A monetary measure for Ecological Footprints of domestic final demand – the UK example

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Abstract:
The aim of this paper is the further development of a concept for converting the outcome of 'Ecological Deficit' as a result of Ecological Footprint accounts into a monetary measure for costs of overshooting Biocapacity. The main idea behind this is the application of Leontief's pollution model (Leontief, 1970) and the introduction of additional industries for eliminating (offsetting) Ecological Deficits. Ecological Footprints are first linked to industry output and to final demand expenditure in a consistent input-output framework. The next step consists of assuming that the supply of additional Biocapacity necessary for sustaining given domestic final demand can be introduced in the form of additional activities using inputs from other industries and value added inputs. The price and quantity-model of this extended input-output framework can then be used to calculate the costs of hypothetically restoring the balance between Footprints and Biocapacity in terms of prices per hectare, gross output and value added of Footprint elimination. This methodology is applied empirically with supply and use tables linked to Footprint accounts for the UK and yields monetary measures for the overuse of natural capital. This monetary measure reveals the property of a (*ceteris paribus*) rising GDP-share of costs of Biocapacity overshooting with GDP growth and can therefore be seen as a monetary indicator of a binding resource constraint.

Key words: input-output models, Ecological Footprint, Leontief's pollution model

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1. Introduction

The 'Ecological Footprint indicator' - first proposed by Wackernagel and Rees (1996) – can be seen as a biophysical measure of natural capital. As Wackernagel, et.al. (2005) have recently pointed out, the Ecological Footprint concept is linked to the paradigm of 'strong' sustainability (see: Neumayer, 2002). The starting point of the paradigm of 'strong' sustainability is the observation of absolute scarcity of certain natural resources that leads to binding resource constraints (Daly, 1990). This binding resource constraint represents a limit for the exploitation of non-renewable natural resources or for the carrying capacity of ecosystems to absorb emissions. The Ecological Footprint can be seen as a measure of this resource constraint, more precisely it measures the overshooting ("Ecological Deficit") of Footprint over Biocapacity. The Footprint concept has been extensively criticised for various reasons (see e.g. Lenzen et al. 2007; Wiedmann and Lenzen 2007; Wiedmann et al. 2006 and references therein). One obvious limitation of the concept when applied at the country level is that also for obviously global environmental problems (CO_2 emissions) the arbitrary national boundaries constitute the base of the available Biocapacity. Additionally, each country causes Ecological Footprint in other regions via imports and produces Ecological Footprint for others via export. This latter aspect has been considered in several applications of the Ecological Footprint approach, especially in the literature that links Ecological Footprint accounts with input-output model systems. Linking Footprint to input-output models started with Bicknell et al., (1998), and has become an important field of application of the Footprint approach (see, among others: Ferng, 2001 and 2002; Lenzen, Murray, 2001, 2002 and 2003; McDonald, Patterson, 2004). Wiedmann, et.al. (2006) give an extensive literature overview and also propose a new methodology of linking national Ecological Footprint accounts to input-output tables. This line is followed here, so that Ecological Footprints can be allocated to industries and in a second step to final demand (including the impacts of external trade).

The main contribution of this paper is to extend the input-output model with Ecological Footprint accounting in order to derive monetary measures of the overshooting of Ecological Footprint over the constraint determined by Biocapacity. It must be noted here that this translation into monetary units does not intend to overrule the paradigm of 'strong' sustainability given by Biocapacity. The monetary measure must not be seen as a substitution of natural capital by man-made capital, but as an estimate for the *ex post* costs of providing the necessary additional natural capital (land) in order to meet the constraint.

This extension of the input-output model consists of applying Leontiefs (1970) pollution model. This idea has recently been formulated by Kratena (2008) in an integrated input-output/Ecological Footprint model with offsetting activities in the spirit of the well known 'pollution model' of Leontief (1970). The structure of Leontief's pollution model has there been used to introduce an emission offsetting sector in terms of an additional technology at the industry level describing the cultivation of land necessary for eliminating the Ecological Deficit. That resulted in a model where the costs of emissions were measured as a Ricardian rent by industry. This interpretation of Leontief's pollution model coincides with the vertically integrated models extensively described in Steenge (1978) and Lowe (1979) and recently taken up by Lager (1998). For the special case, when 'tolerated' and total emissions are linked, i.e. a fixed share of total emissions has to be eliminated, the vertically integrated model delivers the result of output prices depending on the output level. Rising output therefore leads to rising prices; Lager (1998) shows the analogy of this result to the concept of Ricardian rent. Kratena (1990, 2008) also applies this formulation of Leontief's pollution model with a Ricardian rent at the industry level.

The initial idea of integrating an emission offsetting activity for Ecological Footprints into an input-output model formulated in Kratena (2008) shall be taken up here. Instead of dealing with the offsetting technology as part of the production process in each industry, a separate emission elimination sector like in Leontief's original work shall be modelled here. That should allow us deriving all the different measures of environmental costs formulated in the line of Leontief's pollution model (Lowe, 1979) and derive more general conclusions. Besides that, we also include the impact of external trade on Ecological Footprints and apply the supply-use scheme generally used in European input-output statistics. We can show that in a vertically integrated formulation of Leontief's pollution model even when the level of 'tolerated' emissions is not linked to total emissions but constant (as in the case of Biocapacity), the cost of emission offsetting rise more than proportionally with final demand and output. Therefore we derive the result of a (*ceteris paribus*) rising GDP-share of these costs along with GDP growth, which is a monetary measure of the resource constraint given by Biocapacity.

The paper is structured as follows: in section 2 the input-output quantity and price model with Ecological Footprints in a supply-use scheme is set up. Different measures for the economic costs of Ecological Footprints are then derived. In section 3 the UK data and the linking of the data set is described. Empirical results with the model for 2003 and a simulation exercise for a rise in GDP are presented and discussed in section 4. Tentative conclusions and important issues for future research are finally formulated in section 5.

2. Leontief's pollution model with Ecological Footprint accounts

Starting point of our model is the well known 'pollution model' dating back to Leontief (1970), which shall be formulated for a make-use system including the Footprint of external trade. The make-use system comprises the make matrix **V** and the use matrix **U** with elements v_{ji} and u_{ij} if j are activities and i commodities. Both matrices are in a first step converted into coefficients matrices, namely the 'market shares' matrix **D** with elements d_{ji} indicating the share of each commodity produced by a certain industry and the usual technical coefficient matrix **B** with elements b_{ij}:

$$d_{ji} = \frac{v_{ji}}{q_i} \qquad b_{ij} = \frac{u_{ij}}{x_j} \tag{1}$$

Leontief's pollution model is set up as a partitioned input-output model with part 1 as the economic part comprising industries and commodities and part 2 as the aggregate Ecological Footprint measured as one land category (in gha). We define B_{21}^{D} as a 1*j vector of direct domestic ecological Footprint coefficients per industry (measured in gha/£million) as in Wiedmann, et.al. (2006) and E_{21}^{M} as the product of B_{21}^{M} (1*j vector of direct imported ecological Footprint coefficients per industry) and the matrix of technical coefficients for imported commodities, B_{11}^{M}. The Ecological Footprint per unit of imported commodity is assumed to equal the domestic Footprint coefficient, which is of course a very rough approximation. On the other hand the 'true' imported Footprint coefficients could only be derived from a multi-regional input-output model with bilateral trade flows between the UK and all other countries (country groups) as well as ecological Footprints per unit of commodity produced in all other countries (country groups) as in Turner, et.al. (2007) and in Wiedmann, et.al. (2007a). It must be noted that the accuracy of such an approach will also depend entirely on the country grouping.

The market shares matrix D_{11} can be used to link domestic output by industries, X_1 with output by commodities:

$$Q_1^D: \; X_1 = D_{11} Q_1^D \tag{2}$$

The emission elimination sector of Leontief's pollution model is captured in the matrix of domestic input coefficients per unit of Ecological Footprint set off by cultivation of land (afforestation), B_{12}^{D}.[1]

We further take into account the Ecological Footprint induced abroad by imports within final demand reduced by the domestic Ecological Footprint induced by exports. For the Ecological

[1] For sake of simplicity we do not assume that the emission elimination technology comprises imported intermediate inputs.

Footprint coefficients of exports we also apply the direct domestic Ecological Footprint coefficients. Therefore C_{21} is a 1*i vector of import shares in final demand by commodity multiplied by direct imported ecological Footprint coefficients minus export shares in final demand by commodity multiplied by direct domestic Ecological Footprint coefficients.

In Leontief's pollution model the 'tolerated' level of emissions is given as negative final demand, $-\overline{Y}_2$ and the gross output of partX2) is total emissions that have to be eliminated. In our case $-\overline{Y}_2$ is given by the Biocapacity so that the Ecological Deficit has to be eliminated. As the elimination of Ecological Deficit itself requires intermediate demand from part 1, the total gross emissions that have to be eliminated exceed the Ecological Deficit. The full partitioned model can therefore be written as:

$$\begin{bmatrix} B_{11}^{D} & B_{12}^{D} \\ B_{21}^{D} + E_{21}^{M} & 0 \end{bmatrix} \begin{bmatrix} X_1 \\ \hline X_2 \end{bmatrix} + \begin{bmatrix} I & 0 \\ C_{21} & I \end{bmatrix} \begin{bmatrix} Y_1 \\ \hline -\overline{Y}_2 \end{bmatrix} = \begin{bmatrix} Q_1^{D} \\ \hline X_2 \end{bmatrix} \quad (3)$$

The Footprint account is determined by:

$$X_2 = \left(B_{21}^{D} D_{11} + E_{21}^{M} D_{11}\right) Q_1^{D} + C_{21} Y_1 - \overline{Y}_2 \quad (4)$$

In (4) the balancing equation for Footprint and Biocapacity states that total Footprint generated in excess of given Biocapacity has to be eliminated. The system can be written in explicit form for final demand by:

$$\begin{bmatrix} I - B_{11}^{D} D_{11} & -B_{12}^{D} \\ -B_{21}^{D} D_{11} - E_{21}^{M} D_{11} & I \end{bmatrix} \begin{bmatrix} Q_1^{D} \\ \hline X_2 \end{bmatrix} = \begin{bmatrix} I & 0 \\ C_{21} & I \end{bmatrix} \begin{bmatrix} Y_1 \\ \hline -\overline{Y}_2 \end{bmatrix} \quad (5)$$

The corresponding price system can in analogy be written as:

$$\begin{bmatrix} p_1^{D} & p_2 \end{bmatrix} \begin{bmatrix} I - B_{11}^{D} D_{11} & -B_{12}^{D} \\ 0 & I \end{bmatrix} + \begin{bmatrix} p_1^{M} & p_2 \end{bmatrix} \begin{bmatrix} -B_{11}^{M} & 0 \\ 0 & 0 \end{bmatrix} = \begin{bmatrix} v_1 & v_2 \end{bmatrix} \quad (6)$$

In (6) the matrix of imported technical coefficients is labelled as B_{11}^{M} and p_1^{D} is the domestic commodity price and p_1^{M} the import price. Again the domestic commodity price could be transformed into a price by industry via application of the market shares matrix, D_{11}. The price of emission elimination p_2 is formulated per unit of emission eliminated. By inverting the matrices $\begin{bmatrix} I - B_{11}^D D_{11} & -B_{12}^D \\ -B_{21}^D D_{11} - E_{21}^M D_{11} & I \end{bmatrix}$ and $\begin{bmatrix} I - B_{11}^D D_{11} & -B_{12}^D \\ 0 & I \end{bmatrix}$ the explicit solution of the quantity and the price model can be obtained.

2.1. The vertically integrated model

As has been mentioned above, the literature on Leontief's pollution model has put forward different formulations of the vertically integrated model, especially concerning the price model. The vertically integrated price model becomes especially appealing, when the polluter pays-principle is applied and the level of tolerated emissions is linked to total emissions (Steenge, 1978; Lowe, 1979 and Lager, 1998). This line of research will not be followed here, as we are interested in a general solution of the model for the total economic cost of overshooting the resource constraint ($-\overline{Y}_2$) given by Biocapacity. These calculations represent a simple extension of the Footprint indicator without assigning any costs to industries or other political conclusions like the polluter pays-principle. Dealing with tolerated emissions as a fixed resource constraint ($-\overline{Y}_2$) and not as a fixed share of total emissions is another feature of our analysis that does not allow formulating the vertically integrated price model where prices depend on quantities (i.e. the non-substitution theorem does not hold). Nevertheless we will show that in the vertically integrated version of the quantity model the property of a rising share of costs of overshooting the resource constraint in GDP is also upheld.

The cost of overshooting Biocapacity in terms of national accounts is given as the additional value added that has to be produced in order to eliminate emissions. Lowe (1979) has in his analysis of Leontief's pollution model already derived the aggregates of the pollution elimination sector. The costs of pollution elimination can be defined as the 'unproductive' value added that arises from this activity (Leontief, 1970 and Lehbert, 1972). This measure shall also be used here.

The gross output of the emission elimination sector is obviously given by:

$$p_2 X_2 = p_1^D B_{12}^D X_2 + v_2 X_2 \qquad (7)$$

Equation (7) represents the sum of intermediate demand and value added of part 2 valued at the prices which are the solution of system (5). The measure for the costs of emission offsetting can be defined as the additional 'unproductive' value added that is created in the economy without contributing to economic final demand. This is given by:

$$\overline{V} = v_1 B_{12}^D X_2 + v_2 X_2 \qquad (8)$$

The first term describes the additional value added in the economic sector due to intermediate demand of the pollution elimination sector. The second term describes the value added of the pollution elimination sector itself. Both are linked to the level of gross pollution elimination, X_2. As we differentiate only one type of land in part 2 all these variables are scalars and B_{12}^D is a column vector.

We can therefore proceed by writing the vertically integrated model as:

$$\left[I - B_{11}^D D_{11}\right] Q_1^D - B_{12} X_2 = Y_1 \qquad (9)$$

$$X_2 = E_{21} Q_1^D + C_{21} Y_1 - \overline{Y}_2 \qquad (10)$$

Here the matrix of domestic and imported Footprint coefficients of production $\left[B_{21}^D D_{11} + E_{21}^M D_{11}\right]$ has been comprised in one matrix, E_{21}. Inserting (10) into (9) gives the solution for Q_1^D:

$$Q_1^D = \left[I - B_{11}^D D_{11} - B_{12} E_{21}\right]^{-1} \left[\left(I + B_{12} C_{21}\right) Y_1 - B_{12} \overline{Y}_2\right] \qquad (11)$$

This expression for economic output by commodities can then be used to determine the level of gross pollution elimination:

$$X_2 = E_{21} \left[I - B_{11}^D D_{11} - B_{12} E_{21}\right]^{-1} \left[\left(I + B_{12} C_{21}\right) Y_1 - B_{12} \overline{Y}_2\right] + C_{21} Y_1 - \overline{Y}_2 \qquad (12)$$

Inserting (12) into the equation for additional value added (our measure of cost of overshooting Biocapacity) gives the final expression:

$$\overline{V} = \left(v_1 B_{12} + v_2\right) \left\{ E_{21} \left[I - B_{11}^D D_{11} - B_{12} E_{21}\right]^{-1} \left[\left(I + B_{12} C_{21}\right) Y_1 - B_{12} \overline{Y}_2\right] + C_{21} Y_1 - \overline{Y}_2 \right\} \qquad (13)$$

It is obvious that $\overline{V}$ increases with a multiplier for any increase of final demand above the limit that is reconcilable with Biocapacity and therefore the share $\overline{V} / p_1^D Y_1$ also increases with economic growth beyond the resource constraint. Therefore we get an analogous result like in Lager (1998) and Kratena (2008) of rising costs per unit of output of Biocapacity overshooting for rising final demand levels.

3. Data

3.1 UK supply, use and imports tables

A modified matrix balancing procedure, able to handle conflicting external data and inconsistent constraints, was used to produce UK supply, use and imports matrices by 123 sectors for the year 2003. For the purpose of this article, all tables have subsequently been aggregated to the 59 sectors of NACE Rev 1.1. The full details of the balancing procedure are described in the UK-MRIO project report (Wiedmann et al. 2008) and conference paper (Wiedmann et al. 2007b).

In the UK, input-output data are collated and published regularly by the Office for National Statistics (ONS) as part of the national accounting framework (Mahajan 2006; ONS 2006).[2] Publicly available input-output data from the ONS were used as a basis for initial data. Additional information such as the transition matrix from basic to purchaser's prices in the Analytical Tables 1995 form other crucial information about the structure of imports and other data.

Supply tables

For the purpose of this project, the supply tables published by Eurostat (Eurostat 2007) could be taken without further modifications. The IO data from ONS is consistent with the

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

European System of Accounts (ESA 95). The Eurostat publications show supply tables in the NACE 59 sector resolution (and thus in a more detailed format than the 30 sector supply tables published by ONS).

Creating domestic use tables in basic prices

Combined use tables for intermediate and final demand are provided by ONS in 123 sector format (ONS 2006) and by Eurostat in 59 sector format (Eurostat 2007). Two modifications had to be made before these tables could be used; they had a) to be converted from purchasers' prices to basic prices and b) imports had to be subtracted in order to obtain the domestic use tables for intermediate and final demand. The 'Transition matrix' published by ONS in the 'UK Input-Output Analytical Tables 1995' achieves both steps in one go by combining imports, trading margins and taxes less subsidies in one table (Ruiz and Mahajan 2002). Wiedmann et al (2008) describe how this transition matrix was used to create the initial estimates for imports matrices and to derive domestic use matrices in basic prices for each year 1992 to 2004. More specific information, such as transition and/or imports matrices for years other than 1995 – which would have made our initial estimates more accurate – was not available from ONS (Mahajan 2007), (see also Druckman et al. 2007, pp11).

Whilst the use and transition tables are provided in product by industry form, the published imports table is in product by product form, which according to (Ruiz and Mahajan 2002) was calculated by applying RAS to known product column totals of a product by industry table. The imports table was therefore re-engineered into a product by industry table by re-applying RAS to the published industry column totals. The resulting product by industry imports table was then subtracted from the published product by industry transition matrix to obtain a transition matrix that refers only to distributors' trading margins and taxes less subsidies on products. Finally, the domestic use table in basic prices was obtained by subtracting the transition and imports tables from the original use table.

3.2 UK Ecological Footprint accounts

The National Footprint Accounts (NFA) from Global Footprint Network (GFN) form a data basis upon which national Ecological Footprints have been calculated for 149 countries (Wackernagel et al. 2005; WWF et al. 2006). Using UN statistics on production, imports, exports 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 from the Global Footprint Network (Wackernagel et al. 2005).

For this contribution, we have used the methodology described in Wiedmann et al. (2006) relating the NFA figures to distinct economic sectors in order to provide a basis for input-output calculations.

The Ecological Footprint of UK domestic production (4.2 gha/cap in 2003) was redistributed to 59 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 private property areas 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 allocation of the production Footprint was done separately for the seven NFA land types:

- The domestic production energy Footprint for fossil fuels (2.6 gha/cap) was assigned to the 59 NACE 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 2007). These cover the total terrestrial emissions of CO_2 in the United Kingdom.
- The Footprint for nuclear energy (0.31 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 0.41 and 0.22 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, 0.14 gha/cap for total use) and forest area (0.11 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.

This allocation procedure basically constitutes an expansion of national environmental accounts with Ecological Footprints. The Ecological Footprints derived in that way represent the direct ecological requirements of UK economic sectors, i.e. the environmental pressure caused by land appropriation and CO_2 emissions of UK production activities. Per capita numbers were multiplied with the population in 2003 (59,164,605 residents) and direct Footprint intensities (gha/£) for domestic production per sector were derived by dividing by total (monetary) sector output.

The same Footprint intensities were used for imports to the UK, thus assuming the same production efficiency for foreign and domestic production.

3.3. The Footprint elimination technology

In Kratena (2008) the emission elimination technology for Germany has been based on the relationship between the Biocapacity of forestry and the economic data set for the forestry sector from German input-output tables. Obviously this methodology represents only one possible approximation to the empirical application of the Footprint elimination technology. What would actually be needed is a full accounting of costs of afforestation or other technologies that as an outcome yield bioproductive land. The most important and crucial issue in this cost calculation is the assignation of investment costs along the 'bioproductive lifetime' of this natural capital stock. That means in the case of CO_2 sequestration by forests that the costs can only be split up within the period in which forests actually are net emission absorbers. In this study we reviewed different studies on afforestation technologies and their costs, namely Benitez, et.al. (2007), the Stern Review (2006) and IPCC (2007). The latter two comprise literature reviews of different studies and both name Benitez, et.al. as one important source. Therefore we based our calculations mainly on information from Benitez (2007). It is not straightforward to derive the Footprint offsetting technology in all its details from this study. The data for cost estimates from Benitez, et.al. (2007) that have been used here are:

land price	1000 US $/ha
plantation costs	800 US $/ha
discount rate	5%
lifetime, sequestration	25 years
depreciation rate	4%

That yields unit costs (in terms of an input-output model) of bioproductive capacity per ha for plantation (460 £) and land (570 £)[3]. These costs have then been split up to value added components (capital costs, wages) and intermediate inputs according to the type of cost. The sum of intermediate inputs has then been split up across delivering activities according to the column of the forestry sector in the 2003 UK supply and use table.

4. Empirical results: the costs of Ecological Footprint overshoot

The results of the link between Footprint accounts and UK supply and use tables are condensed in Table 1. The Footprint of domestic production of 199.6 millions of gha is identical with the corresponding NFA number, excluding the (direct) Footprint of consumer expenditure (travel & non-travel). The direct Footprint of consumption of private households has been calculated, but is not included in these calculations with input-output analysis. The Footprint of imports is split up into imports of intermediate inputs and imports of final demand in our accounting framework. The impact of the latter is mixed up with the (negative) impact of exports on Footprint. Therefore we can only compare the net impact of trade on Footprint between the two accounting methodologies. That yields a balance of 15.9 millions of gha (Mgha) in the input-output model vs. 82.2 Mgha in the NFA accounts from GFN. This difference simply reflects the different methodologies of attributing indirect Footprints caused by external trade to the national economy, as well as the fact that we use the single region assumption of identical Footprint intensities (see also Wiedmann, submitted).

In order to take into account that the direct Footprint of consumption of private households has been left out in the Footprint of domestic production, but must nevertheless be eliminated as it is part of the Ecological Deficit, we subtract it from available Biocapacity. Therefore 96.6 Mgha of Biocapacity from the NFA are reduced to 49.3 Mgha, yielding an Ecological Deficit of 166.1 Mgha that needs to be offset by the emission elimination sector.

[3] Using an exchange rate of 1.9 US$ per £ Sterling for 2003.

>>>>> Table 1: UK Footprint accounts, 2003

The result of the assignment of Footprints of production to the single industry is shown in Table 2. Dividing the absolute Footprint in Mgha by the domestic output by industries yields the Footprint coefficients used in this model.

>>>>>>Table 2: UK domestic Footprint of production, 2003

The results of the assumptions on the emission elimination technology described in 3.3 are shown in Table 3. This technology contains mainly value added costs (including capital costs) and costs of intermediate inputs with the structure of the corresponding column of the forestry sector. Note that for this technology the own inputs of forestry have been set equal to zero. This assumption is made in order to avoid a high feedback effect of our technology on Footprints. The forestry sector is characterized by a high direct Footprint coefficient due to the fact that this activity is mainly a Biocapacity user. In our case we want to describe a technology that represents a Biocapacity supplier and therefore exclude this effect.

>>>>>> *Table 3: The Ecological Deficit-elimination technology*

The solution for the 'economic part' of the vertically integrated model according to equation (11) yields an output vector for Q_1^D (by commodities) which differs from the original supply use table 2003 for UK due to the assumed elimination of the Ecological Deficit. Table 4 shows this deviation (in %) of output, which in total amounts to 2.1%.

>>>>>> Table 4: Output effects (in %) of elimination of Ecological Deficit

Tables 5 and 6 show the results of the model solution for the elimination sector. In a simple simulation exercise we have assumed that the final demand increases proportionally across commodities by 10% in order to analyse the impact on the elimination of the Ecological Deficit. As has been noted above we do not integrate the price model by assuming the application of the polluter pays-principle so that unit costs and prices of the elimination sector are constant. The gross output of the elimination sector represents a share of 7.4% in total gross output 2003 in the UK. It must be emphasized however that this number is a direct consequence of the *assumptions* for the Footprint elimination technology in section 3.3. This share rises to 8.3% in the case of a 10% proportional increase in final demand. The same effect can be shown for value added of Footprint elimination and its share in total (original) value added, which rises from 10.8% in the base case 2003 to 12.3%. This rise in the share of emission elimination costs represent the absolute resource constraint given by Biocapacity. Economic growth *ceteris paribus* leads to a rising share of emission elimination costs in the case of an absolute resource constraint ('strong sustainability'). This can only be overcome by technical progress (decoupling) or structural change, which would result in a *non*-proportional increase in final demand.

>>>>> Table 5: The Ecological Deficit - elimination sector (2003)

>>>>> Table 6: The Ecological Deficit - elimination sector (+10% in final demand)

The corresponding output effects of the 10% proportional increase in final demand are shown in Table 7. Due to the multiplier effect the 10% increase in final demand magnifies to a 12.4% increase in gross output with significant differences across industries.

>>>>>> *Table 7: Output effects (in %) of elimination of Ecological Deficit, (+10% in final demand)*

We interpret the total additional value added that is generated by offsetting the Ecological Deficit as an unproductive activity that does not increase the consumption possibilities of the economy and therefore as a monetary measure for the Ecological Deficit. In Table 8 this total additional value added is shown. It consists of the direct value added of the elimination sector as in Table 5 and 6 and the additional value added in the economy generated by intermediate inputs delivered. This additional value added amounts to 11.8% of GDP in the base case 2003 and rises to 13.4% of GDP with a 10% increase in final demand. Again we emphasize that the absolute amount of these results is fully based on – though not arbitrary but still questionable - *assumptions* for the Footprint elimination technology.

>>>>> *Table 8: Costs of elimination of Ecological Deficit*

5. Conclusions

The main idea of this paper was the application of Leontief's (1970) pollution input-output model with Ecological Footprint to derive a monetary measure of the overshooting of Ecological Footprint over the constraint of Biocapacity. It must be noted that the result of an absolute value of about 12% of GDP for the UK in 2003 heavily depends on simple assumptions about the emission offsetting sector. We can show that in a vertically integrated formulation of Leontief's pollution model for given Biocapacity the costs of emission offsetting rise more than proportionally with final demand and output. A *ceteris paribus* rise in GDP therefore increases the share of these costs in GDP. This can be interpreted as a monetary measure of an absolute resource constraint given by Biocapacity.

We see our paper as a further contribution to linked Footprint/input-output modelling with an extension towards a monetary valuation. It is still – like Kratena (2008) – a first empirical experiment with numbers and the statistical base of our calculations shall be improved considerably in future research.

That concerns first of all the collection and verification of a sound data base for the Footprint elimination technology by the provision of new Biocapacity. Another issue is a better estimation of trade induced and directly consumption induced Footprints. One of the main assumptions used in our work is that Footprint intensities for production in other countries are the same as for the UK, in other words, that imports have been produced with technologies identical to the ones used in the UK. This assumption can be relaxed by employing a multi-region input-output model that distinguishes between production technologies of trading partners in the model. Work in this direction is currently under way (Wiedmann, submitted). Besides these data issues we would also see several future research lines starting from this approach. A different methodology of calculating the costs of an absolute resource constraint consists in calculating the implicit rents of scarce resources in a model as in Duchin (2005) and Julia, Duchin (2007).

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Table 1: UK Footprint accounts, 2003

Footprint	in Mgha
domestic production	200
imported intermedaites	26
total production	225
imports - exports	-10
Total	215
	0
Biocapacity	97
consumer expenditure, travel	17
consumer expenditure, non-travel	30
Biocapacity, Y_2	49
Ecological Deficit	166

Table 2: UK domestic Footprint of production, 2003

	in Mgha	coefficients Mgha/mill £
Products of agriculture, hunting and related services	40	1987
Products of forestry, logging and related services	6	7779
Fish and other fishing products; services incidental of fishing	8	8247
Coal and lignite; peat	0	90
Crude petroleum and natural gas	6	214
Uranium and thorium ores	0	0
Metal ores	0	0
Other mining and quarrying products	1	310
Food products and beverages	3	44
Tobacco products	0	22
Textiles	1	94
Wearing apparel; furs	0	25
Leather and leather products	0	67
Wood and products of wood and cork (except furniture)	1	96
Pulp, paper and paper products	1	106
Printed matter and recorded media	1	17
Coke, refined petroleum products and nuclear fuels	5	300
Chemicals, chemical products and man-made fibres	5	100
Rubber and plastic products	1	54
Other non-metallic mineral products	4	317
Basic metals	6	502
Fabricated metal products, except machinery and equipment	1	27
Machinery and equipment n.e.c.	1	18
Office machinery and computers	0	9
Electrical machinery and apparatus n.e.c.	0	20
Radio, television and communication equipment and apparatus	0	13
Medical, precision and optical instruments, watches and clocks	0	11
Motor vehicles, trailers and semi-trailers	1	17
Other transport equipment	0	18
Furniture; other manufactured goods n.e.c.	0	43
Secondary raw materials	0	46
Electrical energy, gas, steam and hot water	62	1399
Collected and purified water, distribution services of water	0	62
Construction work	3	16
Trade, maintenance and repair services of motor vehicles; retail of automotive fuel	1	17
Wholesale trade and commission trade services	1	14
Retail trade services	2	22
Hotel and restaurant services	1	19
Land transport; transport via pipeline services	8	191
Water transport services	7	1045
Air transport services	9	656
Supporting and auxiliary transport services; travel agency services	0	7
Post and telecommunication services	0	9
Financial intermediation services, except insurance and pension funding services	0	2
Insurance and pension funding services, except compulsory social security services	0	2
Services auxiliary to financial intermediation	0	5
Real estate services	0	2
Renting services of machinery and equipment	0	19
Computer and related services	0	2
Research and development services	0	16
Other business services	3	17
Public administration and defence services; compulsory social security services	2	24
Education services	2	27
Health and social work services	2	14
Sewage and refuse disposal services, sanitation and similar services	1	50
Membership organisation services n.e.c.	1	78
Recreational, cultural and sporting services	1	10
Other services	0	17
Private households with employed persons	0	11
Consumer expenditure - non travel	30	
Consumer expenditure - travel	17	

Table 3: The Ecological Deficit-elimination technology

	mill £/Mgha
Products of agriculture, hunting and related services	0,00
Products of forestry, logging and related services	0,00
Fish and other fishing products; services incidental of fishing	0,00
Coal and lignite; peat	0,00
Crude petroleum and natural gas	0,00
Uranium and thorium ores	0,00
Metal ores	0,00
Other mining and quarrying products	0,04
Food products and beverages	1,18
Tobacco products	0,00
Textiles	0,12
Wearing apparel; furs	0,40
Leather and leather products	0,01
Wood and products of wood and cork (except furniture)	0,96
Pulp, paper and paper products	0,09
Printed matter and recorded media	13,39
Coke, refined petroleum products and nuclear fuels	7,57
Chemicals, chemical products and man-made fibres	4,07
Rubber and plastic products	0,29
Other non-metallic mineral products	0,20
Basic metals	0,19
Fabricated metal products, except machinery and equipment	1,50
Machinery and equipment n.e.c.	0,81
Office machinery and computers	1,06
Electrical machinery and apparatus n.e.c.	0,25
Radio, television and communication equipment and apparatus	0,06
Medical, precision and optical instruments, watches and clocks	0,28
Motor vehicles, trailers and semi-trailers	4,44
Other transport equipment	8,26
Furniture; other manufactured goods n.e.c.	3,17
Secondary raw materials	0,90
Electrical energy, gas, steam and hot water	7,65
Collected and purified water, distribution services of water	0,30
Construction work	18,70
Trade, maintenance and repair services of motor vehicles; retail of automotive fuel	0,39
Wholesale trade and commission trade services	13,56
Retail trade services	0,03
Hotel and restaurant services	0,06
Land transport; transport via pipeline services	11,45
Water transport services	0,00
Air transport services	0,21
Supporting and auxiliary transport services; travel agency services	1,56
Post and telecommunication services	4,77
Financial intermediation services, except insurance and pension funding services	0,00
Insurance and pension funding services, except compulsory social security services	4,09
Services auxiliary to financial intermediation	0,00
Real estate services	0,00
Renting services of machinery and equipment	6,96
Computer and related services	2,79
Research and development services	0,00
Other business services	1,31
Public administration and defence services; compulsory social security services	2,65
Education services	0,00
Health and social work services	0,00
Sewage and refuse disposal services, sanitation and similar services	0,11
Membership organisation services n.e.c.	2,45
Recreational, cultural and sporting services	3,63
Other services	0,82
Private households with employed persons	0,00
Consumer expenditure - non travel	132,74
Consumer expenditure - travel	0,00
Value added	734,56
Gross Output	867,30

Table 4: Output effects (in %) of elimination of Ecological Deficit, 2003

Products of agriculture, hunting and related services	0.3
Products of forestry, logging and related services	1.8
Fish and other fishing products; services incidental of fishing	0.3
Coal and lignite; peat	4.8
Crude petroleum and natural gas	4.6
Uranium and thorium ores	0.0
Metal ores	1.9
Other mining and quarrying products	1.2
Food products and beverages	0.7
Tobacco products	0.0
Textiles	0.8
Wearing apparel; furs	1.9
Leather and leather products	1.0
Wood and products of wood and cork (except furniture)	5.8
Pulp, paper and paper products	2.5
Printed matter and recorded media	12.0
Coke, refined petroleum products and nuclear fuels	9.9
Chemicals, chemical products and man-made fibres	2.5
Rubber and plastic products	1.9
Other non-metallic mineral products	2.4
Basic metals	1.9
Fabricated metal products, except machinery and equipment	3.2
Machinery and equipment n.e.c.	1.1
Office machinery and computers	2.4
Electrical machinery and apparatus n.e.c.	1.5
Radio, television and communication equipment and apparatus	0.3
Medical, precision and optical instruments, watches and clocks	0.9
Motor vehicles, trailers and semi-trailers	2.5
Other transport equipment	8.4
Furniture; other manufactured goods n.e.c.	5.9
Secondary raw materials	5.1
Electrical energy, gas, steam and hot water	6.0
Collected and purified water, distribution services of water	2.0
Construction work	3.2
Trade, maintenance and repair services of motor vehicles; retail of automotive fuel	1.1
Wholesale trade and commission trade services	3.2
Retail trade services	0.0
Hotel and restaurant services	0.1
Land transport; transport via pipeline services	6.0
Water transport services	0.7
Air transport services	1.3
Supporting and auxiliary transport services; travel agency services	3.4
Post and telecommunication services	3.0
Financial intermediation services, except insurance and pension funding services	1.6
Insurance and pension funding services, except compulsory social security services	2.3
Services auxiliary to financial intermediation	0.6
Real estate services	0.5
Renting services of machinery and equipment	7.7
Computer and related services	2.4
Research and development services	0.8
Other business services	1.7
Public administration and defence services; compulsory social security services	0.6
Education services	0.2
Health and social work services	0.1
Sewage and refuse disposal services, sanitation and similar services	0.7
Membership organisation services n.e.c.	6.4
Recreational, cultural and sporting services	2.0
Other services	1.8
Private households with employed persons	0.0
TOTAL	2.1

Table 5: The Ecological Deficit - elimination sector (2003)

	in mill. £ per 1.000 gha
value added	0.7346
unit price	0.8673
	in mill. £
gross output	149983
in % of total	7.37
intermediate inputs	22954
value added	127029
in % of total GDP	10.8

Table 6: The Ecological Deficit - elimination sector (+10% in final demand)

	in mill. £ per 1.000 gha
value added	0.7346
unit price	0.8673
	in mill. £
gross output	169436
in % of total	8.32
intermediate inputs	25931
value added	143505
in % of total GDP	12.3

Table 7: Output effects (in %) of elimination of Ecological Deficit, (+10% in final demand)

Products of agriculture, hunting and related services	10.3
Products of forestry, logging and related services	12.1
Fish and other fishing products; services incidental of fishing	10.3
Coal and lignite; peat	15.4
Crude petroleum and natural gas	15.1
Uranium and thorium ores	10.0
Metal ores	12.2
Other mining and quarrying products	11.3
Food products and beverages	10.8
Tobacco products	10.0
Textiles	10.9
Wearing apparel; furs	12.1
Leather and leather products	11.1
Wood and products of wood and cork (except furniture)	16.6
Pulp, paper and paper products	12.8
Printed matter and recorded media	23.5
Coke, refined petroleum products and nuclear fuels	21.1
Chemicals, chemical products and man-made fibres	12.9
Rubber and plastic products	12.1
Other non-metallic mineral products	12.7
Basic metals	12.1
Fabricated metal products, except machinery and equipment	13.6
Machinery and equipment n.e.c.	11.3
Office machinery and computers	12.7
Electrical machinery and apparatus n.e.c.	11.6
Radio, television and communication equipment and apparatus	10.4
Medical, precision and optical instruments, watches and clocks	11.0
Motor vehicles, trailers and semi-trailers	12.8
Other transport equipment	19.5
Furniture; other manufactured goods n.e.c.	16.7
Secondary raw materials	15.7
Electrical energy, gas, steam and hot water	16.8
Collected and purified water, distribution services of water	12.2
Construction work	13.6
Trade, maintenance and repair services of motor vehicles; retail of automotive fuel	11.3
Wholesale trade and commission trade services	13.6
Retail trade services	10.0
Hotel and restaurant services	10.1
Land transport; transport via pipeline services	16.8
Water transport services	10.8
Air transport services	11.4
Supporting and auxiliary transport services; travel agency services	13.9
Post and telecommunication services	13.4
Financial intermediation services, except insurance and pension funding services	11.8
Insurance and pension funding services, except compulsory social security services	12.6
Services auxiliary to financial intermediation	10.7
Real estate services	10.6
Renting services of machinery and equipment	18.6
Computer and related services	12.7
Research and development services	10.9
Other business services	12.0
Public administration and defence services; compulsory social security services	10.6
Education services	10.2
Health and social work services	10.1
Sewage and refuse disposal services, sanitation and similar services	10.8
Membership organisation services n.e.c.	17.2
Recreational, cultural and sporting services	12.2
Other services	12.0
Private households with employed persons	10.0
TOTAL	12.4

Table 8: Costs of elimination of Ecological Deficit

2003	
Value added, sector 1	11751
Value added, sector 2	127029
Total additional value added	138780
in % of GDP	11.8
Increase of 10% in final demand	
Value added, sector 1	13276
Value added, sector 2	143505
Total additional value added	156781
in % of GDP	13.4