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# Examining the Global Environmental Impact of Regional Consumption Activities – Part 1: A Technical Note on Combining Input-Output and Ecological Footprint Analysis

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# Abstract

In recent years there have been a number of attempts to develop a more comprehensive approach to the issue of measuring resource use and/or pollution generation embodied in trade flows, including contributions that combine input-output techniques and Ecological Footprint analysis. In this two-part paper we describe how to enumerate the resource and/or pollution content of inter-regional and inter-national trade flows (Part 1) and we present a literature review of recent methodological and empirical developments (Part 2). It is straightforward in principle to extend the basic input-output approach to capture international trade flows. However, in practice, problems of data availability and compatibility, and of computability of extended input-output matrices, mean that simplifying assumptions are generally applied, but with the implications of these assumptions often not made fully explicit. What appears to be absent from previous applications is an account of the analytical method by which Ecological Footprints should ideally be estimated in an international input-output accounting analysis. This allows an explicit analysis of the problems that prevent the application of the full method and identification of the most appropriate short-cut methods in a transparent way. The objective of this paper is to provide such an account.


*Keywords:* Ecological Footprint, input-output analysis, multi-region input-output models, international trade, embodied environmental impacts

# 1. Introduction

## 1.1. Ecological Footprints

The Ecological Footprint, as introduced by Wackernagel and Rees (1996), measures human demand on bioproductivity by assessing how much biologically productive land and sea area is necessary to maintain the consumption of a given human population. The calculation of Ecological Footprints starts from the consumption of resources in terms of mass units and transforms this mass into land appropriation in a second step (Monfreda et al., 2004). A considerable share of the Footprint consists of the notional forest area that would be required to absorb carbon dioxide emitted from the combustion of fossil fuels.

The total land appropriation derived in this way can then be compared to available biocapacity, also expressed in land and sea areas. If global demand exceeds global supply of biologically productive area, this indicates an 'overshoot' situation in terms of a shortfall of bioproductivity needed for human purposes.

National Footprint Accounts (NFA) are generated annually by the Global Footprint Network for most countries of the world (GFN, 2005; WWF, 2006). They account for the consumption of land by the countries' residents wherever this land might be located. The Footprint associated with products imported from foreign countries, for example, is fully added to the consumers' Footprint account. Therefore, the concept of Ecological Footprint analysis strictly follows the principle of consumer responsibility[1], a term introduced in the context of discussions on greenhouse gas accounting (Munksgaard and Pederson, 2001).

This principle is in contrast to the producer responsibility principle[2], which is the basis of the Kyoto Protocol. Here, only territorial greenhouse gas emissions of a nation are accounted for; the emission embodiments of trade are not taken into account (Task Force on National Greenhouse Gas Inventories, 1996). Accordingly, many national greenhouse gas policies are aimed at reducing domestic greenhouse gas emissions and, in the Kyoto Protocol, national reduction goals based on a previous level of domestic emissions are used as a benchmark for success and compliance. But the consumption of imported goods and services, in some countries amplified by the relocation of domestic production abroad

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[1] Also called 'consumption (accounting) principle'.

[2] Also called 'production (accounting) principle'.

and subsequent import substitution, gives rise to environmental impacts in other places around the world and this calls for the consideration of greenhouse gas embodiments in international trade flows and their correct accounting.

As a consequence, an extensive discussion on the allocation of greenhouse gas emissions is conducted in the literature (e.g. Wyckoff and Roop, 1994; Kondo et al., 1998; Munskgaard and Pedersen, 2001; Ferng, 2003; Bastianoni et al., 2004; Sánchez-Chóliz and Duarte, 2004; Mongelli et al., 2005; Hoekstra and Janssen, 2006). In parallel to this discussion there is a development of models that are able to account for pollution embodied in trade. Recently, a range of multi-region input-output models has been described in the literature, a review of which is provided in Part 2 of this paper (Wiedmann et al., resubmitted).

In its current state the method to generate National Footprint Accounts (Monfreda et al., 2004; Wackernagel et al., 2005) can only provide a rough estimate of land appropriation associated with the trading of goods. Using FAOSTAT data (FAO, 2005) on domestic production, imports, exports and yields for a number of primary and secondary products from agriculture, forestry and fisheries, the accounts estimate the apparent net consumption of a nation and the associated appropriation of land. The national energy Footprint is calculated via $CO_2$ emissions data from IEA[3] or CDIAC[4]. For the trade balance of manufactured products, embodied energy data from disparate sources are used to convert their quantities into energy equivalents. These values are then assigned $CO_2$ equivalents and subsequently energy Footprints.

Recent improvements of the NFA feature the exhaustive use of global trade data from UN Comtrade (2005) in SITC classification on a 4-digit level and improved embodied energy data for over 600 commodities (Wackernagel et al., 2005). While the method is practical for computing the apparent resource consumption of 150 countries in the world, there are still fundamental shortcomings in the methodology[5]:

- For domestically produced bio-products national conversion efficiency factors are used to calculate the Footprint, whereas average global conversion efficiency factors are used for imports. The Footprint of exported products from biological resources is

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[3] International Energy Agency, Paris, France

[4] Carbon Dioxide Information Analysis Center, Oak Ridge, Tennessee, USA

[5] See also Wiedmann and Lenzen, 2007.

weighted in proportion to the amount of products imported and produced domestically and their respective conversion factors.

- Manufactured products have the same embodied energy regardless of the country of manufacture, i.e. the same energy intensities for imports and exports are used and they are the same for each country. For the conversion into energy Footprints via embodied $CO_2$ emissions, world average carbon dioxide intensity is used for all imports, whereas for exports of manufactured products the average carbon dioxide intensity of the exporting economy is used, reflecting the national fuel mix for energy production.
- Imports and exports of services are not included in the NFA analysis. This means that any direct and indirect resource use and/or pollution embodied in trade flows of services are not accounted for.

More generally, since only the total imports and exports from and to the rest of the world are listed for each country and thus no trade supply chains are identified, no distinction can be made as to where or how the imported products are produced. Hence, no account is taken for differences in production technology in trading partners, or, specifically, the direct and indirect Footprint intensity of trade flows of goods and services (with trade in the latter, and associated Footprints, neglected all together).

## 1.2. The application of environmental input-output techniques

Given that the focus of the Ecological Footprint is to capture the total (direct plus indirect) resource use embodied in final consumption in an economy, input-output would seem to be the ideal accounting framework. Input-output analysis is based around a set of sectorally disaggregated economic accounts, where inputs to each industrial sector, and the subsequent uses of the output of those sectors, are separately identified. The primary function of input-output analysis is to quantify the interdependence of different activities within the economy. It uses straightforward mathematical routines to track all direct, indirect and, where appropriate, induced, resource use embodied within consumption (Leontief, 1970, Miller and Blair, 1985). Input-output tables are generally constructed in monetary units for national accounting purposes. However, Leontief's (1970) initial environmental exposition was in physical units. This is an empirical issue (see for example Allan et al, 2007; Lenzen and Murray, 2001; Hubacek and Giljum, 2003; Minx et al., 2006; Weisz and Duchin, 2006); the analytical arguments do not differ.

In this paper (Part 1 of 2) we review documented applications of input-output methods to estimate Ecological Footprints and provide an account of the analytical method by which Ecological Footprints should ideally be estimated in an international input-output framework. We argue that multi-region input-output (MRIO) analysis is the appropriate method to allocate resource and/or pollution embodiments of consumption correctly and that it could ultimately be used to calculate national accounts of Ecological Footprints, following the consumer responsibility principle.

## 2. The basic environmental input-output method

The central input equation (see Leontief, 1970, Miller and Blair, 1985) is

[1] $$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{y}$$

where $\mathbf{x}$ is an $N\times1$ vector of gross outputs with elements $x_i$, where $i = 1,\ldots,N$, for each economic sector $i$, $\mathbf{y}$ is an $N\times1$ vector of final demands with elements $y_i$. $\mathbf{A}$ is the direct requirements (or input-output coefficients) matrix with elements $a_{ij}$ (where j=1,…$M$ and $M = N$), describing the amount of intermediate demand of output from domestic sector $i$ used by domestic sector $j$, per unit of output $x_j$ from sector j. $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ is the $N\times N$ Leontief inverse with elements $b_{ij}$ describing the amount of output generated in each sector $i$ per unit of final demand for the output of sector $j$.

Total resource use (or pollution generation[6]) in production is determined as

[2] $$\mathbf{f}^{\mathbf{x}} = \mathbf{\Omega x}$$

where $\mathbf{f}^x$ is a $K\times1$ vector, with elements $f_k^x$, where $k = 1,\ldots,K$, representing the total use of resource $k$ generated by all production activities in the economy. $\mathbf{\Omega}$ is a $K\times N$ matrix where element $\varpi_{k,i}$ is the average use of resource $k$ per unit of gross output in sector $i$.

[6] See McGregor *et al* (2004a).

Then the standard input-output attribution (Leontief, 1970; Miller and Blair, 1985) can be employed so that equation [1] is extended to

[3] $$\mathbf{f}^{y} = \mathbf{\Omega}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$$

where $\mathbf{f}^{y}$ is a $K\times1$ vector, with element $f_k^y$ being the total use of resource $k$ directly or indirectly required to satisfy total final demand, $\mathbf{y}$, in the economy.

If final demanders also directly use resources, [3] would be extended for final demand as

[3a] $$\mathbf{f}^{y*} = \mathbf{\Omega}^{x}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} + \mathbf{\Omega}^{y}\mathbf{y}$$

where we distinguish the *KxN* matrix of resource use coefficients for the *N* production sectors, now relabelled $\mathbf{\Omega}^{x}$, from a $K\times Z$ matrix, $\mathbf{\Omega}^{y}$, where each *Kx1* column within has elements $\varpi_{k,z}$ as the average direct use of resource $k$ per unit of expenditure by final demand group $z$.[7] For simplicity we abstract from this extension in the current exposition but, as shown in [3] and [3a], it is straightforward to introduce this element where appropriate.

Note that, in the closed or world economy example, it is the case that $\mathbf{f}^{x} = \mathbf{f}^{y}$, so that all resource use in production can be attributed to final consumption demand for the outputs of that production.

## 3. Applications of the basic environmental input-output method to Ecological Footprints and attempts to extend to the open economy case

In recent years there have been a number of contributions to the literature attempting to use input-output techniques to calculate Ecological Footprints (Bicknell et al., 1998;

[7] Examples for resource use occurring directly in households are the energy used during the combustion of household and car fuels or land occupied by a residential building.

Ferng, 2001; Ferng, 2002; Lenzen and Murray, 2001; McDonald and Patterson, 2003 and 2004; Lenzen et al., 2005; Wiedmann et al., 2006) or similar indicators (Eder and Narodoslawsky, 1999; Proops et al., 1999; Hubacek and Giljum, 2003; Sánchez-Chóliz and Duarte, 2004).

Applying the input-output method to an Ecological Footprint basically involves populating the matrix $\mathbf{\Omega}$ of resource use coefficients with a set of Ecological Footprint coefficients. That is, a *KxN* matrix of direct Footprint coefficients $\mathbf{\Omega} = \mathbf{f}^{\mathbf{x}} . \hat{\mathbf{x}}^{\mathbf{-1}}$ is established with elements $\varpi_{k,i} = f_{k,i} / x_i$ for each economic sector *i*, for example by disaggregating an existing Ecological Footprint account for the production in a country. Then a calculation of the form shown in [3] is used to estimate what types of final consumption directly or indirectly give rise to the pre-existing Footprint estimate. Such an approach is described in Wiedmann et al (2006) who reconcile the National Footprint Account of the UK – in terms of bioproductivity – with the UK economic National Accounts. Their method has been applied empirically to calculate the Ecological Footprint of local authorities, regions and devolved countries in the UK (Barrett et al., 2005; WWF-UK, 2006) as well as of UK socio-economic groups (Birch et al., 2004).

Other studies attempt to calculate the Ecological Footprint using other metrics: Bicknell et al (1998) were the first to present an application of input-output analysis to estimate an Ecological Footprint for New Zealand, where $\mathbf{\Omega}$ is a matrix of land-use coefficients. The main critique of their work (see for example Lenzen and Murray, 2001, McGregor et al, 2004a) is that Bicknell et al (1998) use a closed-economy framework where imports are exogenously given and the direct and indirect land-use coefficients of these imports are assumed to be identical to those in New Zealand.

In closed-economy input-output studies on $CO_2$ and other quantities (Schaeffer and Leal de Sá 1996, Hayami and Kiji 1997, Lenzen 1998, Hayami et al. 1999, Machado et al. 2001; see also Wiedmann et al, submitted) this assumption is usually implemented by adding the imports coefficients matrix $\mathbf{A}^{m}$ to the domestic direct requirements matrix, which we now distinguish as $\mathbf{A}^{\mathbf{d}}$, so that the modified total requirements coefficients are

[4] $$\mathbf{\Omega} \, [\, \mathbf{I} - (\mathbf{A}^{m} + \mathbf{A}^{\mathbf{d}}) \,]^{-1}$$

where $\mathbf{\Omega}$ is the same for all trading nations that directly or indirectly produce the goods and services that are imported to the country studied. Whether domestic multipliers are under- or overestimated through this assumption depends on whether land inputs per unit of output are higher or lower in the trading partners' territories. As some of the examples in the literature review (Part 2 of this paper, Wiedmann et al., submitted) show, resource use and pollution intensities per industrial sector can vary substantially between different countries. One extreme example quoted by Peters and Hertwich (2006a) is that $CO_2$ emission intensity for electricity production in China (generated mainly by coal power plants) is 231 times higher than for Norway (generated mainly by hydro power).

Similarly, in the case of direct resource-use and pollution intensities, Turner (2006) demonstrates the potential information loss when proxy measures of $\mathbf{\Omega}$ are used. In the case of standard economic multiplier analysis, with respect to the importance of region- and/or country-specific A-matrices, a number of studies have been conducted in the regional literature (see, for example Isserman, 1980; Harrigan et al, 1980a, 1980b; Round, 1983; Richardson, 1985; Flegg et al, 1995 and McCann and Dewhurst, 1998) focusing on how economic input-output relationships differ across even small regional economies within the same national economy.

The Bicknell et al (1998) approach of assuming New Zealand production structure applies in the rest of the world would seem particularly unrealistic: if a proxy must be used it would seem more valid to use information from an economy that is large relative to the rest of the world (the US, for example). However, Bicknell et al (1998) are not alone in making this type of assumption: for example, in a review of alternative methods the Office for National Statistics in the UK (2002) recommend, albeit with caution, a similar approach in the case of greenhouse gas emissions embodied in imports to the UK (see McGregor et al., 2004a, 2004b).

In another modification of the metric, Lenzen and Murray (2001) employ an input–output framework in terms of land disturbance, where land use coefficients are weighted by land condition, or impact on land. These authors model the open economy by internalising current as well as capital imports into intermediate demand. The multipliers of domestically produced commodities and imports are still identical. The same imports assumption is applied in a comparative bioproductivity-based Footprint study of the Australian State of Victoria (Lenzen et al., 2005), which aimed at reconciling differences between the manual accounting practices of the Global Footprint Network, and input-output accounting.

Ferng (2001) identifies another shortcoming in Bicknell et al.'s (1998) estimation procedure and suggests corrections in the methodology. Instead of a land multiplier vector, Ferng uses a land multiplier composition matrix, distinguishing land types by sectors and demonstrates that significantly different results are obtained by the two methods. Ferng (2002) also improves the methodology for the energy component of the Footprint by using a standard input-output approach for the calculation of embodied energy. In this framework imports to intermediate and final demand are considered separately but still with the assumption that the exporting countries have the same producing technology as the domestic economy. Also, no distinction is made for the origins of the intermediate inputs used by the producing sectors in those exporting countries (Ferng, 2002).

Bicknell et al.'s methodology has been developed further by McDonald and Patterson (2003 and 2004) in a sub-national input-output framework that explicitly models the land appropriation of 16 regions in New Zealand, including the embodied Footprints of regional imports and exports. Another application based on input-output analysis is described in a recent study by McDonald et al. (2006) that quantifies patterns of resource use and waste generation ('ecofootprints') of different age groups in New Zealand. In both cases however, the same single-region assumption as in the approach of Bicknell et al. (1998) is adopted, i.e. it is assumed that products imported from overseas have exactly the same embodied impact-per-$ ratio as products made in New Zealand.

The single-region assumption, albeit an improvement compared to the NFA method, needs to be challenged for setting up an accurate Footprint account for consumption, because the inclusion of land use and emissions associated with imports from all over the world exceeds the national boundaries of input-output tables.

A methodologically sound respond to this challenge is to extend the basic multi-sectoral single region input-output framework to the inter-regional case and to employ a multi-region input-output (MRIO) model ideally covering all trading partners of the country under investigation. A few studies comparing single versus multi-region input-output models of energy and $CO_2$ (e.g. Proops et al, 1999; Lenzen et al, 2004) have already demonstrated that multipliers and embodiments can differ substantially, thus warranting the extension to many regions. The MRIO model is discussed in the next section.

# 4. Theory of a multi-region input-output method for the Ecological Footprint

Given their widespread application (see Part 2 of this paper, Wiedmann et al., submitted), MRIO models would constitute obvious improvements of the Footprint method. In this section we provide an exposition of the extension of the basic single-region framework in equations [1] to [3] to the multi-region case, and to explicitly identify the key practical problems that are likely to arise and what the most appropriate solutions may be.

For the purpose of simplicity, the following exposition (derived from McGregor et al., 2004a and Miller and Blair, 1985) is given in terms of a 2-region world. However, it is straightforward to extend to the multiple region case (see Allan et al, 2004). In [1] we identified the key equation determining the $Nx1$ vector of output $\mathbf{x}$ in the single region input-output framework. We take this as region 1 in a 2-region world and separate the element $\mathbf{y}$ (final demand) into local final demand in region 1 of commodities produced in region 1 ($\mathbf{y}_{11}$) and export demand in region 2 for region 1 commodities ($\mathbf{y}_{12}$). Similarly for region 2, final demand for region 2 commodities is split into export demand in region 1 ($\mathbf{y}_{21}$) and local demand in region 2 ($\mathbf{y}_{22}$). We have

[7]
$$\begin{pmatrix} \mathbf{x}_{11} & \mathbf{x}_{12} \\ \mathbf{x}_{21} & \mathbf{x}_{22} \end{pmatrix} = \begin{pmatrix} \mathbf{I} - \mathbf{A}_{11} & -\mathbf{A}_{12} \\ -\mathbf{A}_{21} & \mathbf{I} - \mathbf{A}_{22} \end{pmatrix}^{-1} \begin{pmatrix} \mathbf{y}_{11} & \mathbf{y}_{12} \\ \mathbf{y}_{21} & \mathbf{y}_{22} \end{pmatrix}$$

where elements $a_{ij}^{rs}$ of the $N \times J$ submatrices $\mathbf{A}_{\mathbf{rs}}$ show the transactions between sector $i$ in producing region $r$ and using sector $j$ in consuming region s, per unit of output of sector $j$ in region $s$ . The partitioned matrix $(\mathbf{I} - \mathbf{A})^{-1}$ is the inter-regional Leontief inverse, breaking down the gross output multiplier for each sector in each region into gross outputs that are induced by domestic and by foreign final demand. In other words, by having partitioned the **A**-matrix for each region into local and imported intermediate consumption, and the **y** vector for each region into domestic and traded final demand, we can determine the level of inter-regional spillovers in terms of how activity in one region drives activity in the other.

Of course, the activity we are interested in here is resource use. Just as we extended the basis economic framework in equation [3] for the single region case, we simply introduce a $(K \times N)$ matrix of coefficients $\mathbf{\Omega}^x$, showing the direct resource-use intensity of output in each production sector $i$ for each region:

[8]

$$\begin{pmatrix} \mathbf{f}^{y}_{11} & \mathbf{f}^{y}_{12} \\ \mathbf{f}^{y}_{21} & \mathbf{f}^{y}_{22} \end{pmatrix} = \begin{pmatrix} \mathbf{\Omega}^{x}_{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{\Omega}^{x}_{2} \end{pmatrix} \begin{pmatrix} \mathbf{I-A}_{11} & \mathbf{-A}_{12} \\ \mathbf{-A}_{21} & \mathbf{I-A}_{22} \end{pmatrix}^{-1} \begin{pmatrix} \mathbf{y}_{11} & \mathbf{y}_{12} \\ \mathbf{y}_{21} & \mathbf{y}_{22} \end{pmatrix}$$

$$= \begin{pmatrix} \mathbf{\Omega}^{x}_{1}\mathbf{L}_{11}\mathbf{y}_{11} + \mathbf{\Omega}^{x}_{1}\mathbf{L}_{12}\mathbf{y}_{21} & \mathbf{\Omega}^{x}_{1}\mathbf{L}_{11}\mathbf{y}_{12} + \mathbf{\Omega}^{x}_{1}\mathbf{L}_{12}\mathbf{y}_{22} \\ \mathbf{\Omega}^{x}_{2}\mathbf{L}_{21}\mathbf{y}_{11} + \mathbf{\Omega}^{x}_{2}\mathbf{L}_{22}\mathbf{y}_{21} & \mathbf{\Omega}^{x}_{2}\mathbf{L}_{21}\mathbf{y}_{12} + \mathbf{\Omega}^{x}_{2}\mathbf{L}_{22}\mathbf{y}_{22} \end{pmatrix}$$

where $\mathbf{f}^{y}_{11}$ is a *Kx1* vector of the amount of resources that are used in production activities in region 1 to support region 1 final demand, while $\mathbf{f}^{y}_{21}$ is the amount of resources used in region 2 production to support region 1 final demand. The sum of these, in a 2-region world, will give us the Ecological Footprint for region 1 final demand:[8]

[9] $$\mathbf{f}^{y}_{1} = \mathbf{f}^{y}_{11} + \mathbf{f}^{y}_{21}$$

And the Ecological Footprint of region 2 is equal to

[10] $$\mathbf{f}^{y}_{2} = \mathbf{f}^{y}_{22} + \mathbf{f}^{y}_{12}$$

Similarly if we extend to the *N*-region case, this will simply involve summing down a column with an additional *N*-2 entries for each additional region. For example $\mathbf{f}^{y}_{1}$ would become

[11] $$\mathbf{f}^{y}_{1} = \mathbf{f}^{y}_{11} + \mathbf{f}^{y}_{21} + ... + \mathbf{f}^{y}_{n1}$$

[8] As mentioned above, the direct resource use by final consumers is omitted here for simplicity.

# 5. Practical issues for the application of the inter-regional framework

In order to estimate the MRIO system in Eq. [8] information is required on

- the direct imports to final consumption in the local economy/country, s, broken down by commodity and country of origin (to derive the elements of $\mathbf{y}_{\mathbf{r,s}}$ for each external region, r, from which imports are drawn)
- the imports used as intermediate inputs for each local industry in economy/country s, broken down by commodity and country of origin, r (to derive the elements of $\mathbf{A}_{\mathbf{rs}}$ )
- an input-output table for each country from which imports are drawn (to determine the elements of the inter-regional trade component, $\mathbf{-A}_{\mathbf{rs}}$ , of the partitioned inter-regional Leontief inverse, $\left[\mathbf{I - A}\right]^{\mathbf{-1}}$, in order to determine multiplier effects in the exporting country, r).

The input-output tables from each of the exporting countries, r, would themselves need to have the following characteristics:

- a sector mapping (i.e. a matrix that maps, or re-classifies sector *i* in the exporting country, r, into sectors *i* in each of the importing nations, s)
- a comparable set of input-output coefficients for resource use (i.e. for each sector *i* there must be a coefficient $\varpi_{ki}$ within the matrix $\mathbf{\Omega}$ showing the average direct resource intensity for resource *k* of producing one unit of output)
- equivalent input-output data to track direct and indirect imports from all other countries that the exporting country, r, trades with.

Moreover, in so far as each exporting country, r, imports from other countries not already included in the analysis, these too would need a full set of compatible input-output and resource-use accounts plus detailed import information.

Unless the economy under consideration had extremely limited trade links, an inter-regional world input-output table that is consistently nationally and sectorally disaggregated would be required. This system would have to be augmented with an associated set of resource use accounts. Such a database is not available at present.[9] Thus, there are three basic problems that have so far prevented the application of a full inter-regional framework of the type described above. The first is data availability, mainly in terms of flows of traded commodities between sectors in different countries. The second is reconciliation of data from different sources in different countries. The third is computability, particularly in terms of balancing conflicting data. Full discussions of these issues of the challenges involved in applying multi-region input-output frameworks can be found in Lenzen *et al* (2004) (see also Peters and Hertwich, 2006b).

# 6. Conclusions

This paper has argued that adopting a multi-region input-output accounting approach is the most appropriate method of calculating Ecological Footprints. In Part 2 of this paper (Wiedmann *et al*, submitted) we review existing applications of input-output techniques to estimate the environmental impacts embodied in trade. However, we have argued that, while empirical work of any kind, and particularly when it involves examining inter-sectoral, inter-regional and international interdependencies is fraught with information problems, meaning that short-cut methods are often employed. The nature and implications of simplifying assumptions adopted are often not made explicit.

Our motivation in this paper is that only by making explicit what we want to do, can we make systematic and transparent decisions about what short-cut methods should be applied in practice.

For example, from the exposition of the inter-regional method in Section 4, we can see which data are required: the $\mathbf{A_{rs}}$ local and traded input-output coefficient matrices (to allow us to derive the inter-regional Leontief inverse, $[\mathbf{I - A}]^{-1}$), the $\mathbf{\Omega}$ matrices (to convert these into resource-use multiplier matrices) and the sectoral output and final consumption vectors, $\mathbf{x}$ and $\mathbf{y}$ respectively. At the start of this section we have detailed the implications in terms of actual data components required. In the absence of any one of these for a given case, we can make and explain systematic and transparent decisions over whether these should be estimated (for example see Allan et al, 2004). In the absence of

[9] McGregor et al (2004b) encounter difficulties even in constructing a 2-region framework for Scotland and the rest of the UK.

data for individual regions or countries decisions can be made explicitly over whether proxy data should be drawn from other economies with similar economic structures, technology etc, or whether using an appropriate large country to proxy for a trading block is suitable. For example, as argued in Section 3, in the Bicknell et al (1998) study it would have been better if it were assumed that imports were produced using technology present in a large or closely linked trading nation like the US or Australia, rather than assume all countries share the same technology as New Zealand.

However, in the last few years data availability has become better and more comprehensive due to improvements in input-output databases (Dimaranan and McDougall, 2005; Yamano and Ahmad, 2006.) and trade data and models (Eurostat, 2003; Pain et al., 2005) and environmental accounts (United Nations, 2003). Therefore, it can be expected that more comprehensive and robust techniques for estimating Ecological Footprints will be developed in the near future. Our recommendation is that such developments should be made with a view to full application of the multi-region input-output approach detailed in this paper.

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