	1.643	2.275	1.816	1.793	1.961	1.739	1.982	2.498	2.890	3.541	3.219
45	Other chemical products	1.355	1.527	1.595	2.410	1.681	1.808	1.834	1.753	2.096	2.302	2.533	3.303	2.997
46	Man-made fibres	0.154	0.172	0.162	0.252	0.193	0.200	0.196	0.112	0.176	0.173	0.203	0.230	0.212
47	Rubber products	0.606	0.697	0.748	1.113	0.862	0.659	1.015	0.993	0.837	0.911	0.977	1.241	1.141
48	Plastic products	1.224	1.293	1.343	1.833	1.442	1.832	1.656	1.849	1.678	1.989	2.132	2.516	2.383
49	Glass and glass products	0.345	0.374	0.389	0.517	0.414	0.256	0.491	0.564	0.481	0.574	0.574	0.694	0.686
50	Ceramic goods	0.669	0.722	0.857	1.306	0.949	0.943	1.189	1.179	1.108	1.308	1.288	1.456	1.468
51	Bricks, tiles and construction products, baked in clay	0.013	0.013	0.015	0.019	0.021	0.022	0.019	0.038	0.037	0.027	0.029	0.030	0.026
52	Cement, lime and plaster	0.024	0.025	0.024	0.024	0.030	0.030	0.032	0.017	0.035	0.037	0.048	0.039	0.043
53	Articles of concrete, plaster and cement; cutting, shaping and	0.159	0.184	0.182	0.256	0.214	0.189	0.236	0.290	0.295	0.340	0.278	0.340	0.356
54	Basic iron and steel and of ferro-alloys; manufacture of tubes and	2.061	2.454	2.566	3.400	2.248	0.964	2.115	1.460	1.871	2.201	2.495	3.211	3.681
55	Basic precious and non-ferrous metals	3.528	3.913	4.008	6.095	4.572	1.638	6.040	4.417	5.597	6.221	4.915	5.905	6.584
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	1.048	1.037	0.951	1.457	1.212	1.262	1.544	1.202	1.272	1.503	1.506	1.790	1.666
58	Tanks, reservoirs and containers of metal; manufacture of central	0.313	0.313	0.329	0.592	0.406	0.376	0.419	0.347	0.423	0.468	0.443	0.725	0.738
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	0.766	0.782	0.844	1.078	0.910	1.505	1.116	1.188	1.100	1.349	1.356	1.647	1.554
61	Other fabricated metal products	1.116	1.120	1.179	1.657	1.341	1.636	1.524	1.342	1.332	1.660	1.617	1.952	1.977
62	Machinery for the production and use of mechanical power, except	1.389	1.614	1.614	2.540	1.861	1.911	1.972	1.556	1.877	2.217	2.071	2.713	2.567

63	Other general purpose machinery	2.431	2.637	2.780	4.653	3.689	3.595	3.783	3.000	3.485	4.116	3.768	4.850	4.668
64	Agricultural and forestry machinery	0.538	0.628	0.662	0.935	0.730	0.731	0.680	0.521	0.542	0.625	0.634	0.816	0.753
65	Machine tools	0.688	0.705	0.867	1.523	1.024	1.657	1.233	0.965	1.013	1.082	0.994	1.104	1.004
66	Other special purpose machinery	1.881	2.042	2.194	3.970	2.662	2.824	3.106	2.152	2.326	2.533	2.419	3.206	3.023
67	Weapons and ammunition	0.078	0.225	0.201	0.289	0.258	0.224	0.240	0.078	0.125	0.123	0.121	0.101	0.055
68	Domestic appliances not elsewhere classified	1.061	1.156	1.214	1.665	1.347	1.836	1.427	1.252	1.495	1.857	2.072	2.439	2.311
69	Office machinery and computers	5.617	7.168	7.736	12.070	9.380	10.059	12.270	11.661	12.047	12.131	10.371	11.066	9.644
70	Electric motors, generators and transformers; manufacture of	1.204	1.334	1.560	2.273	1.837	1.798	2.176	2.062	2.201	2.344	2.158	2.691	2.580
71	Insulated wire and cable	0.255	0.414	0.423	0.736	0.534	0.359	0.552	0.445	0.688	0.659	0.493	0.595	0.642
72	Electrical equipment not elsewhere classified	0.919	1.077	1.172	1.631	1.275	0.861	1.328	1.128	1.333	1.282	1.338	1.697	1.691
73	Electronic valves and tubes and other electronic components	0.924	1.412	1.631	2.792	2.271	1.596	1.633	2.060	3.190	3.633	3.744	2.507	2.638
74	Television and radio transmitters and line for telephony and line	1.058	1.297	2.030	3.022	3.188	3.230	4.065	4.116	5.401	6.136	6.676	6.214	5.228
75	Television and radio receivers, sound or video recording or	1.756	1.971	2.254	3.120	2.592	2.202	2.412	2.253	2.580	3.079	3.203	4.114	4.363
76	Medical, precision and optical instruments, watches and clocks	3.127	3.328	3.117	4.036	3.421	3.919	3.822	3.464	3.627	4.102	3.890	5.120	4.901
77	Motor vehicles, trailers and semi-trailers	9.060	10.145	11.054	17.636	13.482	14.315	16.160	13.174	14.245	16.340	17.695	22.617	21.219
78	Building and repairing of ships and boats	0.826	0.637	1.263	0.961	0.833	0.937	0.548	0.548	0.627	0.806	0.815	1.298	1.075
79	Other transport equipment	0.617	0.655	1.017	0.969	0.682	0.691	0.848	0.751	0.861	0.814	0.850	1.131	1.075
80	Aircraft and spacecraft	3.771	4.392	4.659	3.729	4.490	6.454	8.849	7.554	6.315	8.279	8.168	10.903	8.506
81	Furniture	3.987	4.062	4.382	5.720	4.603	4.351	5.751	5.600	6.537	7.060	8.326	9.564	9.597
82	Jewellery and related articles; manufacture of musical	6.628	7.979	9.633	7.563	7.128	9.562	8.620	6.671	5.442	5.683	6.486	7.819	6.979
83	Sports goods, games and toys	8.660	9.233	7.320	7.480	6.492	6.806	7.683	6.953	7.020	6.851	7.797	8.548	7.834
84	Miscellaneous manufacturing not elsewhere classified; recycling	2.454	2.701	2.756	3.716	2.740	2.113	3.200	3.249	2.876	2.942	3.266	3.636	3.232
85	Production and distribution of electricity	3.324	3.845	3.381	3.108	3.004	2.750	2.846	1.449	2.490	2.280	2.156	2.080	3.022
86	Gas; distribution of gaseous fuels through mains; steam and hot	2.972	3.011	2.267	1.973	2.656	3.133	1.866	1.207	2.623	3.024	2.985	2.885	3.681
87	Collection, purification and distribution of water	0.085	0.103	0.107	0.144	0.118	0.126	0.151	0.092	0.118	0.124	0.135	0.157	0.166
88	Construction	7.426	8.119	8.529	11.672	8.484	9.320	10.459	8.638	10.648	13.195	13.035	15.062	15.822
89	Sale, maintenance and repair of motor vehicles, and motor cycles;	1.852	2.254	2.336	3.434	2.706	3.078	3.573	2.708	3.416	4.209	4.014	4.466	4.517
90	Wholesale trade and commission trade, except of motor vehicles	4.149	4.851	4.785	6.499	5.750	6.268	6.682	5.967	7.021	8.160	8.120	8.494	8.375
91	Retail trade, except of motor vehicles and motor cycles; repair	2.247	2.581	2.951	3.861	3.571	3.734	4.381	3.593	4.773	5.738	5.837	6.144	5.939
92	Hotels and restaurants	7.468	8.572	8.821	9.500	9.275	9.499	10.281	9.009	10.304	12.200	12.932	13.251	13.063
93	Transport via railways	0.730	0.822	0.945	1.203	1.326	1.541	1.651	1.811	1.970	2.164	2.155	1.953	1.962
94	Other land transport; transport via pipelines	2.037	2.203	2.230	2.444	2.657	2.866	3.237	1.148	3.806	4.320	4.421	4.576	4.393
95	Water transport	6.237	7.160	7.491	7.619	7.928	9.702	8.699	8.133	8.827	10.601	10.472	10.798	12.317
96	Air Transport	15.786	16.305	17.429	17.047	17.962	19.670	22.778	23.639	27.037	29.277	29.160	27.323	27.036
97	Supporting and auxiliary transport activities; activities of travel	0.354	0.404	0.425	0.488	0.446	1.064	0.531	0.700	0.561	0.687	0.595	0.556	0.566
98	Post and courier activities	0.080	0.107	0.116	0.139	0.132	0.124	0.131	0.104	0.127	0.144	0.144	0.157	0.152
99	Telecommunications	0.945	1.097	1.126	1.435	1.339	1.173	1.630	1.360	1.819	2.265	2.412	2.984	2.964
100	Financial intermediation, except insurance and pension funding	0.365	0.452	0.441	0.637	0.703	0.884	0.880	0.793	1.188	1.359	1.226	1.216	1.190
101	Insurance and pension funding, except compulsory social security	1.527	1.567	1.525	1.821	1.508	1.432	2.066	1.641	2.505	3.421	2.972	2.660	2.460
102	Activities auxiliary to financial intermediation	0.385	0.455	0.573	0.631	0.713	0.579	0.860	0.642	0.980	1.138	1.045	1.114	1.205
103	Real estate activities with own property; letting of own property,	0.004	0.003	0.003	0.004	0.004	0.004	0.004	0.003	0.004	0.004	0.004	0.008	0.007
104	Letting of dwellings, including imputed rent	1.441	1.693	1.747	2.264	1.808	1.885	2.128	1.773	2.357	2.811	2.679	2.901	2.787
105	Real estate activities on a fee or contract basis	0.038	0.047	0.051	0.061	0.064	0.079	0.077	0.066	0.085	0.108	0.128	0.131	0.167
106	Renting of machinery and equipment without operator and of	0.719	0.798	0.756	0.901	0.776	0.723	0.781	0.646	0.860	0.923	0.816	0.750	0.659
107	Computer and related activities	0.646	0.763	0.979	1.477	1.272	1.209	1.661	1.229	1.598	1.676	1.617	1.738	1.793
108	Research and development	0.104	0.129	0.148	0.151	0.200	0.233	0.368	0.357	0.380	0.550	0.613	0.764	0.825
109	Legal activities	0.077	0.085	0.091	0.106	0.104	0.120	0.137	0.108	0.158	0.188	0.228	0.211	0.281
110	Accounting, book-keeping and auditing activities; tax consultancy	0.006	0.008	0.009	0.014	0.011	0.017	0.030	0.032	0.033	0.036	0.043	0.040	0.048
111	Market research and public opinion polling; business and	0.080	0.080	0.075	0.087	0.079	0.087	0.118	0.091	0.107	0.112	0.132	0.131	0.117
112	Architectural and engineering activities and related technical	0.330	0.361	0.392	0.476	0.461	0.458	0.552	0.381	0.423	0.583	0.520	0.577	0.615
113	Advertising	0.084	0.097	0.099	0.127	0.101	0.078	0.147	0.117	0.171	0.195	0.192	0.269	0.225
114	Other business services	0.663	0.746	0.821	1.033	1.025	0.970	1.113	0.927	1.162	1.348	1.533	1.593	1.449
115	Public administration and defence; compulsory social security	9.860	9.914	10.014	10.815	9.980	9.220	12.257	9.797	11.010	12.738	14.075	18.549	17.997
116	Education	2.442	2.668	2.613	3.252	3.224	3.346	3.410	2.551	3.406	3.926	4.134	4.445	4.353
117	Human health and veterinary activities	4.341	4.714	4.965	6.570	5.745	5.169	6.384	5.626	7.358	10.005	10.499	12.579	12.411
118	Social work activities	1.254	1.319	1.315	1.489	1.448	1.395	1.314	1.091	1.312	1.614	1.958	2.435	2.605
119	Sewage and refuse disposal, sanitation and similar activities	0.420	0.515	0.517	0.672	0.545	0.512	0.573	0.451	0.609	0.710	0.758	0.823	0.825
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	3.084	3.387	3.480	4.176	3.746	3.673	4.029	3.478	3.877	4.382	4.926	5.675	5.623
122	Other service activities	0.796	0.877	0.885	1.088	0.972	0.952	1.072	0.791	1.016	1.143	1.129	1.205	1.123
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)	**206**	**227**	**235**	**282**	**253**	**259**	**291**	**263**	**291**	**336**	**343**	**380**	**374**
	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

14 Appendix G: References

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