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METHODS

Allocating ecological footprints to final consumption categories with input–output analysis

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Abstract

We present and discuss a method that allows the disaggregation of national Ecological Footprints by economic sector, detailed final demand category, sub-national area or socio-economic group. This is done by combining existing National Footprint Accounts with input–output analysis. Calculations in the empirical part are carried out by using supply and use tables for the United Kingdom, covering the reporting period 2000. Ecological Footprints are allocated to detailed household consumption activities following the COICOP classification system and to a detailed breakdown of capital investment. The method presented enables the calculation of comparable Ecological Footprints on all sub-national levels and for different socio-economic groups. The novelty of the approach lies in the use of input–output analysis to re-allocate existing Footprint accounts, in the detail of disaggregation by consumption category and in the expanded use of household expenditure data. This extends the potential for applications of the Ecological Footprint concept and helps to inform scenarios, policies and strategies on sustainable consumption. The method described in this paper can be applied to every country for which a National Footprint Account exists and where appropriate economic and environmental accounts are available. The approach helps to save time in data collection and improves the consistency between Ecological Footprint estimates for a particular human society from different researchers. For these reasons, the suggested methodology includes crucial steps on the way towards a standardisation of Ecological Footprint accounts.

Keywords: Ecological footprint; Input–output analysis; Comparability; Allocation method; Household expenditure; Sustainable consumption

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1. Introduction

1.1. The need for a combined Ecological Footprint approach

1.1.1. Current Ecological Footprint accounting and some of its insufficiencies

The Ecological Footprint measures human demand on nature by assessing how much biologically productive land and sea area is necessary to maintain a given consumption pattern. This can then be compared to available biocapacity, also expressed in land and sea areas. If global demand on area exceeds global supply of biologically productive area, this would indicate an overshoot, which is a core concern for sustainability. While initially introduced in the 1990s (Wackernagel and Rees, 1996), the method has been further developed and has been used in numerous studies in recent years (e.g. Wackernagel et al., 1999; Simmons et al., 2000; Barrett, 2001; Lenzen and Murray, 2001, 2003; Lewan and Simmons, 2001; Barrett and Scott, 2003; Stöglehner, 2003; Wood and Lenzen, 2003; McDonald and Patterson, 2003, 2004; Erb, 2004; Haberl et al., 2004; Monfreda et al., 2004; Nijkamp et al., 2004; Wackernagel et al., 2004a; Aall and Norland, 2005; Barrett et al., 2005; van Vuuren and Bouwman, 2005). In 2004, a new set of Ecological Footprints for 149 countries of the world has been calculated and published in the Living Planet Report 2004 (WWF, 2004). The Ecological Footprint has been adopted by a growing number of government authorities, agencies, organisations and communities as a metric of ecological performance (e.g. Environment Waikato, 2003; EPA Victoria, 2003; James and Desai, 2003; WSP Environmental and Natural Strategies, 2003a,b; NAfW, 2004; NRG4SD, 2004).

Despite its success and popularity, the Ecological Footprint concept has been criticised for, amongst other issues, not accurately reflecting the impacts of consumption (van den Bergh and Verbruggen, 1999; Lenzen and Murray, 2001; Ferng, 2002), not correctly allocating responsibilities (Herendeen, 2000; McGregor et al., 2004a) and not being useful for policy makers (van den Bergh and Verbruggen, 1999; Ayres, 2000; Moffatt, 2000; Ferng, 2002).

In particular, the current National Footprint Account (NFA) method which is based on resource balance accounting on a national scale (Monfreda et al., 2004) neither provides a breakdown by economic sector nor by final demand category or detailed consumption activity. Although based on a comprehensive account of resource flows, it does not rely on consumption statistics by economic sector and hence fails to depict the mutual interrelationships of economic activities and to assign indirect environmental burden arising from inter-industrial dependencies. For example, the NFA method does not provide Ecological Footprints for services that often use a very small amount of resource inputs directly. However, services trigger resource flows indirectly, because they use numerous intermediate products from other industries for their service provision. Rosenblum et al. (2000) and Suh (2004a) for example show that those indirect requirements account for the majority of resource use of services.

Furthermore, two specific problems arise when one tries to generate Ecological Footprints for use in decision-making by local or regional governments and authorities:

- Lack of data: the smaller the area and population under investigation the more difficult it becomes generally to obtain accurate data on resource consumption. Detailed information on the consumption volumes of materials and products is usually only held at the national level (in databases such as PRODCOM[1] or UN Comtrade[2]). At local authority level only few data are available; examples for the UK being the consumption of electricity and natural gas (DTI, 2004) or municipal waste (DEFRA, 2004).
- Comparability of results: numerous Footprint studies for sub-national geographical areas in recent years have used different methods and data sets and have produced results that are not directly comparable with each other. Initial recommendations to tackle this problem were drawn from an international workshop in the European Common Indicators Project (Lewan and Simmons, 2001).

[1] Products of the European Community, Eurostat, http://epp.eurostat.cec.eu.int/portal/page?_pageid=1090,1137397&_dad=portal&_schema=PORTAL.

[2] UN Commodity Trade Statistics Database, UN Statistics Division, http://unstats.un.org/unsd/comtrade.

However, no commonly accepted procedure of calculating sub-national Footprints is yet available. This is of concern for decision-makers who might want to adopt the Ecological Footprint as a performance indicator, suggesting a need for a standardised methodology for Footprint accounting at both national and sub-national levels (GFN, 2004a).

While these problems are of a methodological nature, lacking policy relevance is another perceived weakness of the Ecological Footprint. Generally, the Ecological Footprint is used to merely describe the human demand on nature. The underlying dynamics leading to this resource consumption, however, are usually not explored. A UK Government report (DEFRA/DTI, 2003) acknowledges that the drivers behind the environmental impacts of consumption are less well understood than those behind the environmental impacts of production. So far, no existing model offers satisfactory explanations of the environmental impacts of different consumer lifestyles and socio-economic groups although first attempts have been made to explore this application potential for the Ecological Footprint (Lenzen and Murray, 2001, 2003).

1.1.2. The combined approach

In order to provide meaningful analyses for policy-makers at all levels it is vital that future Ecological Footprint studies address the insufficiencies mentioned above. In this paper we present a methodology based on input–output analysis that allows the disaggregation of existing national Footprint estimates by economic sector, final demand category, sub-national area or socio-economic group, whilst ensuring full comparability of results. Taking the existing National Footprint Accounts (NFA) provided by the Global Footprint Network (GFN, 2004b) as a starting point, we then disaggregate the total Footprint of the United Kingdom, for the year 2000, by using input–output analysis based on economic supply and use tables. With this method it is possible to:

... allocate the existing and commonly accepted national Footprint estimates to detailed final consumption categories. The breakdown is based on expenditure data and includes a detailed disaggregation of household consumption activity by standard classification and of capital investment (gross fixed capital formation). Thus, the mutual interrelationships among economic sectors are taken into account and direct as well as indirect Ecological Footprints are assigned to consumer activities that are relevant for sustainable consumption policies. The approach also allows the clustering of detailed consumption categories to policy areas such as food, energy, housing, transport, household consumption, services etc.

... generate comparable sub-national Footprint accounts, based on detailed expenditure data in the area under investigation. This enables the direct comparison of results on different spatial scales. A first study employing the presented approach has been undertaken in Wales (Barrett et al., 2005).

... calculate Ecological Footprints of socio-economic groups, based on the spending behaviour of 55 different socio-economic types. Such an analysis informs about typical consumption patterns and helps to formulate policy strategies on sustainable consumption (Birch et al., 2004).

... bring Footprint analysis into the scope of ecological–economic modelling frameworks and to enable scenario analysis, which is at the heart of today's sustainability approaches.

The proposed procedure builds on and contributes to existing research (see below for a more detailed review of recent studies). It links existing National Footprint Accounts to standardised, national environmental–economic accounting and therefore builds on two consistent data sets that are produced annually. Economic national accounts are generated and made available by government statistical offices. Although several studies have applied input–output analysis to modify Ecological Footprint calculations before (Bicknell et al., 1998; Lenzen and Murray, 2001; McDonald and Patterson, 2003, 2004), this is the first time that an existing National Footprint Account (NFA)—in this case for the UK in 2000—has been linked to and disaggregated by means of input–output analysis. Rather than using actual land use or land disturbance as input data, the method uses the NFA data based on bioproductivity as a starting point for calculations.

Ecological Footprints of expenditure and socio-demographic patterns have also been explored before (Lenzen and Murray, 2001, 2003). Again, the novelty of our approach lies in the application for the UK and the possibility that all results can be directly compared to existing National Footprint Accounts.

This type of analysis is possible if detailed and adequate data for expenditure on final consumption is available, which was the case for household expenditure in this study. Thus, with this method Footprint analyses can be carried out which—due to a lack of consumption related data—would either not have been possible before or would have required substantially more time and effort.

For these reasons, the method proposed helps to increase the policy relevance of Footprint accounts and ensures consistency and comparability of results between different spatial levels and across countries. This becomes even more important once a common standard for Footprint accounting is achieved.

1.2. Input–output analysis and the Ecological Footprint—a short review

Environmental extended input–output analysis (Leontief and Ford, 1970; Victor, 1972; Miller and Blair, 1985) is a well established approach that allows resource flows and environmental impacts to be assigned to categories of final consumption. Some more recent examples for the use of environmental input–output analysis include analyses of international trade (Proops et al., 1999; Ahmad and Wyckoff, 2003; Meyer et al., 2003; Ferguson et al., 2004; Peters and Hertwich, 2004), estimation of land use changes in China (Hubacek and Sun, 2001) as well as pollution attribution and calculation of regionally specific fuel use (McGregor et al., 2001; Turner, 2003) Further applications assess the environmental impacts of spending options (Lenzen and Dey, 2002) and explore the interdependence of industries in terms of environmental pressure and resource depletion (Lenzen, 2003). Material flow calculations at the national and international level (Moll et al., 1999, 2002; Hinterberger and Giljum, 2003; Giljum and Hubacek, 2004; Suh, 2004a) and Life Cycle Assessments (LCA) have also been combined with input–output analysis (Hendrickson et al., 1998; Joshi, 1999; Lenzen, 2002; Suh and Huppes, 2002; Suh, 2004b; Suh et al., 2004).

Bicknell et al. (1998) were the first to present a way of calculating Ecological Footprints by using an input–output methodology. The total Ecological Footprint of New Zealand is derived by using real land use data and by incorporating embodied energy multipliers in an 80 sector input–output framework. Ferng (2001) identifies some shortcomings in the estimation procedure of Bicknell et al. and provides the necessary corrections in the methodology. Most importantly, Ferng uses a composition of land multipliers instead of aggregated land multipliers to estimate the Ecological Footprint associated with production activities and demonstrates that significantly different results are obtained by the two methods.

The methodology of Bicknell et al. has recently been updated and improved by McDonald and Patterson (2003, 2004) in a multi-regional input–output framework for New Zealand. They generate regional input–output tables and a regional land appropriation model to calculate the Ecological Footprints and interdependencies of 16 regions in New Zealand. The results are disaggregated by land type and economic sector.

As proposed by van den Bergh and Verbruggen (1999), Lenzen and Murray (2001) apply input–output analysis to base Footprint estimates on actual—instead of hypothetical—land use and land disturbance in Australia. They also take into account greenhouse gases other than CO_2 and emission sources other than energy use and introduce a new land type category called ‘emissions land’. Hence, those Footprint estimates cover a scope that is different from that of the National Footprint Accounts. However, Lenzen et al. Wackernagel et al. have recently worked together on a project in Victoria which focused on ways to align the two methods (Lenzen et al., 2005).

Lenzen and Murray (2003) also demonstrate how their input–output based approach can be used to create national, regional and individual Ecological Footprint accounts, to decompose Footprint accounts in production layers and structural paths and to demonstrate the relationship between socio-economic (e.g. household expenditure) and demographic factors and the Ecological Footprint.

Ferng (2002) improves the methodology for the energy component of the Footprint by using a standard input–output approach for the calculation of embodied energy. Ferng is the first to apply a standard economic scenario approach based on a computable general equilibrium model to assess the impact of different policies on the Footprint. This helps to reconcile economic and environmental policies in the future.

Wood and Lenzen (2003) demonstrate how input–output analysis can be used to produce holistic Ecological Footprint accounts for institutions. In addition to direct (on-site) land requirements and emissions, their analysis covers all higher-order requirements based on the institutions' annual operating costs and factor multipliers from a generalised input–output analysis. Wood and Lenzen also show that the proportion of upstream impacts is significant and cannot be neglected; their comparison shows that previous Footprint studies that do not apply input–output analysis produce considerable lower results. They also explore a further potential of the input–output framework by breaking down the Ecological Footprint totals into detailed contributing paths which in turn enables the use of the results in policy formulation.

Hubacek and Giljum (2003) first applied physical input–output analysis to estimate land Footprints (land appropriation) for the production of exports from Europe, arguing that physical multipliers for this kind of calculation would be more appropriate, as the most land intensive sectors are also the sectors with the highest amounts of material flows. In his reply to this paper, however, Suh (2004c) shows that the results may vary significantly when using physical input–output tables (PIOT) depending on crucial issues like double counting, the treatment of wastes and the effect of closing the system toward direct material inputs. Giljum and Hubacek themselves demonstrate that results differ when using physical input–output tables, depending on whether waste is seen as a final demand category or as a by-product in intermediate production (Giljum and Hubacek, 2004).

McGregor et al. (2004a,b) present input–output analysis as an alternative to Ecological Footprint calculations. In their applications to the Jersey and Scottish economy however, they only attribute CO_2 and pollutant emissions to elements of final demand and do not calculate any land use quantities. In order to account for pollution generation and resource use within the geographical boundaries of Jersey and Scotland, the authors endogenise trade in the input–output system. This procedure, in essence, allocates pro rata the pollution of production for exports to the sectors and final demand uses that import. By doing so, the responsibility for regional pollution is reallocated to the consumption of the population living in those regions. A critique of this approach can be found in Moffatt et al. (in press).

In conclusion, a number of research studies have been undertaken in recent years to explore the potential of input–output analysis to calculate Ecological Footprints. All of these approaches focus on different research questions, geographical areas and applications and all are based on different assumptions and data sets. As a result none of the studies are directly comparable and in most cases it would be difficult to adapt the methods to different areas or applications.

The method presented in this paper takes the available National Footprint Accounts (NFA) (GFN, 2004b) as a basis and uses monetary input–output analysis to establish a link with detailed national expenditure data. We do not offer an alternative to the NFA approach as such nor does our method update the NFA results. The novelty of our approach rather lies in the combination of the two methods, the comparability of results on any spatial scale, the detailed disaggregation of national totals and hence in a vastly extended range of potential applications. We hope that the method presented helps with both the process of standardisation of Footprint results and the exploration of new fields of application in the context of sustainable consumption policies.

The rest of the paper is structured as follows. Details of the calculation method are presented in the next section. Results for the UK are presented and discussed in Section 3. This is followed by a description of possible applications of the method in Section 4, illustrating its potential usefulness. Finally, Section 5 concludes the findings.

2. Methodological approach

The method described in this paper applies input–output analysis in a supply and use table framework (SUT) as originally proposed by Gigantes (1970).

Table 1
Overview of the monetary supply and use table framework used in this work

	Commodities	Industries	Final demand	Total output
Commodities		$\boldsymbol{U}_{m\times n}$	$\boldsymbol{Y}^{com}_{m\times o}$	$\boldsymbol{q}$
Industries	$\boldsymbol{V}_{n\times m}$			$\boldsymbol{x}$
Value added		$\boldsymbol{W}$		
Total input	$\boldsymbol{q}$	$\boldsymbol{x}$		$\sum$

with:
$\boldsymbol{V}$=combined matrix for the supply of commodities (m) by industries (n); including imports.
$\boldsymbol{U}$=combined matrix for the use of commodities (m) by industries (n) including imports.
$\boldsymbol{Y}^{com}$ =combined matrix for the final demands (o) for commodities (m), including direct imports and exports.
$\boldsymbol{q}$=commodity output vector, including imports.
$\boldsymbol{x}$=industry output vector, including imports.
$\boldsymbol{W}$=value added/primary input matrix.

Miller and Blair (1985) provide a comprehensive and reader-friendly introduction. Similar procedures have been applied in the environmental field by, for example, Vaze (1997) and Lenzen (2001).

Besides the higher level of control and flexibility provided by such a procedure, the choice for a SUT framework was triggered by the unavailability of analytical tables for recent years. The latest analytical input–output table for the United Kingdom—which are being produced every five years—would have been from the year 1995. Supply and use tables in contrast are available on an annual basis. For an up-to-date policy relevant analysis, the intention of this work was to combine the most recent UK industrial transaction tables from the year 2000 (ONS, 2003) with the latest National Footprint Accounts (WWF, 2004).

The SUT framework represents a complete picture of the UK economy showing all inputs (domestically produced goods and imports) and all outputs (domestic final consumption and exports) in monetary terms. Table 1 provides an overview of the supply and use table framework used. Note that the system we use is closed with respect to imports and exports, i.e. imports are included in the combined supply matrix $\boldsymbol{V}$, the combined use matrix $\boldsymbol{U}$ and—in the form of direct imports—the final demand matrix $\boldsymbol{Y}^{com}$. Exports are included in the final demand matrix $\boldsymbol{Y}^{com}$. Hence, the terms 'commodities' and 'industries' in Table 1 refer to both domestic and foreign markets. Total industry and commodity outputs include imports, which in this approach are treated as competitive and—with respect to imports for intermediate demand—as endogenous.

All calculations have been carried out on a 76×76 sector level imposed by the aggregation level of the UK Environmental Accounts (ONS, 2004).

The method applied involves the following seven steps[3]:

Step 1: associate NFA Ecological Footprints of production and imports with industrial sectors
Step 2: prepare combined supply matrix (76×76)
Step 3: prepare combined use matrix (76×76) in basic prices
Step 4: calculate direct and indirect requirement matrix (76×76)
Step 5: calculate direct and indirect intensity vectors (7×76)
Step 6: calculate Ecological Footprints of final demand categories
Step 7: disaggregate final demand categories

2.1. Step 1: associate NFA Ecological Footprints of production and imports with industrial sectors

The National Footprint Accounts (NFA) constitute the underlying methodology with which Ecological Footprints have been calculated for 149 countries (GFN, 2004b; WWF, 2004). Using UN statistics on production, import, export and yields for a number of resource and product categories, the accounts estimate the apparent net consumption of a nation. Estimates for the embodied energies of secondary products inform the trade balance. The method distinguishes between national conversion efficiency for domestically produced products and global conversion efficiency for imports. Based on the resource balance, the 'global hectares' necessary to satisfy the national demand are calculated. One global hectare (gha) reflects the productivity of a world average bioproductive hectare. A detailed description of the NFA method can be found in Monfreda et al. (2004) as well as a methodology paper

[3] Technical note: All calculations were performed on a desktop PC with Microsoft® Excel®. Specific add-in programmes—'Matrix15.xla' and 'BigMatrix.xla' (Volpi, 2003)—were used to enable calculations with big matrices in Excel®.

from the Global Footprint Network (Wackernagel et al., 2004b).

According to the NFA, the per capita Ecological Footprint of the United Kingdom for the year 2000 amounts to 5.31 gha/cap (Moran, 2004). Table 2 shows a breakdown of this total. In the following we present a methodology to relate these NFA figures to economic sectors in order to provide a basis for input–output calculations.

The Ecological Footprint for the total use of resources (6.47 gha/cap) represents the total land requirements of all inputs to the UK economy. It includes the Footprint for production, imports and stock changes and can be seen as the total demand on nature that is required to produce the total output of the UK economy, including the production of exports.

The total use Footprint acts as a starting point for input–output calculations in our model. In a first step, it is redistributed to 76 industrial sectors as well as direct household consumption in order to obtain specific input data for the input–output analysis. Direct consumption of private households has to be accounted for separately because it is not represented in the inter-industrial transactions described in input–output tables. Two categories were considered here: a) the direct usage of fuels in households as well as consumed land in the form of residences and b) direct emissions from private vehicles as well as road space used by private cars (the refining and distributing of the fuels, however, is attributed to the respective intermediate industries).

The redistribution of the total use Footprint was done separately for the seven land types shown in Table 2 as follows:

- The domestic production energy Footprint for fossil fuels (2.50 gha/cap) was assigned to the 76 industrial sectors and the two direct household consumption categories (domestic consumption of fuels and private transport) by using the respective carbon dioxide emissions from UK Environmental Accounts (ONS, 2004). These cover the total terrestrial emissions of CO_2 in the United Kingdom.
- The fossil fuel energy Footprint of imports (1.29 gha/cap) was redistributed to UK industrial sectors by using an allocation matrix that matches the 64 categories of materials and products used by the National Footprint Accounts with the 76 economic sectors of the input–output framework. By assigning the NFA Footprints of imports to the respective UK industries, consistency with the monetary supply and use table framework is established that combines inputs from domestic industries and imports in both the supply and the use matrix. However, a differentiation is made between the energy Footprint of domestic production and imports. While the National Footprint Accounts use territorial CO_2 emissions of a nation to calculate the energy Footprint of domestic production, they use world-average embodied energy data to convert quantities of imported agricultural and manufactured goods into their energy equivalents (Monfreda et al., 2004). These values are then

Table 2
Summary of the National Footprint Account for the United Kingdom in 2000 (Ecological Footprints in global hectares per capita)

Land type	Domestic production (P)	Imports (I)	Stock changes (SC)	Total use (P+I+SC)	Exports (E)	Apparent consumption (P+I+SC−E)
Energy (fossil fuels)	2.50	1.29	–	3.80	0.78	3.02
Energy (nuclear)	0.29	–	–	0.29	–	0.29
Crop land	0.44	0.40	0.01	0.86	0.20	0.66
Pasture	0.23	0.10	0.001	0.33	0.03	0.30
Built land	0.38	–	–	0.38	–	0.38
Sea	0.17	0.20	−0.002	0.37	0.12	0.24
Forest	0.09	0.36	–	0.45	0.03	0.42
Total Ecological Footprint (gha/cap)	4.10	2.36	0.01	6.47	1.16	5.31

(Data from the Global Footprint Network; Moran, 2004. Figures may not add up to the stated totals due to rounding).

converted to CO_2 emissions and corresponding energy Footprints, assuming a world average fuel mix. Imports of services are not explicitly addressed in the NFA method.

- The Footprint for nuclear energy (0.29 gha/cap) was attributed to one industrial sector only—electricity production and distribution—representing the main user of nuclear material (Footprint calculations usually do not account for the military use of nuclear material).
- The Footprints for cropland and pasture (total use of 0.86 and 0.33 gha/cap, respectively) were assigned completely to the agricultural sector.
- The Ecological Footprint for built land (0.38 gha/cap) includes area for hydro-power and was attributed to industrial and domestic sectors by using real land requirements for non-domestic premises, based on research undertaken by Bruhns et al. (2000), as well as land area occupied by transport infrastructure and domestic buildings (DTLR, 1999).
- The Footprints for fishery (marine and inland water, 0.37 gha/cap for total use) and forest area (0.45 gha/cap) were assigned to the fishing and the forestry sector, respectively. An estimated forest Footprint of 0.002 gha/cap was directly allocated to domestic fuel consumption in order to account for the domestic use of fuel wood for heating which is not valued in economic terms.

The results of Step 1 basically constitute an expansion of national environmental accounts with Ecological Footprints. The Ecological Footprints derived in that way represent the *direct* ecological requirements of the 76+2 economic sectors, i.e. the environmental pressure caused by land appropriation and CO_2 emissions of UK production activities and imports.

However, such an account does not yet show the affiliation of Ecological Footprints with consumption activities. Input–output analysis is therefore used to allocate Footprints to final consumption categories as outlined in the following steps.

2.2. Step 2: prepare combined supply matrix (76 × 76)

A supply table shows the commodities supplied by (domestic) industries for a particular year. Principal products are recorded on the principal diagonal, while secondary products are shown as the off-diagonal elements of the matrix. The recent publications of supply tables by the UK Office for National Statistics (ONS) include the two vectors of industrial and commodity output as well as the supply matrix in summary form only because of disclosure rules prohibiting the publication of data that may be traced to a single contributor from ONS inquiries (ONS, 2003). However, earlier versions of environmental accounts include complete supply matrices, with 1998 being the most recent year available (ONS, 1999). In order to update the complete supply table with recent information for the year 2000, the RAS procedure was applied (Bacharach, 1970; Allen, 1975; Miller and Blair, 1985). The RAS method allows the updating of the n^2 elements of the supply table with 2n pieces of new information. These are the vectors of total commodity output $\boldsymbol{q}^{\text{new}}$ and total industry output $\boldsymbol{x}^{\text{new}}$, which are provided in the SUT publication (ONS, 2003).

Imports were included in the re-estimation of the supply table due to the lack of availability of separate information on the industrial use of imports. Hence, in this combined supply table, imported commodities are treated as competitive to domestic products. As mentioned above, however, the National Footprint Accounts use world-average conversion factors for the imports of secondary products, whereas national conversion factors are used for domestically produced secondary products (Monfreda et al., 2004).

2.3. Step 3: prepare combined use matrix (76 × 76) in basic prices

The industrial dimension of the combined use matrix shows, for each industry, the total costs incurred in the production process as intermediate consumption, including the costs for imported intermediate products and services. The product dimension of the use matrix shows intermediate consumption and final demand by product and is valued at purchasers' prices. Again, both intermediate and final demand estimates include goods and services both domestically produced and imported.

The officially published use tables are only available in a mixed price system (ONS, 2003) rendering it unsuitable for immediate application. In order to make the use table consistent with the supply table, the intermediate flow matrix needs to be transformed from purchasers' into basic prices. In particular, this requires the exclusion of direct taxes and re-distribution of trade margins (Ruiz, 2002). A use matrix in basic prices for the year 2000 was courteously provided by Cambridge Econometrics (Lewney, 2004) and integrated with the available ONS data.

2.4. Step 4: calculate direct and indirect requirement matrix (76 × 76)

Similar to the A matrix of the standard input–output model (Leontief and Ford, 1970) a technical coefficient matrix $\boldsymbol{B}$ with generic elements b_{ij} can be derived from the use matrix (Miller and Blair, 1985).

$$\boldsymbol{B} = [b_{ij}] = \left[\frac{u_{ij}}{x_j}\right] \tag{1}$$

where: $\boldsymbol{u_{ij}}$=use of commodity $\boldsymbol{i}$ by industry $\boldsymbol{j}$ and $\boldsymbol{x_j}$=total output of industry $\boldsymbol{j}$ including imports. Each element $\boldsymbol{b_{ij}}$ represents the amount of commodity $\boldsymbol{i}$ required to produce one unit of the output of industry $\boldsymbol{j}$. Therefore, the input–output systems can be written as:

$$\boldsymbol{q} = \boldsymbol{B}x + \boldsymbol{y}^{com} \tag{2}$$

where: $\boldsymbol{q}$=commodity output vector (including imports); $\boldsymbol{B}$=technical coefficient matrix; x=industry output vector and $\boldsymbol{y}^{com}$=vector of the final demand for commodities. To derive the direct and indirect requirement matrix (generally known as the 'Leontief Inverse' in the standard input–output model), information on primary and secondary production needs to be added to the framework. For this, a matrix $\boldsymbol{D}$ can be defined whose individual coefficients d_{ji} are often referred to as commodity output proportions.

$$\boldsymbol{D} = [d_{ji}] = \left[\frac{v_{ji}}{q_i}\right] \tag{3}$$

where: $\boldsymbol{v_{ji}}$=supply of commodity $\boldsymbol{i}$ by industry $\boldsymbol{j}$ and $\boldsymbol{q_i}$=total (domestic+imported) supply of commodity $\boldsymbol{i}$.

Matrix $\boldsymbol{D}$ can be used to 'weight' the technical coefficient matrix $\boldsymbol{B}$ and assign all secondary products to the industry where they have been originally produced. This implies that we treat all secondary products as by-products being manufactured with the same technology as the principal product of this industry (industry based technology assumption). Alternatively, we could have considered secondary products as subsidiary and assigned them to the industry, where they constitute the principal product. We opted for the industry based assumption as it appeared reasonable to link secondary production to the Ecological Footprint of the respective industry as assigned in Step 1. The only superior treatment would have been to apply the best suited assumption for each individual industry in a hybrid technology system as done by Vaze (1997). However, the required information for such a procedure was not available.

A symmetric (industry-by-industry) input–output framework can then be constructed in the following way:

$$\boldsymbol{x} = \left[(\boldsymbol{I} - \boldsymbol{DB})^{-1} \cdot \boldsymbol{D}\right] \cdot \boldsymbol{y}^{com} \tag{4}$$

where: $\boldsymbol{x}$=industry output vector; $\boldsymbol{I}$=identity matrix; $\boldsymbol{D}$=industry-based technology coefficient matrix; $\boldsymbol{B}$=technical coefficient matrix and $\boldsymbol{y}^{com}$=vector of the total final demand for commodities. The bracketed term $[(\boldsymbol{I}\text{-}\boldsymbol{DB})^{-1}\boldsymbol{D}]$ represents the direct and indirect requirement matrix (the 'Leontief Inverse') of the SUT framework.

2.5. Step 5: calculate direct and indirect intensity vectors (7 × 76)

The Ecological Footprints per industrial sector from Step 1 are then divided by the total output of these industries at basic prices including imports. The result is a 7 × 76 matrix—7 Footprint land types and 76 industries—for Ecological Footprints per industry output (in gha/cap/M£), called the *direct intensity matrix* $\boldsymbol{EF}^{\mathrm{dir}}$. It expresses the Ecological Footprints that are directly associated with the production activities of industrial sectors per million pounds of their product output.

Postmultiplying $\boldsymbol{EF}^{\mathrm{dir}}$ with the direct and indirect requirement matrix results in the *total intensity matrix* $\boldsymbol{EF}^{\mathrm{tot}}$ which represents the total (direct and indirect) Ecological Footprints of industrial activities arising through the entire industrial supply chain to provide one unit of product to final demand (unit gha/cap/M£).

$$\boldsymbol{EF}^{\mathrm{tot}} = \boldsymbol{EF}^{\mathrm{dir}} \cdot \left[(\boldsymbol{I} - \boldsymbol{DB})^{-1} \cdot \boldsymbol{D}\right] \tag{5}$$

$\boldsymbol{EF}^{\mathrm{tot}}$ is also referred to as the multiplier matrix. Eq. (5) enables to assign the Footprints of production activities to final demand sectors—as is done in the next step—and thereby accounts for all mutual interdependencies of industrial sectors.

2.6. Step 6: calculate Ecological Footprints of final demand categories

This step allocates Ecological Footprints to final demand categories. This is done by postmultiplying the total intensity matrix $\boldsymbol{EF}^{\mathrm{tot}}$ with the final demand matrix $\boldsymbol{Y}^{com}$. This results in the matrix $\boldsymbol{EF}^{FD}$ which shows the individual Ecological Footprints $\mathrm{ef}_{\mathrm{lo}}$ of final demand category o per land type l (unit gha/cap):

$$\boldsymbol{EF}^{\mathrm{tot}} \cdot \boldsymbol{Y}^{com} = \boldsymbol{EF}^{FD} = [ef_{\mathrm{lo}}] \tag{6}$$

A further insight in the detailed make-up of each Ecological Footprint $\mathrm{ef}_{\mathrm{lo}}$ can be obtained if the corresponding final demand vector $\mathbf{Y}_{\mathrm{o}}^{com}$ is diagonalised and the resulting matrix $\hat{\boldsymbol{Y}}_{\mathrm{o}}^{com}$ is premultiplied with $\boldsymbol{EF}^{\mathrm{tot}}$. This results in a breakdown of the Footprint of any chosen final demand category into the direct and indirect contributions of all of the 76 industrial sectors.

2.7. Step 7: disaggregate final demand categories

Any disaggregation of final demand can be applied to the model. A detailed breakdown of both final household demand and capital investment is provided by the UK Office for National Statistics with the publication of supply and use tables (ONS, 2003). The private household demand vector of the use table is disaggregated according to the COICOP classification (Classification of Individual Consumption According to Purpose). COICOP was jointly developed by the statistical office of the OECD and Eurostat and was first published in 1999. It covers all areas of individual consumption. The intuition behind it is that usually multiple market goods are required to satisfy a certain consumption activity. Therefore, only the combination of market goods in 'consumptive systems' represented by the COICOP columns of the household demand matrix allows thorough examination of household expenditure patterns and resulting environmental implications. Total expenditure by COICOP headings as well as associated Ecological Footprints are shown in Table 4.

The same holds true for capital investment represented in the final demand category 'Gross Fixed Capital Formation'. Here, a breakdown is provided in 39 economic sectors where capital is invested (see also Table 5).

All figures for final demand sub-categories have been converted from purchasers' prices to basic prices by assuming the same ratio as for the total final demand vectors of households and capital investment.

3. Results and discussion

3.1. Results from the allocation of Ecological Footprints to detailed consumption categories

An overview of the results of the input–output calculations is presented in Table 3. The three final demand categories with the highest Footprint are household consumption (3.84 gha/cap), capital investment (0.69 gha/cap) and exports (1.51 gha/cap). These categories will be discussed in detail in the following.

Total household consumption includes the direct consumption of built land and fuels for housing (0.50 gha/cap), built land and fuels for private transport (0.28 gha/cap) and all other consumption by private households (3.06 gha/cap). The last one is by far the largest contributor to the total Footprint and comprises the consumption of food, consumable and durable items as well as services.

A detailed breakdown by COICOP classification of this household consumption is shown in Table 4. The five consumption activities with the highest total Footprint per capita are food (0.68 gha/cap), electricity and gas distribution (0.39 gha/cap), catering services (0.35 gha/cap), transport services (0.18 gha/cap) and other recreational items and equipment (0.18 gha/cap). In these categories we also find the highest energy Footprint (electricity and gas distribution with 0.39 gha/cap), the highest real land Footprint (food consumption with 0.58 gha/cap) and the highest Footprint per pound spent (electricity and gas distribution with 2.84E-05 gha/cap/M£, followed by food, 2.32E-05 gha/cap/M£ and other recreational items and equipment, 2.10E-05 gha/cap/M£).

Table 3
Total (direct plus indirect) Ecological Footprints (EF) of the United Kingdom in 2000 allocated to final demand categories using input–output analysis (all numbers in global hectares per capita)

Land type	Total household consumption			Government	Gross fixed capital formation	Other final demand[a]	Exports		Total final demand	Final national demand
	Domestic fuel and land consumption[b]	Private transport[b]	Other household consumption		(Capital investment)		Exports of goods	Exports of services[c]	(Incl. exports)	(Exports subtracted)
Energy (fossil fuels)	0.358	0.252	1.43	0.250	0.471	0.045	0.757	0.233	3.80	2.80
Energy (nuclear)	–	–	0.193	0.022	0.027	0.006	0.029	0.016	0.293	0.247
Crop land	–	–	0.684	0.019	0.036	−0.0002	0.086	0.032	0.858	0.739
Pasture	–	–	0.259	0.007	0.014	−0.0001	0.033	0.012	0.325	0.280
Built land	0.141	0.026	0.102	0.031	0.020	0.013	0.025	0.020	0.378	0.332
Sea	–	–	0.214	0.008	0.004	−0.003	0.115	0.029	0.367	0.223
Forest	0.002	–	0.181	0.034	0.120	0.003	0.091	0.022	0.454	0.340
Total EF (gha/cap)	0.50	0.28	3.06	0.37	0.69	0.06	1.14	0.37	6.47	4.97
Normalised total EF (gha/cap) (see text for details)	0.55	0.30	3.23	0.41	0.76	0.07	–	–	–	5.31

[a] Includes non-profit institutions serving households and changes in inventories and valuables.
[b] These Footprints have been allocated directly—not using input–output analysis—as described above in Step 1.
[c] These are sales of services to the rest of the world by UK corporations and households as measured on a balance of payments basis. Top service exporting sectors in the UK are business services, such as advertising, market research, technical, legal and management consultancy and other financial services.

Table 4
Expenditure and Ecological Footprints of household consumption involving intermediates, allocated using input–output analysis; UK, 2000

COICOP number	Household consumption involving intermediates	Total expenditure (basic prices)	Energy footprint[a]	Real land Footprint[b]	Total Ecological Footprint	Total Ecological Footprint per expenditure (× 1,000,000)
		M£	gha/cap	gha/cap	gha/cap	gha/cap/M£(× 1,000,000)
01.1	Food	29,347	0.102	0.579	0.681	23.2
01.2	Non-alcoholic beverages	3390	0.010	0.030	0.040	11.8
02.1	Alcoholic beverages	5241	0.016	0.046	0.062	11.8
02.2	Tobacco	2826	0.004	0.019	0.023	8.2
03.1	Clothing	13,715	0.020	0.004	0.024	1.8
03.2	Footwear	4288	0.006	0.004	0.010	2.3
04.1	Actual rentals for housing	23,715	0.017	0.015	0.031	1.3
04.2	Imputed rentals for housing	54,008	0.037	0.034	0.071	1.3
04.3	Maintenance and repair of the dwelling	9979	0.035	0.030	0.064	6.5
04.4	Water supply and misc. dwelling services	5073	0.014	0.002	0.017	3.3
04.5	Electricity and gas distribution	13,874	0.389	0.005	0.394	28.4
05.1	Furniture, furnishings, carpets etc.	4836	0.039	0.011	0.050	10.3
05.2	Household textiles	3044	0.009	0.002	0.011	3.6
05.3	Household appliances	34,323	0.061	0.038	0.099	2.9
05.4	Glassware, tableware and hh utensils	1793	0.009	0.001	0.011	6.0
05.5	Tools and equipment for house and garden	2367	0.010	0.005	0.016	6.6
05.6	Goods and services for household maintenance	4402	0.007	0.002	0.009	2.0
06.1	Medical products, appliances and equipment	2924	0.007	0.002	0.009	3.2
06.2	Out-patient services	2688	0.004	0.002	0.006	2.1
06.3	Hospital services	1910	0.003	0.001	0.004	2.0
07.1	Purchase of vehicles	22,397	0.090	0.011	0.101	4.5
07.2	Operation of personal transport equipment	27,502	0.074	0.014	0.088	3.2
07.3	Transport services	24,644	0.155	0.024	0.179	7.3
	of which: railway transport				0.024	
	of which: other land transport				0.050	
	of which: water transport				0.015	
	of which: air transport				0.088	
	of which: ancillary transport services				0.002	
08.1	Postal services	936	0.001	0.0003	0.002	1.6
08.2	Telephone and telefax equipment	243	0.0004	0.0001	0.0005	2.0
08.3	Telephone and telefax services	12,734	0.017	0.004	0.021	1.6
09.1	Audio-visual, photo and similar equipment	21,095	0.043	0.020	0.063	3.0
09.2	Other major durables for recreation and culture	3657	0.011	0.008	0.018	5.1
09.3	Other recreational items and equipment	8421	0.052	0.125	0.177	21.0
09.4	Recreational and cultural services	20,686	0.024	0.016	0.039	1.9
09.5	Newspapers, books and stationery	5942	0.019	0.008	0.026	4.5
10.	Education	10,382	0.015	0.009	0.023	2.2
11.1	Catering services	54,951	0.118	0.231	0.349	6.4
11.2	Accommodation services	8901	0.019	0.037	0.057	6.4
12.1	Personal care	7387	0.024	0.004	0.028	3.8
12.3	Personal effects	34,215	0.061	0.047	0.107	3.1
12.4	Social protection	10,649	0.014	0.008	0.022	2.1
12.5	Insurance	23,430	0.033	0.011	0.044	1.9
12.6	Financial services	9270	0.025	0.008	0.032	3.5
12.7	Other services	9870	0.013	0.008	0.021	2.1
	Non-resident household expenditure in UK	−11,629	−0.030[c]	−0.046[c]	−0.076[c]	6.5
	UK resident holidays abroad	17,557	0.045	0.064	0.109	6.2
	Total	546,981	1.62	1.44	3.06	

[a] Comprises energy land for fossil fuels and nuclear energy.
[b] Comprises crop land, pasture, built land, sea and forest.
[c] Expressed on a gha/cap basis, with "capita" meaning "UK resident".

The expenditure breakdown by COICOP includes all consumption activities of households that are valued in monetary terms, i.e. it comprises everything people spend money on. This also includes expenditure on services and hence the presented method allows the calculation of total (direct plus indirect) Ecological Footprints for service activities. Service industries are at the end of the value-added chain and they require a variety of resources from the secondary and primary sector, many of which have a substantial Ecological Footprint. This can be demonstrated by looking at the per capita Footprint of food consumption in households (0.68 gha/cap) and catering services (0.35 gha/cap). If this is compared with the amount of food in 2000 that was eaten in households (0.570 t/cap) and that was eaten out (0.069 t/cap) (ONS, 2001) it becomes obvious that the Ecological Footprint per tonne of food eaten is significantly higher when the food is provided by a catering service (1.2 gha/t for eating in versus 5.1 gha/t for eating out).

Capital investment or Gross Fixed Capital Formation (GFCF) relates principally to investment in tangible fixed assets such as plant and machinery, transport equipment, dwellings and other buildings and structures. Unlike other authors (Lenzen and Murray, 2001; McGregor et al., 2004a) we do not endogenise capital investment into the input–output tables (which would be a 'partial closure' of the input–output system). Instead we deliberately retain GFCF as a final demand category, thus allowing explicit demonstration of the Ecological Footprint of infrastructure and machinery. Table 5 shows a detailed breakdown of capital investment following information on expenditure provided by the official tables for final demand (ONS, 2003).

The following five investment categories show the highest Footprint per capita: dwellings (0.113 gha/cap), real estate activities (0.086 gha/cap), retail trade (0.040 gha/cap), post and telecommunications (0.038 gha/cap) and wholesale trade (0.035 gha/cap). Most of the capital invested in 2000 was in four of these five categories: M£24,555 in dwellings, M£18,273 in real estate activities, M£11,910 in post and telecommunications and M£8,550 in wholesale trade. Investment in dwellings is also responsible for both the highest energy Footprint (0.071 gha/cap) and the highest real land Footprint (0.043 gha/cap). Investment in agriculture, forestry and fishing—which ranks sixth in terms of Footprint per capita (0.032 gha/cap)—shows by far the highest Footprint per money invested, with 2.01E-5 gha/cap/M£.

As can be seen in Table 3 exports account for the second highest Ecological Footprint of all final demand categories (1.51 gha/cap). This figure is substantially higher than the one calculated by the National Footprint Accounts (1.16 gha/cap, see Table 2). Obviously, the indirect Ecological Footprint of economic activities are weighted differently by the two methods which becomes most apparent in the Footprint for exports. This can be demonstrated by looking at the different ways by which the Footprint of exports is calculated.

In order to account for embodied energy in traded goods the National Footprint Accounts (NFA) converts quantities of agricultural and manufactured goods into their energy equivalents, using the best available data on energy intensity of goods (Monfreda et al., 2004; Wackernagel et al., 2004b). In the current accounts, the same energy intensities for imports and exports are used and they are the same for each country. These values are then assigned CO_2 equivalents and subsequently energy Footprints. For imports this is done by using a world average carbon dioxide intensity of production; for exports the average carbon dioxide intensity of the primary energy production of the exporting country is used. The NFA does not take into account imports and exports of services.

In contrast, the method presented in this paper starts from the Footprints for domestic production in the UK and imports to the UK and uses input–output calculations to re-allocate the total to final demand categories, including exports. This automatically assigns specific energy intensities and carbon dioxide intensities to the production of exports with all upstream effects of the national economy taken into account. Also, the export of services is considered separately, again with all indirect impacts included. If one looks at the Ecological Footprint of exports of goods alone, the figures generated by the two methods do not differ much (1.16 gha/cap with the NFA method versus 1.14 gha/cap with the input–output method; compare Tables 2 and 3).

From this it may be concluded that the use of generic embodied energies in the NFA method results in a fairly accurate estimation of the Footprint for exported goods but that the omission of exports of services leads to an underestimation of the total Footprint of exports. This in turn leads to an overestimation of the Footprint for consumption. While the

Table 5
Expenditure and Ecological Footprints of capital investment, allocated using input–output analysis; UK, 2000

Standard Industrial Classification, SIC(92)	Capital investment (gross fixed capital formation)	Total expenditure (basic prices)	Energy Footprint [a]	Real land Footprint [b]	Total Ecological Footprint	Total Ecological Footprint per expenditure (× 1,000,000)
		M£	gha/cap	gha/cap	gha/cap	gha/cap/M£ (× 1,000,000)
01, 02, 05	Agriculture, forestry and fishing	1585	0.007	0.025	0.032	20.1
11	Extraction of oil and gas	2973	0.013	0.003	0.016	5.4
10, 12–14	Other mining and quarrying	277	0.001	0.0002	0.001	5.3
23	Solid and nuclear fuels, oil refining	670	0.002	0.001	0.003	4.8
24	Chemicals and man-made fibres	2,470	0.010	0.002	0.012	4.9
26	Other non-metallic minerals	556	0.003	0.0005	0.003	5.9
27–28	Basic metals and metal products	1066	0.005	0.0007	0.005	5.0
29	Machinery and equipment	823	0.004	0.0007	0.004	5.2
30–33	Electrical and optical equipment	2036	0.008	0.001	0.009	4.5
34–35	Transport equipment	2354	0.010	0.002	0.012	5.2
15–16	Food, beverages, tobacco	2102	0.009	0.002	0.012	5.5
17–19	Textile and leather products	313	0.001	0.0002	0.002	5.1
21–22	Pulp and paper, printing and publishing	1914	0.008	0.003	0.011	5.5
20, 25, 36, 37	Other manufacturing	1429	0.007	0.001	0.008	5.5
40.1	Electricity	2884	0.013	0.002	0.015	5.2
40.2, 40.3	Gas	634	0.002	0.0003	0.003	4.4
41	Water	1323	0.004	0.002	0.006	4.8
45	Construction	1826	0.008	0.001	0.009	5.2
50	Motor vehicles sales and repairs	4130	0.011	0.002	0.014	3.3
51	Wholesale trade	8550	0.027	0.008	0.035	4.1
52	Retail trade	6165	0.030	0.011	0.040	6.6
55	Hotels and restaurants	3847	0.017	0.006	0.023	6.0
60.1	Rail transport	129	0.0005	0.0001	0.001	4.2
60.2, 60.3	Other land transport	2224	0.009	0.002	0.011	4.9
61	Water transport	586	0.002	0.0002	0.002	3.2
62	Air transport	3189	0.007	0.001	0.008	2.6
63	Other transport services	4062	0.012	0.006	0.017	4.3
64	Post and telecommunications	11,910	0.033	0.006	0.038	3.2
65–67	Financial intermediation	6144	0.018	0.006	0.023	3.8
70–74	Real estate activities	18,273	0.067	0.019	0.086	4.7
75	Public administration etc.	4527	0.012	0.006	0.018	4.0
	Roads	1745	0.004	0.003	0.007	4.1
80	Education	2926	0.008	0.004	0.012	4.1
85	Health and social work	3241	0.009	0.004	0.013	3.9
90	Sewage and refuse disposal	2930	0.010	0.004	0.014	4.9
91–93	Other services	6279	0.021	0.007	0.028	4.5
	Dwellings	24,555	0.071	0.043	0.113	4.6
	Transfer costs for land, etc.	8436	0.013	0.009	0.022	2.6
	Valuables	315	0.002	0.0002	0.002	6.2
	Total	151,398	0.50	0.19	0.69	

[a] Comprises energy land for fossil fuels and nuclear energy.
[b] Comprises crop land, pasture, built land, sea and forest.

Footprint for apparent consumption in the NFA method amounts to 5.31 gha/cap (Table 2) the input–output calculations suggest 4.97 gha/cap for final national consumption (Table 3).

In order to make the results derived from the two methods comparable we therefore suggest a simple normalising procedure. After the deduction of exports the resulting final national demand Footprints for each land type (last column in Table 3) are recalibrated to match the total consumption Footprints from the NFA method (last column in Table 2). This is done for all land types separately and the recalibration factors for each land type are then applied throughout the final demand categories, excluding exports. This results in slightly higher values of final demand Footprints (compare the two bottom rows in Table 3).

By applying this normalising procedure, the difference in Ecological Footprint totals of the two methods (mainly stemming from the different treatment of service exports) is re-allocated evenly to all consumption activities within the UK. This ensures absolute comparability with results from the National Footprint Accounts, even if sub-national accounts and Footprints for socio-economic groups are calculated as described in the application examples below. This procedure also leaves room for improvements in the National Footprint Accounts. If future versions of the NFA method were to take into account exports of services, for example, the differences between the two methods would become smaller and would ultimately vanish if the same data sets, assumptions and calculations were used.

3.2. Assumptions and limitations of the methodology presented

In the following section we focus on the critical assumptions that are specific to the method employed in this paper. A general and detailed discussion of input–output analysis and Ecological Footprints can be found in Bicknell et al. (1998, p. 157) and to some extent in McDonald and Patterson (2004, p. 56). For the assumptions and limitations of general input–output analysis we refer to Dorfman et al. (1958), Victor (1972), and Miller and Blair (1985).

Two assumptions relate to the treatment of imports in the model. Firstly, in the combined supply table, imported commodities are treated as competitive to domestic products, i.e. the monetary value of imports is assigned to industries in exactly the same way as the domestic supply of products. This was done because of a lack of data and if input–output tables for imports are made available in the future[4] the model can be adapted to account for imports separately.

Secondly, by adopting the National Footprint Account totals the assumption was inherited that all imported goods were produced with a world-average carbon dioxide intensity, not distinguishing between different origins of the products. This assumption could only be relaxed by building up a multi-regional or international input–output model (Furukawa, 1986; Lenzen et al., 2004; Peters and Hertwich, 2004). However, besides being an extremely labour intensive task (essentially all trading partners or regions should be present in such a model), there are still many methodological problems in the practical implementation as outlined by Lenzen et al. (2004), associated with the required reconciliation of many different data sources from different countries and the lack of data in specific areas (e.g. trade in services).

Further assumptions are associated with the use of the RAS procedure for obtaining an up-to-date supply table. Miller and Blair (1985) point out that differences in estimates of total output obtained with and without the RAS estimation are small. The method should be even less restrictive in the employed supply and use setting. Firstly, there was up-to-date information on the allocation of primary products that account for 92% of the total industry output (ONS, 2003). Therefore, uncertainty is only associated with the allocation of the eight percent of secondary products represented in the off-diagonal elements of the supply table. Secondly, the information in the use table remains unaffected by the RAS procedure.

The assignment of secondary products according to the industry-based technology assumption—even though frequently applied in practice (e.g. Lenzen et al., 2004)—is certainly a limiting factor as it introduces error into the analysis. However, this error is comparably small as it only affects the eight percent of industrial output the secondary products account

[4] Note that analytical input–output tables usually provide this information. The most recent analytical tables for the UK, for example, show imports for intermediate and final demand in monetary terms in a 138-sector breakdown for the year 1995.

for. We think that this assumption is less restrictive than using the outdated technological information from the 1995 analytical table. Moreover, supply and use tables are published as a time-series and are being updated every year, which opens a greater potential for research and applications.

The model presented is based on static input–output calculations for one year which means that it should not be used as a forecasting tool straight away as it is unlikely that coefficients remain unchanged over the forecast time period. This is clearly a limitation if the model is to explore different policy scenarios over time. However, dynamic input–output models can help to relax the strong assumption of a fixed production technology. The required time series for both the National Footprint Accounts as well as supply and use tables are available for several past decades. Moreover, by using structural decomposition analysis (e.g. Betts, 1989; Munksgaard et al., 2000) it would also be possible to identify the underlying causes for changes in environmental pressures.

It could be argued that the use of monetary information to model land appropriation is inadequate and that physical input–output tables (PIOT) should be used instead. Apart from specific problems when using physical tables—we refer to the ongoing discussion on physical versus monetary input–output analysis in the literature (compare Hubacek and Giljum, 2003; Suh, 2004c; Giljum and Hubacek, 2004)—it is the non-existence of PIOTs for most countries, let alone PIOT time series that makes their practical application virtually impossible. The excellent availability of monetary supply and use tables on the other hand opens up a great potential for practical applications of the presented model.

Finally it should be mentioned that the method presented implicitly adopts all assumptions and limitations of the National Footprint Account methodology, a detailed description of which is given elsewhere (Monfreda et al., 2004; Wackernagel et al., 2004b,c). However, these limitations are not inherent to the approach presented in this paper as it can re-allocate any alternative or improved national Footprint. In this respect the method presented is independent of the National Footprint Accounts but relies on them as the best available and most comprehensive Footprint data at national level to date.

4. Application examples

With the proposed methodology a vast range of practical applications is conceivable. Some examples are listed below. However, for lack of space they have not been elaborated further.

Example 1. Ecological Footprints of any sub-national area (region, local authority area, city, district, borough, etc.) can be calculated, provided that suitable expenditure data are available for this area. The method is based on detailed household expenditure data by socio-economic group, COICOP classification and local area. These data are then compiled and treated as a final demand category in the input–output calculus, resulting in Footprints for household consumption that are comparable on any spatial level. A real data analysis was undertaken (Barrett et al., 2005) that calculated the Ecological Footprints in 2000 of Wales (5.25 gha/cap), the city of Cardiff (5.59 gha/cap) and the local authority area of Gwynedd in North Wales (5.28 gha/cap), which can be directly compared with the Footprint of the UK (5.31 gha/cap).

Example 2. Ecological Footprints of different socio-economic groups in a society can be calculated. Estimates of annual expenditure by socio-economic group and COICOP can be used to create highly detailed consumption profiles that act as final demand category in input–output calculations. In a real data assessment of UK socio-economic groups (Birch et al., 2004) we used the ACORN system (A Classification Of Residential Neighbourhoods) to produce 55 types of consumption profiles and corresponding Ecological Footprints. These cover the entire spectrum of household expenditure and provide a robust pattern of consumption behaviour, whilst being consistent with Government national statistics on household expenditure.

The variation in the overall Ecological Footprint of ACORN types is substantial. The greatest extreme is an Ecological Footprint of 6.61 gha/cap for ACORN Type 21 (“Prosperous Enclaves, Highly Qualified Executives”) compared with 4.09 gha/cap for ACORN Type 50 (“Council Areas, High Unemployment, Lone Parents”). The results of our study (presented in Birch et al., 2004 and Barrett et al., 2005) also support the findings by Lenzen and Murray (2001) who established a relatively strong correlation between per capita expenditure and the Footprint (R^2=0.82). We found a similar correlation of R^2=0.76 as illustrated in Fig. 1.

Example 3. The method presented allows exploration of the impacts of tourism by using expenditure data for foreign or domestic tourism in a country. As an example we employ our approach to estimate the average Ecological Footprint of overseas visitors to the UK, reflecting the according environmental impact during the length of their stay. The comprehensive expenditure pattern of foreign visitors—which includes all tourist activities with monetary transactions—can be found under "Non-resident household expenditure in UK" in the COICOP breakdown of final household consumption (ONS, 2003; see also Table 4). Applying the input–output analysis as described above and expressing the result as an absolute figure, not on a per capita basis, results in a Footprint of 4.7 million gha in 2000. In order to derive a per person number, total overseas 'visitor years' can be used which are calculated by multiplying the total number of visitors in one year with the average length of their stay.

The result is a figure of 8.5 gha/person. This suggests that the impact of a visitors 'lifestyle'—whilst they are staying in the UK and not including ongoing consumption in their country of origin—is considerably higher than that of a UK resident for which the Ecological Footprint is 5.3 gha/cap. The reason for this significant difference is likely to be due to tourists consuming more services and travelling more than residents.

5. Conclusions

The method presented in this paper employs a hybrid analysis by combining Ecological Footprint accounting with monetary input–output analysis, thus vastly expanding the range of applications with consistent and comparable Footprint results. The consistent disaggregation of national Footprints by economic sector, final consumption category, subnational area or socio-economic group offers various advantages:

- By taking into account Ecological Footprints of upstream production processes, the ultimate responsibility for specific consumption activities can be assigned, including the utilisation of services. It could be shown that this leads to a slightly higher Footprint of UK export activities compared to the National Footprint Account method.
- The procedure enables comparable numbers to be produced, which is particularly relevant if Footprint results from different spatial levels need to be evaluated.
- Standardised economic national accounts provide a reliable basis for input–output calculations. The

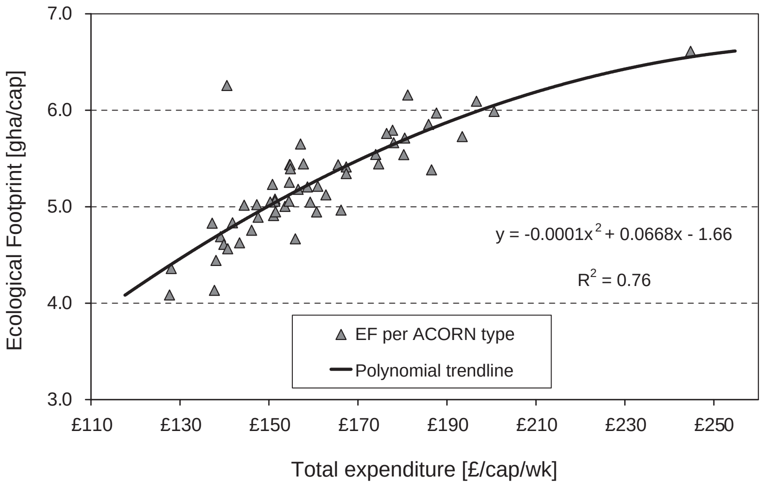

Fig. 1. Correlation (elasticity) between Ecological Footprint (EF) and per capita expenditure of socio-economic types (data from Barrett et al., 2005).

proposed method is applicable in all countries for which supply and use tables or analytical input–output tables, Environmental Accounts and National Footprint Accounts exist[5].

- The integration of Footprint accounting into standard economic models allows a systematic evaluation of policy options as extensive scenario analysis becomes possible.

Furthermore, the method presented shows a way towards a standardisation of Footprint estimates. Defining a standard accounting procedure will be an ongoing, elaborate and long-lasting process. We hope that the work described in this paper makes an essential contribution to this process.

All these issues become relevant in the context of the current debate on Sustainable Consumption and Production (see e.g. OECD, 2002; UNEP, 2002). In order to enable the implementation of appropriate policies it is crucial to understand the environmental impacts of resource consumption at global, regional and local level and amongst different socio-economic groups, and to identify underlying causes of consumption. This helps to formulate tailor-made policies and to ensure that strategies towards achieving sustainable consumption are coherent.

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[5] The United Nations database on National Accounts Statistics contains a complete and consistent set of time series from 1970 onwards of main national accounts aggregates for all UN Members States and all other countries and areas in the world (http://unstats.un.org/unsd/snaama/Introduction.asp).

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