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A CARBON FOOTPRINT TIME SERIES OF THE UK – RESULTS FROM A MULTI-REGION INPUT–OUTPUT MODEL

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The framework and results of an international multi-region input–output (MRIO) model for the UK are presented. A time series of balanced input–output tables for the UK was constructed for the period 1992 to 2004 by using a matrix balancing procedure that is able to handle conflicting external data and inconsistent constraints. Detailed sectoral and country-specific trade data for the UK were compiled and reconciled with the UK input–output data, and economic and environmental accounts for three world regions were integrated in a UK-specific MRIO model. This was subsequently used to calculate a time series of national carbon footprints for the UK from 1992 to 2004. Greenhouse gas emissions embedded in UK trade are distinguished by destination of imports to intermediate and final demand. Most greenhouse gases show a significant increase over time in consumer emissions and a widening gap between producer and consumer emissions. Net CO_2 emissions embedded in UK imports increased from 4.3% of producer emissions in 1992 to a maximum of 20% in 2002. The total estimated UK carbon footprint in 2004 was 730 Mt for CO_2 and 934 Mt CO_2 equivalents for all greenhouse gases.

Keywords: Multi-region input–output model; Embedded greenhouse gas emissions; Carbon footprint; Consumer emissions; Balance of emissions embedded in trade (BEET); UK

1. INTRODUCTION

The traditional approach of accounting for greenhouse gas emissions of a country under the United Nations Framework Convention on Climate Change (UNFCCC) (United Nations, 1992, Article 12, p.15) takes a production-based, or territorial, perspective. A complementary approach is to include emissions associated with imports to the country and subtract export-related emissions. This consumption-based, or ‘footprint’, perspective (Munksgaard and Pedersen, 2001; Peters, 2008) has recently attracted wider attention in the context of the ongoing climate policy negotiations for an international, post-Kyoto agreement on climate change (Peters and Hertwich, 2008a, 2008b; Hertwich and Peters, 2009). It opens up the possibility of extending the range of policy and research applications considerably, e.g. on the change in global and trade-related emission levels

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resulting from a relocation of production between countries (Weber et al., 2008; Guan et al., 2009). In the international policy context consumption-based emission accounting is mainly framed as a discussion on how to assign responsibility for emissions between countries (e.g. Andrew and Forgie, 2008; Peters and Hertwich, 2008b).

In the United Kingdom, the ‘Framework for Sustainable Consumption and Production (SCP)’, launched by the UK Department for the Environment, Food and Rural Affairs in 2003 (DEFRA, 2003), led to an increasing policy focus on the life-cycle environmental and social impacts of goods and services consumed in the UK. More recently there has been an increasing emphasis on the idea that companies take some responsibility for the production-related impacts of the goods that 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 a study to identify the most appropriate approach to constructing an indicator for emissions embedded in trade flows to and from the UK. One of the conclusions from that study was that it is important to consider explicitly 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 has sufficiently disaggregated sectors (Wiedmann et al., 2007). It was furthermore concluded that an international multi-region input–output (MRIO) model would be the most suitable approach for the purpose of national carbon footprint accounting.

As a follow-up, the first stage of the implementation of a UK-MRIO model was commissioned by DEFRA with the goal to produce a reliable and robust account of environmental impacts of trade and thus overall UK consumption in a headline indicator for Sustainable Development. One central question was whether any reductions in UK greenhouse gas emissions over time were being offset by increases in embedded emissions associated with the production of imports to the UK. The project was therefore to compare the production and the consumption-based national emission inventory over a period of time. This was also to be the first truly multi-regional model explicitly developed for the UK and using the most detailed input–output data possible.

This paper presents the theoretical framework and empirical results of this project, which had the aim of developing a robust model for an ‘embedded carbon emissions indicator’ (Wiedmann et al., 2008). Section 2 presents a brief review of the literature on similar carbon footprint studies in the UK. A time series of input–output tables from 1992 to 2004 has been constructed as a prerequisite to assemble a UK-specific multi-region input–output model; the novel balancing technique to accomplish this task was used for the first time in a real application and is described in the methodology chapter (Section 3). Detailed sectoral and country-specific trade data for the UK were then compiled and reconciled with input–output data, and economic and environmental accounts for three world regions were integrated in the MRIO model (Section 4). Results for greenhouse gas (GHG) emissions, in particular CO_2 emissions, are presented in Section 5. Section 6 concludes.

As part of the UK-MRIO project we also set out to quantify the error margins associated with the results from the model. The sensitivity of the model with respect to parameter uncertainty was tested by performing a Monte Carlo analysis of the whole model system. The methodology and results of this analysis have been presented in a parallel paper in *Economic Systems Research* (Lenzen et al., 2010, this issue).

2. EVIDENCE FROM THE LITERATURE

A comprehensive review of the literature on models for estimating greenhouse gas emissions embedded in trade has been published previously (Wiedmann et al., 2007; Wiedmann, 2009b). In the following we concentrate on literature referring to the United Kingdom.

Recent studies report an increase in UK carbon dioxide and GHG emissions when calculated according to the consumption perspective. Druckman et al. (2008) estimate total UK consumer emissions of carbon dioxide (UK carbon footprint) by using a two-region input–output model with a domestic technology assumption for the CO_2 intensity of imports, i.e. it is assumed that imported goods have the same upstream carbon footprint per monetary unit as those produced in the UK. They find a rise of 8% in total UK consumption-based emissions between 1990 and 2004 accompanied by a shift in the trade balance of embedded emissions towards imports. This suggests 'that the UK is increasingly exporting its more carbon intensive industries' (Druckman et al., 2008, p. 601) and confirms the trend that consumer products are increasingly imported and not produced within the UK. The authors stress the 'severe policy implications' (Druckman et al., 2008, p. 602) in conjunction with any attempts to reduce emission.

A similar trend is observed by Druckman and Jackson (2009) for the carbon footprint of UK households. In this work, the authors relax the domestic technology assumption in their previous study (Druckman et al., 2008) by deriving different carbon dioxide intensity coefficients of imported products.[1] Results show that carbon dioxide emissions attributable to UK households were 17% above 1990 levels (539 Mt CO_2) in 2004 (631 Mt CO_2), and are estimated to have been increasing by about 3% per annum between 1997 and 2004. The authors furthermore estimate that, in 2004, approximately 48% of embedded carbon dioxide emissions were due to imports from outside the UK, up from 37% in 1990.

The third study considered here, which is by Helm et al. (2007), presents a consumption account of UK greenhouse gas emissions including indirect emissions from overseas tourism, international aviation and shipping and embedded emissions in the UK's trade balance.[2] The latter estimate was derived by multiplying values of imports and exports with average carbon dioxide intensities by country. The study finds a steep increase in emissions embedded in imports – from below 300 Mt CO_2 equivalents (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 sixfold 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.

Another UK-specific study is presented by Minx et al. (2008) who apply structural path analysis in a generalised multi-region input–output model covering 57 sectors and 81

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[1] Using relative intensities from the GTAP 6 database and trade data by region and sector, the model distinguishes the carbon dioxide intensity of 87 countries and world regions. However, the industry structure of the second region in the model is still represented by the UK technology matrix.

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

world regions to identify GHG emission hotspots in the international supply chain of meat products. They find that meat products together account for more than 50% of the UK's food-related carbon footprint. With further analysis required to confirm the results, the analysis suggests that CO_2 might be more important in comparison to CH_4 and N_2O in the global supply chain of meat products than previously suggested in UK life cycle analysis studies. In fact, for non-ruminant and further processed meat products, CO_2 can be the most important individual greenhouse gas driven by energy related CO_2 emissions arising beyond the farm-gate in subsequent manufacturing and distribution processes – a result that has implications on conventional process-based LCA studies that truncate the analysis at lower order upstream production steps.

The main message from the recent literature is unambiguous. The interest in consumption-based emissions accounting has grown significantly. A respectable number of models have been developed worldwide in order to estimate emissions embedded in international trade of numerous countries and regions. Input–output approaches are commonly chosen as they provide the most appropriate methodological framework for complete carbon footprint estimations at the national and supra-national level. However, this is the first time that a bespoke multi-region input–output model has been developed for the UK and applied specifically to create a time series of the UK national carbon footprint. In this paper, we focus on the construction of the model, the data requirements and the interpretation as well as the comparison of the results with other studies. We also touch on the political relevance of the work, which in turn emphasises the importance of this strand of input–output analysis.

3. METHODOLOGICAL APPROACH

The implementation and application of an environmentally extended multi-region input–output framework poses three basic challenges: data availability, data reconciliation and computability. These issues and possible practical solutions have been discussed in detail previously by some of the authors (Lenzen et al., 2004; Turner et al., 2007). Here, we first discuss the issues associated with the development of the data handling protocol before we present the multi-regional model set-up used in this work. This is followed by a description of the data preparation, including the estimation of a time series of UK input–output tables for 1992 and 2004, and the specific limitations of the model.

3.1. Data Handling Protocol

Compiling the required data, estimating missing data and balancing conflicting data 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 able to

- include data in different classifications;
- handle conflicting data consistently;
- cope with suppressed data;
- estimate missing data; and
- accommodate different years for the analysis of time series.

In essence, the data framework employs a novel optimisation technique, called KRAS, which balances data according to constraints that are defined by available data (Lenzen et al., 2009). A prerequisite of KRAS are concordance matrices that match data from different classifications and data templates that translate between original/available data and balanced/optimised data sheets. These templates 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. The outcome of the subsequent KRAS process is a set of balanced data sheets reconciling all external constraints.

Such a data framework is very flexible and easily expandable. It 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. In addition, estimates of uncertainties can 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 (see Lenzen et al., 2004 and Wiedmann et al., 2006). Supply and use matrices can be left separately as shown in the next section. The subsequent inversion of the compound matrix implicitly leads to the same result as the explicit multiplication of the market share matrix by the use matrix in an industry-technology assumption (see, for example, Rueda-Cantuche et al., 2009). Apart from the advantage that arranging data in SUT blocks allows the user to associate physical information, such as greenhouse gas emissions, with either industries or commodities or both, the crucial advantage in the case of the UK is data timeliness. The latest available analytical table is from 1995, whereas supply and use tables are published with a time lag of only two to three years. This reduces uncertainty in the model because changes in the structure of the economy are reflected more accurately if up-to-date input–output information is used.

3.2. Definition of the UK-MRIO Model using a SUT Data Framework

The basic layout of the model framework is depicted in Table 1. For the purpose of this work, which was 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).[3]

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 considered imports to the UK from the world regions and total UK exports, assuming that these uni-directional trade flows are dominant in determining the emissions embedded in total UK trade. We did not model trade flows between the regions themselves. This is due to the fact that imports (and/or exports) matrices between the three world regions were not readily available and the project resources did not allow estimating these matrices from other data sources. Previous research suggests that this failure to account for non-UK trade and for

[3] This decision was driven by data availability and practical considerations.

TABLE 1. Multi-region input–output (MRIO) system employed in this work.

		Intermediate demand								Final demand		
		UK(u)		Region e		Region o		Region w		UK(u)	Region r (=e+o+w)	Total output
		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		$\mathbf{U}^{eu}$		$\mathbf{U}^{ee}$					$\mathbf{y}^{eu}$	$\mathbf{y}^{er}$	$\mathbf{q}^{e}$
	ind			$\hat{\mathbf{q}}^{e}$								$\mathbf{g}^{e}$
Region o	prod		$\mathbf{U}^{ou}$				$\mathbf{U}^{oo}$			$\mathbf{y}^{ou}$	$\mathbf{y}^{or}$	$\mathbf{q}^{o}$
	ind					$\hat{\mathbf{q}}^{o}$						$\mathbf{g}^{o}$
Region w	prod		$\mathbf{U}^{wu}$						$\mathbf{U}^{ww}$	$\mathbf{y}^{wu}$	$\mathbf{y}^{wr}$	$\mathbf{q}^{w}$
	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)
- Region o OECD non-Europe countries (superscript o)
- 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 products
- $\mathbf{y}^{ur}$ Column vectors of final export demand on UK products (exports of goods and services)
- $\mathbf{y}^{ru}$ Column vectors of total final demand in the UK on products imported from region r
- $\mathbf{y}^{rr}$ Column vectors of total final domestic demand on products in region r
- $\mathbf{y}^{sr}$ Column vectors of final demand in country r for products of country s
- $\mathbf{w}^{r}$ Row vectors of primary inputs (income, surplus, tax) into industries (note that $\mathbf{w}^{r}$ contains only value added items and no imports because the latter are contained in the $\mathbf{U}^{ru}$ matrices).
- $\mathbf{E}^{r}$ Row vector of GHG emissions by industry in country/region r

trade feedback loops will not have a major impact on total emission estimates (Lenzen et al., 2004), especially when the number of regions in the model is small (Andrew et al., 2009).

The next step is to derive technical coefficient matrices from the transaction matrices. Defining input coefficient matrices $\mathbf{A}^{rs}$ with $a_{ij}^{rs} = u_{ij}^{rs}/g_j^r$ and output coefficient matrix $\mathbf{B}^{rs}$ with $b_{ij}^{rs} = v_{ij}^{rs}/q_j^r$, we derive a compound direct requirements matrix (the term 'compound' refers to maintaining the representation of supply and use tables, rather than a symmetric input–output table):

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

Setting

$$\mathbf{y}^* = \begin{pmatrix} \mathbf{y}^u \\ 0 \\ \mathbf{y}^{eu} \\ 0 \\ \mathbf{y}^{ou} \\ 0 \\ \mathbf{y}^{wu} \\ 0 \end{pmatrix}, \quad \mathbf{g}^* = \begin{pmatrix} \mathbf{q}^u \\ \mathbf{g}^u \\ \mathbf{q}^e \\ \mathbf{g}^e \\ \mathbf{q}^o \\ \mathbf{g}^o \\ \mathbf{q}^w \\ \mathbf{g}^w \end{pmatrix} \tag{2}$$

with $\mathbf{y}^u = \mathbf{y}^{uu} + \mathbf{y}^{ur}$ = total final demand for the UK, allows us to calculate $\mathbf{A}^*$, which satisfies the basic input–output relationship

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

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

4. DATA PREPARATION AND MODEL LIMITATIONS

This section summarises data sources and manipulations. A detailed description of data preparation procedures can be found in Wiedmann et al. (2008). We also discuss specific assumptions and limitations of the UK-MRIO model. For the general limitations of environmental input–output models we refer to the literature (Miller and Blair, 2009).

4.1. UK Input–Output Data

For the years 1992 to 2004 – the time span investigated in this work – publicly available input–output data from the UK Office for National Statistics (ONS) are in the form of Supply and Use Tables (SUTs) (ONS, 2007b). Only for one year, 1995, is a symmetric 'Analytical Table (AT)' available, compiled by using a hybrid assumption with respect to joint production (Ruiz and Mahajan, 2002). This AT from 1995 also provides a matrix of imports to intermediate and final demand, and a transition matrix from basic to purchaser's prices.[4] Due to an ongoing, major modernisation programme, ONS will not produce an AT for the year 2000 (Beadle, 2007).

Since no matrices for imports to intermediate demand, margin flows and taxes are available for years other than 1995, a three-stage process has been employed, utilising a novel approach of constraint optimisation.

First, UK supply tables from Eurostat, 2007 in 59 sector resolution (and therefore superior to the 30 sector resolution published by ONS) were expanded to the desired 123×123 sector breakdown by using total output of industries and commodities as provided in other published tables (ONS, 2007b). This results in initial estimates for enlarged supply tables. Information on the principal product as a percentage of total industry output and of total commodity output (i.e. the proportion of diagonal versus non-diagonal elements) was used as constraints for the subsequent rebalancing described in the final step below.

Second, combined use tables for intermediate and final demand – as provided by ONS in 123 sector format (ONS, 2007b) were converted from purchasers' prices to basic prices and imports were 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 (valuation) matrix from the 1995 AT was used for the former step.

Finally, these initial estimates for SUTs for all years were reconciled by using a novel balancing technique – called KRAS – that is able to handle conflicting external data and inconsistent constraints. We achieve this capability by introducing standard error estimates for external data. The detailed KRAS procedures are described in Lenzen et al. (2009). A sensitivity analysis based on Monte Carlo simulation has been carried out to test the stability of the results (Lenzen et al., 2010, this issue).

The lack of original data on imports and margins for any year other than 1995 means that the structure of imports, taxes/subsidies and distribution margins of intermediate and final demand is increasingly determined by balancing available row and column totals, for years further away from 1995. Nevertheless, we think that the input–output tables produced in the UK-MRIO project represent an approximation of real economic activity close and robust enough for MRIO modelling purposes. In fact, they are currently the best publicly available input–output information for the UK.[5]

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[4] A 'transition matrix' contains the distribution margins and net taxes on products and is often referred to as 'valuation matrix' (see, for example, Rueda-Cantuche et al., 2009).

[5] Requests for these input–output tables can be directed to the corresponding author. They include (all in basic prices, by 123 sectors and for each year from 1992 to 2004): supply matrices (product by industry), use matrices for intermediate demand ($p \times i$), use matrices for final demand (for products), imports to intermediate and final demand from ROW ($p \times i$ and $p \times p$), symmetric input–output tables (SIOT) for domestic transactions ($p \times p$), and CO_2 direct emissions intensities by sector for the UK.

4.2. Non-UK Input–Output Data

Three world regions, OECD-Europe, other OECD and non-OECD countries, covering the global economy, are used as trading partners in the model. The Netherlands Environmental Assessment Agency (PBL) kindly provided us with 30-sector technical coefficient matrices for 1997 used in the study by (Nijdam et al., 2005) and based on the GTAP 5 database as well as with a similar dataset for the year 2001, based on GTAP 6.[6] Owing to a lack of data for years other than 1997 and 2001, static technical coefficients were assumed for three time periods: 1997 and earlier (using 1997 technical coefficients), 1998–2000 (using average coefficients) and 2001 and later (using 2001 technical coefficients).

Currency conversion from current US$ to current £ was performed by using purchasing power parity (PPP) for gross domestic product (GDP) from OECD for the two years 1997 and 2001 (OECD Statistics, 2008a). For all other years we used consumer price index (CPI) data from the OECD to correct for inflation (OECD Statistics, 2008b). All non-UK data were already in a consistent currency (US$) prior to conversion to pound sterling (£).

In the context of MRIO modelling, the pros and cons of using purchasing power parity (PPP) or market exchange rate (MER) as a mean for currency conversion have been discussed (Peters and Hertwich, 2006a) and the difference between the two methods has been quantified in a couple of MRIO studies (Weber and Matthews, 2007; Kanemoto and Tonooka, 2009). Arguably PPPs have advantages for cross-country comparisons of GDP and MERs are useful for trade data. There are also different types of PPPs (based on GDP or sector specific, different types of consumption) resulting in potentially large differences in international comparisons of real income, output and productivity (see, for example, Rao and Timmer, 2003). Whilst it was outside the scope of this present work we envisage investigating in the future whether the use of PPPs and MER can be combined in an automated hybrid technique and what the quantitative effect would be of using various degrees of conversion methods.

The sector aggregation (30 sectors for the three world regions versus 123 sectors in the UK), as well as the unavailability of coefficient matrices for all years, is thought to constitute a significant limitation of the model. This is because the imports to all UK sectors mapped onto the same foreign sector are treated with an average industry technology and greenhouse gas intensity.

A further limitation is that non-UK input–output data were only available for two years, 1997 and 2001, meaning that exact greenhouse gas (GHG) intensities (in tonnes per £ of output) could only be calculated for these two years. For other years, estimates for GHG intensities were derived by using GDP data from UN statistics to approximate total industry outputs for years other than 1997 and 2001 (see Section 4.4).

4.3. Trade Data and Imports Matrices

Data for trade in goods by 5-digit SITC (Standard International Trade Code) were obtained from HM Revenue & Customs for the years 1996–2004 (HMRC, 2007). Data on the UK trade in services is available from the ‘Pink Book’ published annually by ONS (ONS,

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[6] A description of the Global Trade Analysis Project (GTAP) database is given in Dimaranan (2006). For a critical discussion of the quality and usefulness of GTAP data for MRIO modelling see Peters (2007).

2006). The reconciliation with 123 UK input–output sector totals in Standard Industrial Classification (SIC 2003) and the estimation of trade data for the years 1992 to 1995/96 is described in Wiedmann et al. (2008).

The only information on the actual structure of imports to UK intermediate and final demand was one imports matrix from the UK Analytical Tables 1995 (ONS, 2007b). The initial estimation of import coefficients for years other than 1995 was therefore based on the assumption that the ratio of use of imports by industry over the total imports at the product level is constant over time.

A very important component of the MRIO system is separate tables for imports to the UK from each of the three world regions. We use trade coefficients to generate an initial (pre-balancing) estimate of trade flows to intermediate demand ($\mathbf{U}^{eu}$, $\mathbf{U}^{ou}$, $\mathbf{U}^{wu}$ in Table 1) and to final demand in the UK ($\mathbf{y}^{eu}$, $\mathbf{y}^{ou}$, $\mathbf{y}^{wu}$). We define the percentage of imports of commodity i into country s (here the UK) that come from country r as the trade coefficient c_i^{rs} according to

$$c_i^{rs} = \frac{u_i^{rs}}{\sum_r u_i^{rs}} \quad \text{with} \quad \sum\nolimits_r c_i^{rs} = 1 \tag{4}$$

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:

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

This procedure assumes that the trade coefficients are identical for all entries along a row of the imports matrix, i.e. for all using domestic industries.

The initial estimates for all imports matrices for all years, except for 1995 where original data were available, were subsequently re-balanced using the KRAS procedure (Lenzen et al., 2009) and total imports of commodities as constraints.

4.4. Greenhouse Gas Emissions and Intensities

Annual greenhouse gas (GHG) emissions estimates by the industrial sector for the UK economy were taken from the national Environmental Accounts (ONS, 2007a). The data distinguishes emissions from 91 production and two household activities (travel and non-travel). These total 'producer emissions' (PE) include the emissions from international marine transport and aviation ('bunker emissions'),[7] biomass burning and cross-boundary transport, but exclude land use change and forestry emissions (see Bridging Tables from Environmental Accounts, ONS, 2007a). The PE from Environmental Accounts are therefore different from those in the tables used for reporting to UNFCCC (IPCC) and UNECE.

UK GHG emissions data were further disaggregated to the 123 sector level of the supply and use tables. In the absence of better information, emissions were pro-rated according to gross commodity output.

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

CO_2 emission data for the rest of the world were taken from the database provided by the International Energy Agency. The data are restricted to emissions from fuel combustion and are consistent with the IPCC's sectoral approach (IEA, 2006, Chapter 5). However, in order to gain a more complete picture of GHG emissions embedded in products imported to the UK, emissions from international marine bunkers and international aviation were also included (Wiedmann et al., 2008b).

For non-CO_2 greenhouse gas emissions (CH_4, N_2O, HFC, PFC, SF_6) we combined sectoral estimates developed for the GTAP database (Rose and Lee, 2008) and updated these with sectoral estimates taken from the EDGAR database (van Aardenne et al., 2005). As non-CO_2 GHG emission estimates are only available for the years 1990, 1995 and 2000 we assumed linear trends in order to derive estimates for the time period 1992–2004.

A limitation in our UK-MRIO model is imposed by the sectoral detail of emissions data available by the time the work was undertaken. A full correspondence between Environmental Accounts and input–output data in the UK can only be established at a 76-sector level, meaning that only 76 direct emission intensities could be distinguished. For three world regions only 18 different direct GHG intensities could be assigned to the 30 economic sectors due to the limited breakdown of IEA data, although we used sectoral GDP estimates from the UN (United Nations, 2007) as a proxy for adjusting the output component of direct GHG 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 these three sectors for all years derived from initial information from the 1997 and 2001 GTAP data.

5. THE UK'S NATIONAL CARBON FOOTPRINT – RESULTS FOR EMBEDDED GHG EMISSIONS

The coverage of national greenhouse gas inventories under the Kyoto Protocol corresponds to the national territory and includes all greenhouse gas emissions from the production of goods and services within a country, wherever these are consumed (for the UK, see DEFRA, 2007). We refer to this account of territorial 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. We refer to these estimates as 'producer emissions (PE)' – also sometimes referred to as 'production-based' accounts. This measure includes export-related emissions, but does not 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' accounts, or 'footprints'[8] – refers to

[8] Compare to Wiedmann and Minx (2008).

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 (see also Peters and Hertwich, 2008b). The UNFCCC Inventory and the PE account reflect the way the UK economy provides goods and services to final consumers within the UK and across the world. The CE account can help to identify the driving forces behind the emissions from UK consumption. All three GHG emission accounts are relevant to the decisions needed to develop efficacious and fair policies and specific abatement strategies.

We now present results for the consumer emissions account in the UK, broken down by contributions from domestic production and imports as well as by destination, i.e. domestic final demand and exports. This is depicted in Figure 1, with:

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 = Emissions embedded in imports through intermediate consumption of UK industry attributable to UK final consumption;
3b = Emissions embedded in imports through intermediate consumption of UK industry attributable to UK exports;
4a = Emissions embedded in imports direct to final demand attributable to UK final consumption;
4b = Emissions embedded in imports 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.

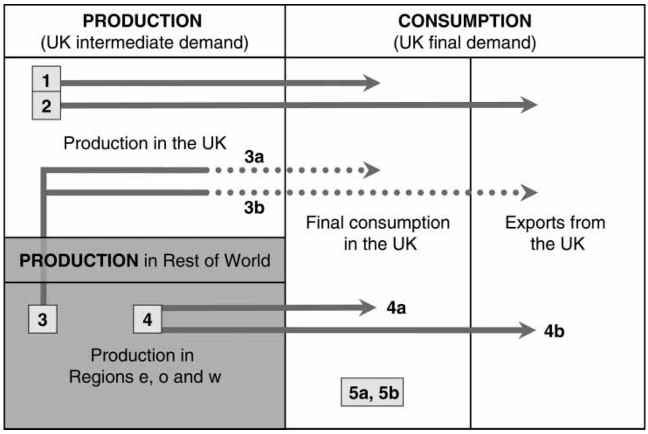
We define:

- Producer Emissions (PE) as **1 + 2 + 5a + 5b** (non-shaded areas in Figure 1).
- Consumer Emissions (CE, carbon footprint) as **1 + 3a + 4a + 5a + 5b**.
- Emissions Embedded in Imports (EEI) as **3a + 3b + 4a + 4b**. EEI occur outside the UK territory (shaded areas) but are caused by UK economic activity.[9]
- Emissions Embedded in Exports (EEE) as **2 + 3b + 4b**. EEE are caused by final demand from the rest of the world for UK products and occur mostly on UK territory (**2**), although some of these emissions occur outside of the UK (**3b + 4b**) when imports are re-exported.
- Balance of Emissions Embedded in Trade (BEET) as **2 – 3a – 4a** = EEE – EEI = PE – CE.

In the following, we first present results for carbon dioxide only and then for all greenhouse gases further below. Figure 2 (and Table A1 in the Appendix) shows the modelling results for all accounting principles and categories of embedded CO_2 emissions as a time series from 1992 to 2004. The main findings are as follows.

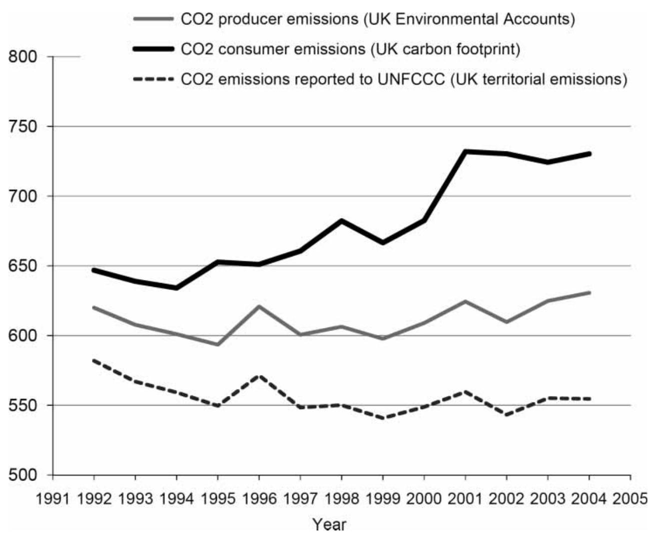
[9] In the literature, the term ‘embodied’ emissions seems to be more widespread. We treat ‘embedded’ and ‘embodied’ as synonyms.

FIGURE 1. Depiction of origin and attributed destination of GHG emissions caused by UK economic activity.



Note: Arrows should be read as 'emissions generated by [beginning of arrow] attributed to [end of arrow]', see text for more details. Region e = OECD Europe, Region o = OECD non-Europe, Region w = non-OECD countries.

FIGURE 2. Total UK CO_2 emissions from 1992 to 2004 according to different accounting principles.



Note: the vertical scale does not start at zero.

- CO_2 consumer emissions are significantly higher than producer emissions or the UNFCCC national total for all years (in 2002, CE were 121 Mt or 20% higher than PE and 186 Mt or 34% higher than the national total reported to the UNFCCC, including overseas territories, see also Figure 2).
- Whilst falling in the early 1990s, CO_2 consumer emissions have increased considerably between 1994 and 2001 and then remained on a level of about 730 Mt in the early 2000s.

From 1992 to 2004, the increase in CE was 13%, while the total territorial emissions reported to the UNFCCC have declined by 5%.

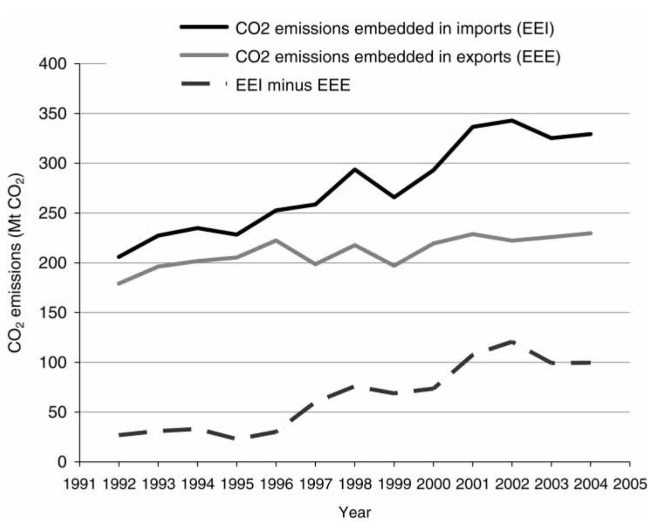
- CO_2 emissions embedded in imports (EEI) are higher than emissions embedded in exports (EEE) for all years. Both increased over time but EEI rose much faster (by 60% between 1992 and 2004) than EEE (by 28%).
- There is a clear trend towards an increasing deficit in the balance of emissions embedded in trade (BEET), meaning that more and more emissions have been 'imported' rather than 'exported'. BEET was −27 Mt of CO_2 in 1992 (−4.3% of producer emissions) and peaked in 2002 with −121 Mt (20% of PE). This is also depicted in Figure 3.

The increase of embedded emissions over time can be compared with a general increase in the trade of goods and services over the same time period. Imports and exports of services have grown faster than those for goods and the trade balance for both goes in an opposite direction (ONS, 2006, pp. 30–53). The finding that CO_2 EEI grow considerably faster than CO_2 EEE (Figure 3) can thus be explained by the increase in imports of goods that have a higher direct CO_2 intensity than services.

Emissions embedded in 'through trade' make up a considerable proportion of emissions embedded in imports and exports (see Table A1 in the Appendix). 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 1992; this figure increased steadily and peaked in 2002 with 38% of EEE coming from import sources.

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',

FIGURE 3. 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.



'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, 2007b) and embedded emissions can be assigned to them (as, for example, done by Hertwich and Peters, 2009) This would provide further insight into the causes for embedded emissions. However, this task was beyond the scope of this paper.

The results from the UK-MRIO model are in line with findings from other researchers. Previous studies applying a range of different methods also suggest that more embedded CO_2 emissions are imported to the UK than exported (see Table 2). The most likely reasons for the differences between other studies and this study are different baseline estimates for territorial (producer) emissions, the use of non-IO techniques, the use of domestic intensities (single-region instead of multi-region assumption) and the use of out-of-date IO tables in some of the studies.

None of these limitations occur in the UK-MRIO model, which is why UK-MRIO can be seen as having a higher level of reliability, as does the multi-regional model provided by Peters and Hertwich (2008a). In fact, results of the UK-MRIO model compare best with the results of their more detailed, multi-directional multi-region input–output model. The calculations by Wilting and Vringer (2009) produce the highest estimate for consumer emissions. In their 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 to which the country belongs, thus limiting country-specific estimations.

Figure 4 shows the time series for all six direct greenhouse gases listed under the UNFCCC for producer emissions (taken directly from UK Environmental Accounts) and consumer emissions (results from the UK-MRIO model). A striking feature of these results is that consumer emissions are consistently higher than producer emissions for all GHGs, except for HFC where CE only became larger than PE from 1999 onwards. Total GHG consumer emissions show a similar pattern to CO_2 with a significant increase between 1994 and 2002 from 844 to 952 Mt CO_2 equivalents (CO_2-e). Consumer emissions of methane (CH_4), however, have declined steadily over the whole time period (from 145 Mt CO_2-e in 1992 to 118 Mt CO_2-e in 2004). This decrease was solely achieved by reductions in the UK's territorial CH_4 emissions of almost 50%. In fact, this impressive decline of territorial methane emissions was partly compensated by increased emissions embedded in imports, which becomes obvious when looking at details of the trade balance. Methane EEI went up 33% while methane EEE went up only 9%.

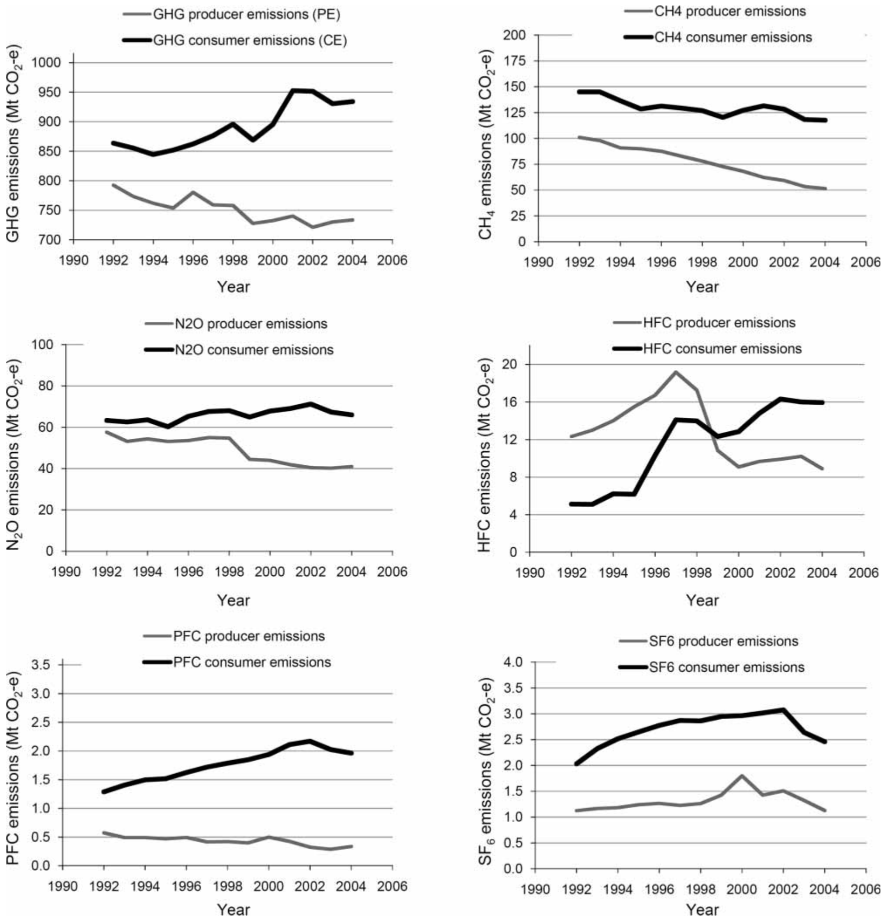
A similar picture can be observed for nitrous oxide and the fluorinated greenhouse gases. N_2O PE decreased by 29% between 1992 and 2004 while the CE increased by 4.2%. Producer emissions of F-gases have remained constant over time or have fallen slightly while their consumer emissions have all increased from 1992 to at least 2002. Note that until 1999, production-based emissions of HFC were higher than consumption-based emissions, indicating a fairly abrupt shift from exports to imports of emissions for this greenhouse gas used in refrigeration (EEE went down by 55% while EEI increased sharply by 773% between 1992 and 2004).

In conclusion it can be said that there is a very clear and significant trend for all greenhouse gases: between 1992 and 2004 the territorial (production-based) emissions have either decreased or remained constant whereas more and more emissions can be attributed to imports to the UK driven by increased demand for intermediate or final products from

TABLE 2. Comparison of CO_2 emissions embedded in UK trade as estimated by different studies (all numbers in Mt of CO_2).

	Druckman et al. (2008)	Harrison et al. (2003)	Nakano et al. (2009)	Nakano et al. (2009)	Wilting and Vringer (2009)	Peters and Hertwich (2008a)	Carbon Trust (2006)	Druckman et al. (2008)
Year	1990	1995	1995	2000	2000	2001	2002	2004
PE	638.0	536.0	533.0	526.0	580.8	618.6	603.9	639.5
CE	643.1	549.0	623.0	722.0	819.8	721.3	646.8	692.6
BEET	−5.1	−13.0	−90.0	−196.0	−239.1	−102.7	−42.9	−53.2
BEET as % of PE	−0.8%	−2.4%	−16.9%	−37.3%	−41.2%	−16.6%	−7.1%	−8.3%
		UK-MRIO (this work)		UK-MRIO (this work)		UK-MRIO (this work)		UK-MRIO (this work)
Year		1992		2000		2001		2004
PE		620.0		609.0		624.4		630.6
CE		646.8		682.5		731.9		730.3
BEET		−26.9		−73.5		−107.5		−99.6
BEET as % of PE		−4.3%		−12.1%		−17.2%		−15.8%

FIGURE 4. Total production-based (producer emissions) and consumption-based (consumer emissions) greenhouse gases in the UK from 1992 to 2004 (in megatonnes of CO_2 equivalents, Mt CO_2-e).



Note: (a) all six direct greenhouse gases combined (as per UNFCCC; note that the vertical scale doesn't start at zero). (b) methane (CH_4) (c) nitrous oxide (N_2O) (d) Hydrofluorocarbons (HFC) (e) Perfluorocarbons (PFC) (f) Sulphur hexafluoride (SF_6)

outside the UK. This has led to an increase in consumer emissions for all greenhouse gases until 2002, except for methane. Between 2002 and 2004, consumer emissions of GHGs have fallen slightly.

6. CONCLUSIONS

The completion of the first stage of a UK specific multi-region input–output model has achieved the production of a time series of balanced input–output tables for the UK from 1992 to 2004 and the robust estimation of the UK's national carbon footprint over the same time period.[10] We have juxtaposed consumer and producer emission estimates for six greenhouse gases and have broken down CO_2 emissions embedded in imports to the UK by destination to intermediate and final demand. The trade balance for embedded CO_2 emissions was calculated for the 13 year period, showing an increased deficit in the balance of emissions embedded in trade. This is due to a strong increase of 60% for emissions embedded in imports whereas export-related emissions have only risen by 28%. A similar significant increase over time in consumer emissions and widening gap to territorial (producer) emissions can be observed for all greenhouse gases, at least until 2002, after which consumer emissions have remained fairly constant.

The construction of balanced supply and use as well as symmetric input–output tables for each year from 1992 to 2004 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 the Office for National Statistics (Beadle, 2007), Analytical Tables for the years 2000 and 2005 will not be produced by the UK Government until 2011.

The UK-MRIO model is also the first 'real world' application of a novel matrix balancing procedure, called KRAS, developed at the University of Sydney (Lenzen et al., 2007, 2009). This shows that KRAS is able to provide useful results in an empirical context. Furthermore, the sensitivity of the model system with respect to parameter uncertainty was tested by performing a Monte Carlo analysis of the whole model system. The results of this uncertainly analysis (presented in Lenzen et al., 2010, this issue) show that the relative standard error for total CO_2 consumer emissions is in the region of 5% and that CO_2 emissions embedded in UK imports were statistically significantly higher than those for exports in all years from 1992 to 2004.

For the future development of the UK-MRIO model, we would suggest identifying and including the most important trading partners of the UK and discerning more detail in UK and foreign production structure in key areas such as energy (e.g. renewables), transport and agriculture. Such a more comprehensive and detailed environmental MRIO system would allow answering very specific policy (and research) questions. In particular, the model would include multi-directional trade and thus enable us to trace the origin and path of, and thus the cause for, embedded emissions in unprecedented detail (see, for example, Peters and Hertwich, 2006b). 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.

The results from the UK-MRIO project report (Wiedmann et al., 2008) have received some media attention in the UK with articles in several daily newspapers as well as coverage by BBC television and radio. The UK national carbon footprint time series was also published as one of the UK Government Strategy indicators on sustainable development (DEFRA, 2008, p. 24). The document shows the total 'Carbon dioxide emissions associated with UK consumption, 1992 to 2004', alongside the territorial accounts of greenhouse gas emissions reported to the UNFCCC. This seems to confirm a similar trend of public

[10] The UK-MRIO model has also been used to estimate fossil fuel energy footprints embedded in UK trade (Wiedmann, 2009a).

interest in other countries and regions to account for emissions from a consumption perspective and thus to obtain additional information into the causes of and possible mitigation options for GHG emissions.

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APPENDIX

Table A1 presents the 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 model, the lower part shows the comparison with the UK Environmental Accounts and the emissions reported to the UNFCCC (bridging table). All numbers represent Mt of CO_2.

TABLE A1. CO_2 emissions associated with UK economic activity and embedded in international trade from and to the UK. (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)	343.1	318.6	315.1	310.0	317.0	314.0	315.2	315.0	316.2	329.2	320.3	326.5	329.1
Domestic UK Emissions due to export (2)	131.2	139.3	141.8	144.9	151.0	139.9	143.0	133.9	143.8	143.3	138.6	147.4	148.6
Imported emissions to domestic industry due to UK final consumption (3a)	74.2	78.8	79.1	97.4	86.3	86.0	95.1	76.0	99.0	117.2	119.8	115.2	118.6
Imported emissions to domestic industry due to UK exports (3b)	35.6	42.5	45.3	62.8	53.7	46.2	55.4	40.7	56.8	64.2	64.6	61.6	63.5
Imported emissions direct to final demand due to UK final consumption (4a)	83.9	91.6	95.7	106.8	94.9	114.0	123.8	126.7	118.3	133.5	139.5	131.5	129.7
Imported emissions direct to final demand due to UK exports (4b)	12.4	14.4	14.7	15.0	17.7	12.4	19.3	22.4	18.8	21.4	19.0	16.9	17.5
UK residential emissions not due to travel (e.g. housing) (5a)[11]	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)	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)	646.8	638.9	634.1	652.7	651.0	660.6	682.2	666.5	682.5	731.9	730.4	724.2	730.3
Emissions embedded in total trade (EET) (2 + 3a + 3b + 4a + 4b)	337.2	366.7	376.6	373.2	403.6	398.4	436.6	399.7	436.8	479.7	481.4	472.6	477.9
Emissions Embedded in Exports (EEE) (2 + 3b + 4b)	179.2	196.2	201.8	205.3	222.4	198.5	217.7	197.0	219.4	228.9	222.2	225.8	229.6
Emissions Embedded in Imports (EEI) (3a + 3b + 4a + 4b)	206.0	227.3	234.9	228.3	252.6	258.6	293.6	265.9	293.0	336.4	342.8	325.2	329.3
Balance of Emissions Embedded in UK Trade (BEET) (2-3a-4a)	−26.9	−31.1	−33.1	−22.9	−30.2	−60.0	−75.9	−68.8	−73.5	−107.5	−120.7	−99.4	−99.6
BEET as percentage of producer emissions	−4.3%	−5.1%	−5.5%	−3.9%	−4.9%	−10.0%	−12.5%	−11.5%	−12.1%	−17.2%	−19.8%	−15.9%	−15.8%
National emission accounts (ONS, 2007a *and personal comm.)*													

(*Continued*)

Table A1. Continued

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
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 (-)[12]	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

[11] Note that ONS Environmental Accounts include a small amount of direct emissions from British tourists overseas, which do not occur on UK territory (in categories **5a** and **5b**). The accounts measure puts emissions on a UK residents' basis by including all emissions generated by UK households and business transport at home and abroad and excluding emissions generated by non-residents [visitor] 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, p. 28).

[12] These adjustments are (i) to correct 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.