The University of Sydney
AUSTRALIA

The 2003-04 Ecological Footprint of the population of Canberra

Prepared by
Centre for Integrated Sustainability Analysis
The University of Sydney

The University of Sydney
Integrated Sustainability Analysis ™

The 2003-04 Ecological Footprint
of the population of the Australian Capital Territory

Report on consultancy work carried out for the Sustainability Policy and Programs within Territory and Municipal Services and the Commissioner for Sustainability and the Environment

by

Centre for Integrated Sustainability Analysis

The University of Sydney

Cover Photo:
Alan Benson
Canberra, view from Mt Ainslie to Black Mountain

Date of Final Report:

Monday, 21st January 2008

For further enquiries please contact:

http://www.isa.org.usyd.edu.au

Richard Wood
Phone: 0424 454723
Fax: (02) 9351 7725
Email: r.wood@physics.usyd.edu.au

School of Physics
A28
The University of Sydney
N.S.W. 2006

Dr Christopher Dey
Phone: (02) 9351 5979
Fax: (02) 9351 7725
Email: c.dey@physics.usyd.edu.au

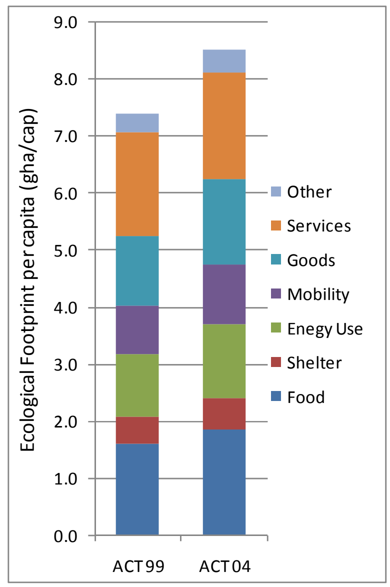
School of Physics
A28
The University of Sydney
N.S.W. 2006

Contents

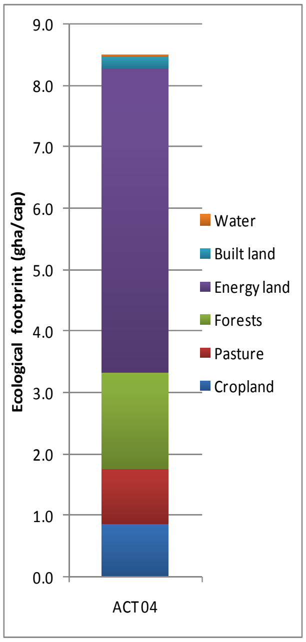
1. Executive Summary

The Ecological Footprint is a method aimed at measuring the sustainability of resource use and pollution of populations. Consumption data are converted into a single index: the land area that represents the exclusive demand that a population places on bioproductivity in order to sustain itself indefinitely. Since the method's conception, many teams around the world have carried out significant modifications and improvements to the concept. Two of these are the implementation of the economic tool of input-output analysis, and the incorporation of a regional, disturbance-based approach. Both modifications contribute to the methodology by adding from macroeconomic theory and biodiversity research. Input-output-based Ecological Footprints are complete in that they cover the supply chains of the entire upstream economy that ultimately enables the production of consumer items.

On average, the Ecological Footprint of a person living in the ACT in 2003-04 is 8.5 global hectares (gha), and with a population of 314,800 people, this amounts to a total of 2,677,400 global hectares, roughly eleven times the area of the ACT. This figure includes all upstream impacts, capital requirements, imports, and capital imports. The fact that the Ecological Footprint of the ACT is larger than its land area represents the fact that impacts of consumption go beyond its border and require significant productive area in other parts of Australia and the World.



In 2004, the 1998-99 Ecological Footprint of a person in the ACT was calculated. Due to methodological changes in the development of the Ecological Footprint, current results are not directly comparable to the 2004 report. Hence a recalculation of 1998-99 data according to current methodology yields a Ecological Footprint of 7.4 global hectares. We have thus seen a growth in the per-capita Ecological Footprint for the ACT of 15%.



The Australian average Ecological Footprint for 2003-04 is 7.3gha, 15% less than the ACT Ecological Footprint. Similarly, the Ecological Footprint of Victoria and Queensland are 7.6 gha and 7.2 gha respectively, whilst the Melbourne and Brisbane Ecological Footprint's are 7.6 gha and 7.3 gha respectively.

The sectors of the economy where the ACT impact occurs are shown to the above right. Food and services are the sectors most responsible for the total impact. However, at a more detailed level, the main commodities which contribute to the ACT's Ecological Footprint are electricity, residential building construction, services of retail trade, hospitality at bars, cafés and restaurants, and both ground and air transport.

In terms of impact on type of land, the Ecological Footprint of the ACT for 2003-04 is shown to the left by land category. By far the largest component is energy land – which represents the amount of bioproductive forest area required to absorb greenhouse gases emitted both by residents of the ACT and in the production of goods and services consumed by the ACT population. Forests, used primarily for construction purposes, also contribute significantly.

2. Project Background

2.1. The Ecological Footprint

The Ecological Footprint is a method aimed at measuring the sustainability of resource use and pollution of populations. Consumption data are converted into a single index: the land area that represents the demand that a population places on the earth's bioproductivity in order to sustain itself indefinitely. More specifically, the Ecological Footprint is a measure of human demand on the bioproductive land area that is required to support the resource demands of a given population or specific activities. This includes the land area needed to provide biological resources (raw materials, food, timber, etc) as well as the (notional) area required to absorb the carbon dioxide emissions emitted due to the consumption patterns of the Australian Capital Territory's (ACT) residents. This land area sits both within and outside the borders of the ACT and therefore the Ecological Footprint is an indicator for the impacts of consumption of the ACT residents wherever the products and services are produced.

The purpose of the Ecological Footprint is to inform the Government, and those involved in environmental management and in decision-making. In addition, stakeholders such as environmental non-government organizations, educators, community groups and individuals may use the information for awareness raising, and in order to educate about the impact of current consumption patterns.

The Ecological Footprint has been identified as a useful concept and effective tool to communicate key messages in State of Environment reporting, enabling the reader to garner a broad overview of the present environmental situation. The Ecological Footprint has the potential to illustrate, symbolically, the links between topical environmental issues such as climate change, and every day individual or local life styles.

Since the method's conception, many teams around the world have carried out significant modifications and improvements to the concept. Two of these are the implementation of the economic tool of input-output analysis, and the incorporation of a regional, disturbance-based approach. Both modifications contribute to the methodology by adding from macroeconomic theory and biodiversity research. Input-output-based Ecological Footprints are complete in that they cover the supply chains of the entire upstream economy that ultimately enables the production of consumer items. Local technologies are normalised using yield and equivalence factors in order to relate consumption to the average productivity of all bioproductive hectares on earth.

What is an Ecological Footprint? There is a limited amount of productive space on the globe to sustain life. This bioproductive land area can be measured in global hectares (gha) which represent the average yield of all biologically productive areas on earth. In 2003 there were 1.8 global hectares (gha) available per person (Global Footprint Network 2006). The Ecological Footprint measures the human demand on this area and highlights the ecological capacity of the planet. It sets out the extent to which we are living beyond the capacity of the planet. It encourages innovation toward 'one planet living'. Ecological Footprint shows how much biologically productive land and water a population requires to support current levels of consumption and waste production using prevailing technology. The world average Ecological Footprint in 2003 was 2.2 gha per person but as this exceeds the 1.8 gha per person available in 2003 it would take 1.25 years to regenerate what humanity consumes in a year. So, average resource consumption globally results in ecological overshoot of about 25%.

The purpose of the proposed project was to carry out the necessary calculations for determining the Ecological Footprint of the ACT and to present the findings in a clear and concise format. The Centre for Integrated Sustainability Analysis (ISA) at the University of Sydney employed and further developed environmentally extended input-output analysis to perform the calculations, building on the experience from previous projects in other parts of Australia and the ACT. The results presented in this report cover the financial year 2003/04 and meets standards in Ecological Footprinting.

2.2. Aims

The aim of this project was to update the 2004 Ecological Footprint report for the ACT in order to investigate the progress towards or away from sustainability occurring in the ACT. The project has four main objectives:

- To calculate the total Ecological Footprint of the ACT for 2004.
- To calculate the Ecological Footprint per-capita of the ACT population
- To give a comparison to the Australian average.
- To give a breakdown of the most important goods and services contributing to the ACT Footprint.

Finally, in order to give a fair comparison between years, a means to compare the 1999 Ecological Footprint with the 20004 ACT Ecological Footprint was required.

The following main sections of the report present a brief methodology, followed by the results and then a detailed description of the mathematics behind the methodology and data used.

3. Project Methodology

3.1. Overview

The results of this Ecological Footprint analysis of the ACT cover the financial year 2003/04 and meet international standards in Ecological Footprinting. This report considers the bioproductivity Ecological Footprint approach (Wackernagel and Rees 1996), i.e. it focuses on the bioproductive land taken up by human activities and is measured in global hectares (= adjusted hectares that represent the average yield of all biologically productive areas on earth).

This Ecological Footprint assessment is based on (1) input-output analysis, describing the interdependencies between economic sectors in Australia; and (2) household expenditure data collected by the Australian Bureau of Statistics. By matching the expenditure data with the results of the input-output analysis for various categories of goods and services, we were able to assess the per-capita environmental impacts of household consumption.

The Centre for Integrated Sustainability Analysis (ISA) at the University of Sydney has assembled a framework for calculating Ecological Footprints tailored to Australian conditions. This framework employs the most detailed and comprehensive information on land disturbance and greenhouse gas emissions available in Australia today, using the Australian Bureau of Statistics' (ABS) comprehensive input-output tables, and the CSIRO's satellite-image-based assessment of land disturbance over the Australian continent. The assessment offered by the University of Sydney guarantees 100% coverage of all upstream impacts on land and emissions, and is therefore the only complete Ecological Footprint assessment to date. Significant truncation errors (often 25-50%) of upstream requirements that are common in conventional Ecological Footprints do not occur in this methodology.

Using the ISA framework, the Ecological Footprint for Australia can be calculated from household expenditure data. This approach has been applied in dozens of applications throughout the past 30 years[8], and is the most robust approach of assessing environmental impacts of populations.

Final Ecological Footprints are based on a static, single-region, open, basic-price, industry-by-industry input-output model of the domestic Australian economy as of 1998-99, coupled with an extensive database on environmental indicators.[1] The methodology has been successfully piloted in a range of Australian company and government applications, a pilot program on TBL reporting, and in the widely publicised nation-wide whole-economy TBL study *Balancing Act* (see http://www.isa.org.usyd.edu.au for details).

[1] (Foran, Lenzen et al. 2005), with a summary in (Foran, Lenzen et al. 2005). See also (United Nations Department for Economic and Social Affairs Statistics Division 1999) and (Lenzen 2001).

Results can be interpreted *ex-post*, that is as answers to the questions: “What Ecological Footprint would have been assigned to the user, given base year economic and resource use structure, and assuming proportionality between monetary and resource flows?” Results can however not readily be interpreted in an *ex-ante*, predictive way, such as: “How would the Ecological Footprint change as a consequence of changes in the user’s financial and resource flows?”[2]

The following sections provides a detailed exposition of the methodology applied in this work. It is aimed at readers who are unfamiliar with the concept of the Ecological Footprint, and who wish to read up on most recent developments. A mathematical exposition of the methodology is included later.

3.2. Background to the Ecological Footprint

The Ecological Footprint was originally conceived as a simple and elegant method for comparing the sustainability of resource use among different populations (Rees 1992). The consumption of these populations is converted into a single index: the land area that would be needed to sustain that population indefinitely. This area is then compared to the actual area of productive land that the given population inhabits, and the degree of unsustainability is calculated as the difference between available and required land. Unsustainable populations are simply populations with a higher Ecological Footprint than available land. Ecological Footprints calculated according to this original method became important educational tools in highlighting the unsustainability of global consumption (Costanza 2000). It was also proposed that Ecological Footprints could be used for policy design and planning (Wackernagel, Onisto et al. 1997), (Wackernagel and Silverstein 2000).

Since the formulation of the Ecological Footprint, however, a number of researchers have criticised the originally proposed method (Levett 1998); (van den Bergh and Verbruggen 1999); (Ayres 2000); (Moffatt 2000); (Opschoor 2000); (Rapport 2000); (van Kooten and Bulte 2000). The criticisms largely refer to the oversimplification in Ecological Footprints of the complex task of measuring sustainability of consumption, leading to comparisons among populations becoming meaningless[3], or the result for a single population being significantly underestimated. In addition, the aggregated form of the final Ecological Footprint makes it difficult to understand the specific reasons for the unsustainability of the consumption of a given population (Rapport 2000), and to formulate appropriate policy responses (Ayres 2000); (Moffatt 2000); (Opschoor 2000); (van Kooten and Bulte 2000). In response to the problems highlighted, the concept has undergone significant modification and improvement (Bicknell, Ball et al. 1998), (Simpson, Petroeschevsky et al. 2000), (Lenzen and Murray 2001).

The original Ecological Footprint is defined as the land area that would be needed to meet the consumption of a population and to absorb all their waste (Wackernagel and Rees 1996).

---

2 For interpretation of static input-output models see (Miller and Blair 1985).

3 For example, as a result of calculations by (Wackernagel 1997), some countries with extremely high land clearing rates (Australia, Brazil, Indonesia, Malaysia) exhibit a positive balance between available and required land, thus suggesting that these populations are using their land at least sustainably.

Consumption is divided into 5 categories: food, housing, transportation, consumer goods, and services. Land is divided into 8 categories: energy land, degraded or built land, gardens, crop land, pastures and managed forests, and 'land of limited availability', considered to be untouched forests and 'non-productive areas', which the authors defined as deserts and ice-caps. The 'non-productive' areas are not included further in the analysis. Data are collected from disparate sources such as production and trade accounts, state of the environment reports, and agricultural, fuel use and emissions statistics. The Ecological Footprint is calculated by compiling a matrix in which a land area is allocated to each consumption category. In order to calculate the per-capita Ecological Footprint, all land areas are added up, and then divided by the population, giving a result in hectares per capita.

The total Ecological Footprint for a population can also be subtracted from the ‘productive’ area that population inhabits. If this gives a positive number, it is taken to indicate an ecological ‘remainder’, or remaining ecological capacity for that population. A negative figure indicates that the population has an ecological 'deficit'. According to the first Ecological Footprint calculation (Wackernagel and Rees 1996), Canadians in 1991 had an Ecological Footprint of 4.27 ha per capita and an ecological remainder of 10.94 ha per capita.

3.3. Including all areas of land

In the original Ecological Footprint, areas which were 'unproductive for human purposes', such as deserts and icecaps, are excluded from the calculation (Wackernagel and Rees 1996). A problem with this approach is that deciding which land is 'unproductive for human purposes' is subjective. There are many examples of indigenous peoples who have lived in deserts, in some cases, for thousands of years, such as the Walpiri people of Central Australia. In addition, large tracts of arid and semi-arid land in Australia support cattle grazing and mining. The ecosystems present in these areas have been, and continue to be, disturbed by these activities. Finally, many ecosystems that are not used directly may have indirect benefits for humans through providing biodiversity or other ecosystem functions. Therefore, in a recent calculation of the Ecological Footprint of Australia (Simpson, Petroeschevsky et al. 2000) all areas of land were included, irrespective of their productivity.

3.4. Input-output-based Ecological Footprinting

In the calculation of Ecological Footprints of populations by (Wackernagel and Rees 1996) and (Simpson, Petroeschevsky et al. 2000), the land areas included were mainly those directly required by households, and those required by the producers of consumer items. These producers, however, draw on numerous input items themselves, and the producers of these inputs also require land. Generally speaking, in modern economies all industry sectors are dependent on all other sectors, and this process of industrial interdependence proceeds infinitely in an upstream direction, through the whole life cycle of all products, like the branches of an infinite tree.

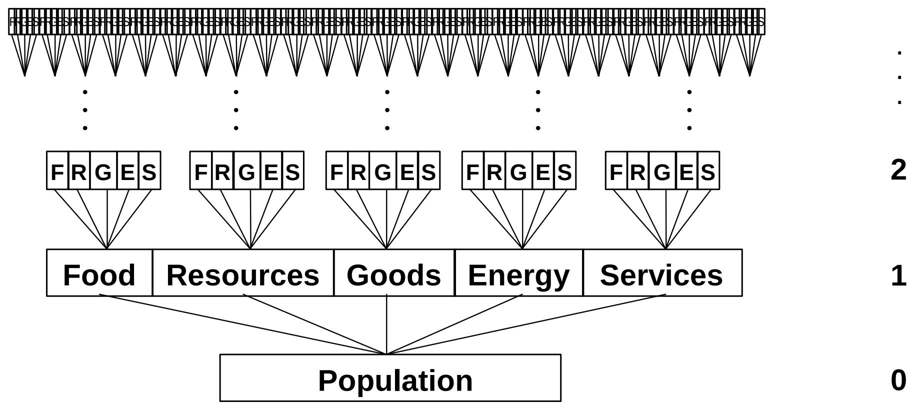


Figure 1: Industrial interdependence in a modern economy: a "tree" of upstream production layers.

Such a production "tree" is shown schematically in Figure 1: the population to be examined represents the lowest level, or production layer zero. The land required directly by the population (for example land occupied by the house, land required to absorb emissions caused in the household, or by driving a private car) is called the direct land requirement. All other, indirect land requirements originate from this layer. The providers of goods and services purchased by the population form the production layer number one, and their land requirements are called first-order requirements. The suppliers of these providers are production layer number two, and so on. The sum of direct and all indirect requirements, is called total requirements.

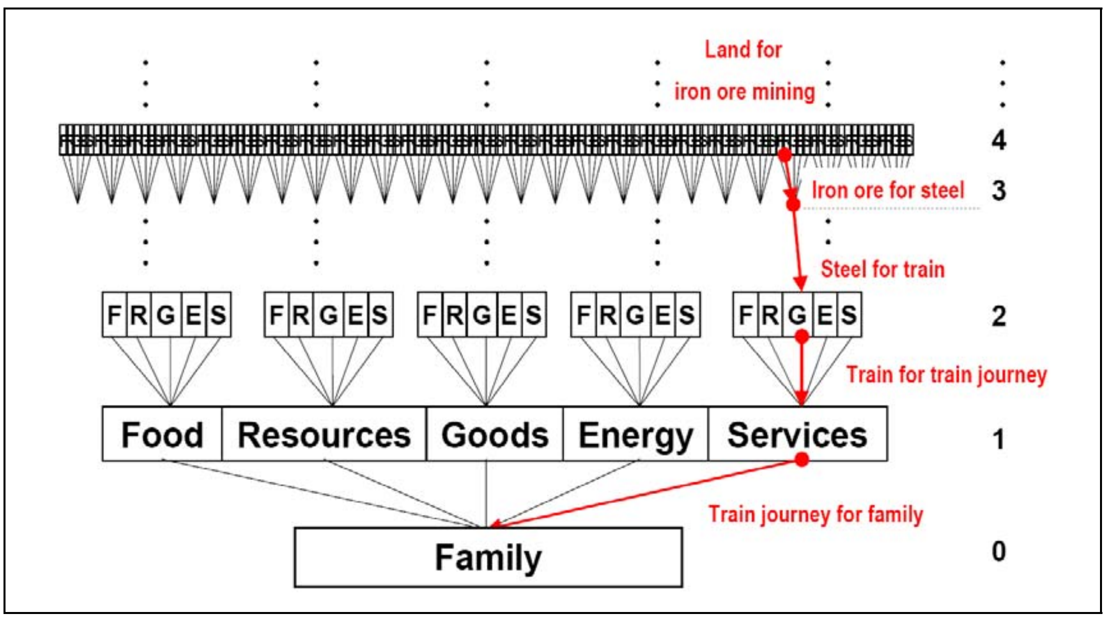


Figure 2: An example of production layers and input paths in Ecological Footprint calculations

A specific example for direct and indirect requirements in the Ecological Footprint of a family is shown in Figure 2. Direct requirements in production layer zero are represented by the land required for the family's home and for absorbing the emissions caused by the burning of petrol, natural gas and other fuels in the household and the car. One item contributing to the family's Ecological Footprint could be a train journey. The family does not directly require land by using this train. However, the train uses diesel fuel, which causes the emission of greenhouse gases. The rail transport operator providing this service is part of production layer 1, and the land required to absorb these emissions is an example for a first-order indirect requirement. Furthermore, the train itself needed to be built, and the land occupied by the train manufacturer (part of layer 2) is a second-order requirement. Land and emissions associated with the steel plant producing the steel sheet (layer 3) for the train are third-order requirements, the land mined to extract the iron ore (layer 4) for making the steel sheet is a fourth-order requirement, and so on. Each stage in this infinite supply process involves land use and emissions. Figure 1 and Figure 2 demonstrate that calculations that consider only layers zero and one underestimate the true Ecological Footprint.

Even though indirect requirements, production layers and structural paths can be very complex, there exists a method for their calculation: input-output analysis. This is a macroeconomic technique that relies on data on inter-industrial monetary transactions, as documented for example in the Australian input-output tables compiled by the (Australian Bureau of Statistics 2001). It was first applied by (Bicknell, Ball et al. 1998) to calculate an Ecological Footprint for New Zealand.
Since its first application in New Zealand, the use of input-output analysis for Ecological Footprint analysis has grown continuously, to include research organisations all over the world.[4] Recently, a pilot study has been completed for Victoria, for the first time comparing the original method with an input-output-based methodology (http://www.epa.vic.gov.au/eco-Footprint/docs/vic_ecofootprint_demand.pdf). At present, the Ecological Footprint methodology is being standardised (http://www.footprintstandards.org/), with a strong focus on input-output analysis.

Input-output-based Ecological Footprints have many advantages: they are complete without artificial boundaries, they draw on detailed data sets which are regularly collected by government statistical agencies, and they can be calculated for industry sectors and product groups, for states, local areas and cities, and for companies and households. Finally, input-output-based Ecological Footprints allow valid trade-offs with other sustainability indicators, thus placing the Ecological Footprint within the broader context of the Triple Bottom Line.

3.5. Ecological Footprint Land Types

The Ecological Footprint distinguishes different types of bioproductive areas that provide renewable resources for human consumption. **Cropland** is the land type with the greatest average

4 (Ferng 2001; Albino and Kühtz 2002; Bagliani, Ferlaino et al. 2002; Hubacek and Giljum 2003; Lenzen, Lundie et al. 2003; Lenzen and Murray 2003; McDonald and Patterson 2003; Nichols 2003; Wood and Lenzen 2003; Wiedmann and Barrett 2005; Wiedmann, Minx et al. 2006; Wiedmann, Barrett et al. 2007; Wiedmann, Lenzen et al. 2007).

bioproductivity per hectare and is used for growing crops for food, animal feed, fibre, oils and biofuels. **Pasture** (or grazing land) is used for raising animals for meat, hides, wool, and milk. **Forest** area is natural or plantation forests used for harvesting timber products and fuelwood. Infrastructure for housing, transportation, and industrial production occupies built-up land. This **built land** is not a bioproductive area but it is assumed to have replaced cropland area, as human settlements are predominantly located in fertile areas of a country. **Water** area needed for human consumption includes lakes and rivers used for freshwater provision, hydropower, fishing, freshwater aquaculture and recreational purposes. Finally, **energy land** is the notional area within the Ecological Footprint that is required to sequester carbon dioxide emissions from human activity. Energy land answers the question "how much woodland and forest area would we need to have in order to absorb all CO2 emissions from the burning of fossil fuels?".

3.6. Methodological changes

As previously mentioned, the Ecological Footprint methodology is being standardised (http://www.footprintstandards.org/), and as a result previous Ecological Footprint calculations may not be directly comparable to current calculations. In this section, we refer specifically to the major methodological changes that have occurred from the first calculation of the ACT Ecological Footprint in 2004 to the current calculation.

Perhaps the most significant change that has come from the standardisation of the methodology is the weighting of impacts on the land by global average bioproductivity factors rather than incorporating disturbance based factors. In the previous calculation, Ecological Footprint impacts were expressed in terms of built land; degraded land; cleared land; thinned land; partially disturbed land; reserves and greenhouse impacted land, with applicable weightings related to the projected ecosystem disturbance. In line with the standards, impacts on the land are now weighted by a yield factor in order to relate local productivity of each land type to the global average productivity of each land type. Land types are then weighted by equivalence factors in order to express land type impacts into a standard unit of biologically productive area –the global hectare.

For the particular case of greenhouse emissions, the previously used disturbance methodology related greenhouse emissions to the projected loss of land area due to climate change. In the bioproductivity approach, emissions are instead calculated by the biocapacity required to sequester carbon emissions through photosynthesis.

The second major change in methods used in this report is the updating and expansion of the Australian database from a baseline year of 1995 to 1999. The expansion of the database draws from detailed economic commodity reports, allowing the incorporation of a greater number of real physical data points for environmentally sensitive economic sectors. The disaggregation of a number of these sectors adds greater precision to results.

The overall effect of these changes is usually small at the aggregate level, and more pronounced at the highly detailed commodity level, dependant on the particular consumption patterns of a population. Hence, in order to allow meaningful comparisons to be made from the 2004 ACT Footprint report for 1998-99 to this current report, the 1998-99 dataset of consumption practices in the ACT has been expanded to the higher level of detail and processed according to the current methodology. This report, therefore, can be seen to supersede the 2004 report such that previous results can be interpreted against current Ecological Footprint standards.

4. Ecological Footprint Results for the ACT

4.1. Overview and key findings

The average ACT resident has an Ecological Footprint of 8.5 global hectares (Table 1), nearly four times higher than the world average, and 17% higher than the Australian average (7.3 gha). This equates to a total Ecological Footprint of 2.7 million global hectares, or 11 times the land area of the ACT. Most of the ACT's Ecological Footprint will be located in other parts of the world to provide the wide range of goods and services consumed by its residents. The Ecological Footprint consists of both "Real Land" (arable land, pasture, forests, built land etc.) and "Energy Land" (the land required to absorb the carbon dioxide emitted through the consumption patterns of a given population) [5].

ACT Ecological Footprint ('000 gha)						
Cropland	**Pasture**	**Forests**	**Energy land**	**Built land**	**Water**	**TOTAL**
275	282	492	1556	71	1	2677
10%	11%	18%	58%	3%	0%	100%

Aust. Ecological Footprint ('000 gha)						
Cropland	**Pasture**	**Forests**	**Energy land**	**Built land**	**Water**	**TOTAL**
15169	16546	29060	78005	3776	39	142596
11%	12%	20%	55%	3%	0%	100%

ACT Ecological Footprint per capita (gha)						
Cropland	**Pasture**	**Forests**	**Energy land**	**Built land**	**Water**	**TOTAL**
0.9	0.9	1.6	4.9	0.2	0.0	8.5

Aust. Ecological Footprint (gha)						
Cropland	**Pasture**	**Forests**	**Energy land**	**Built land**	**Water**	**TOTAL**
0.8	0.8	1.5	4.0	0.2	0.0	7.3

Table 1: The Ecological Footprint of the ACT and the whole of Australia by land type for 2003-04. Results are shown in absolute terms (thousands of global hectares, '000 gha) and per-capita (gha/cap).

For the ACT, the majority of the Ecological Footprint is "Energy Land" (58%). This is due to the heavy reliance on fossil fuels where the major impacts are from the consumption of electricity by

[5] Refer Section 3.5

households (13% of total), the use of flights and the purchase of petrol for cars (both 4% each of total, see below). In terms of "Real Land", the forest Footprint has the largest contribution with about 18% of the total Ecological Footprint. This largely reflects the use of wood in the construction of new houses, with this contributing a third of the forest Footprint in the ACT.

The Ecological Footprint on farming lands (Cropland and Pasture) in the ACT (0.9 gha each) is slightly higher than for the average Australian (0.8 gha each), reflecting a higher than average consumption of foodstuffs within the ACT. Combined, the Ecological Footprint of the farming lands account for 21% of the ACT Ecological Footprint compared to 23% of the Australian Ecological Footprint. Built land contributes only 3% to the Ecological Footprint of the average ACT resident, again reflecting just how little of a person's Ecological Footprint is contained within the urban environment.

A comparison of the ACT Ecological Footprint to other states (Figure 3) shows a similar trend to the Australian average. Victoria has an average per-capita Ecological Footprint of 7.6 gha (also 7.6 gha for Melbourne), whilst Queensland has an average per-capita Ecological Footprint of 7.2 gha (7.3 gha in Brisbane).

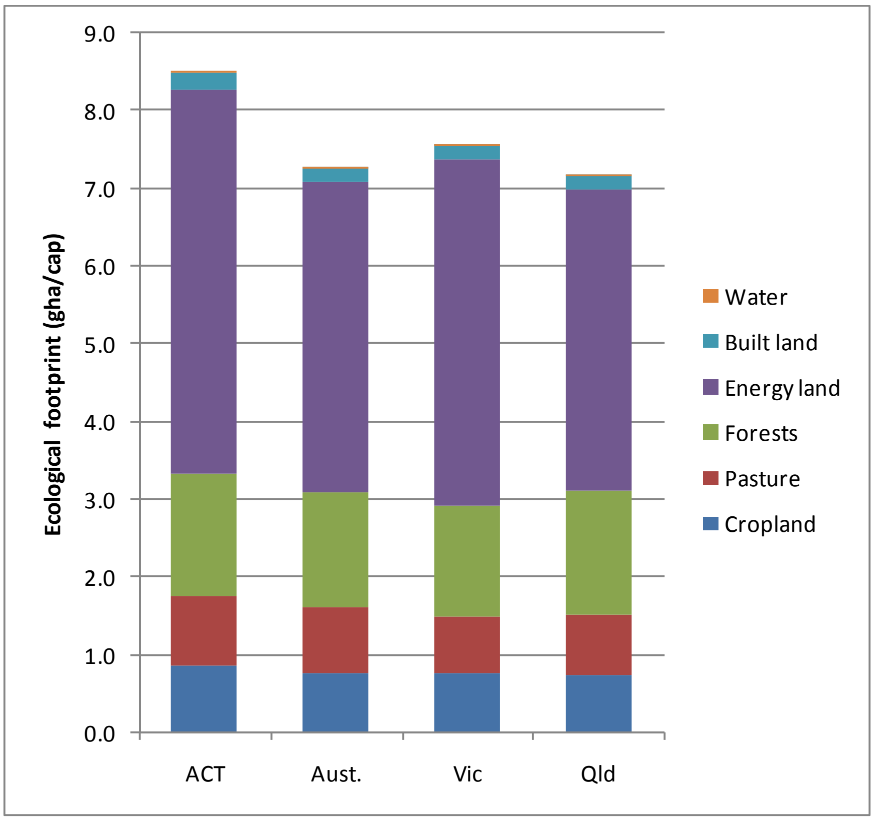


Figure 3: The per-capita Ecological Footprint of the ACT and the whole of Australia by land type, 2003-04.

4.2. Ecological Footprint by consumption category

The results can be organised by land or by consumption activities, such as travelling, the food we eat, the energy we consume, products we buy and the services we use. The graphs below provide more detail. All upstream impacts are included within each category. As an example the land required to grow wheat, as well as the energy used to harvest the wheat is all included within the "Food" category.

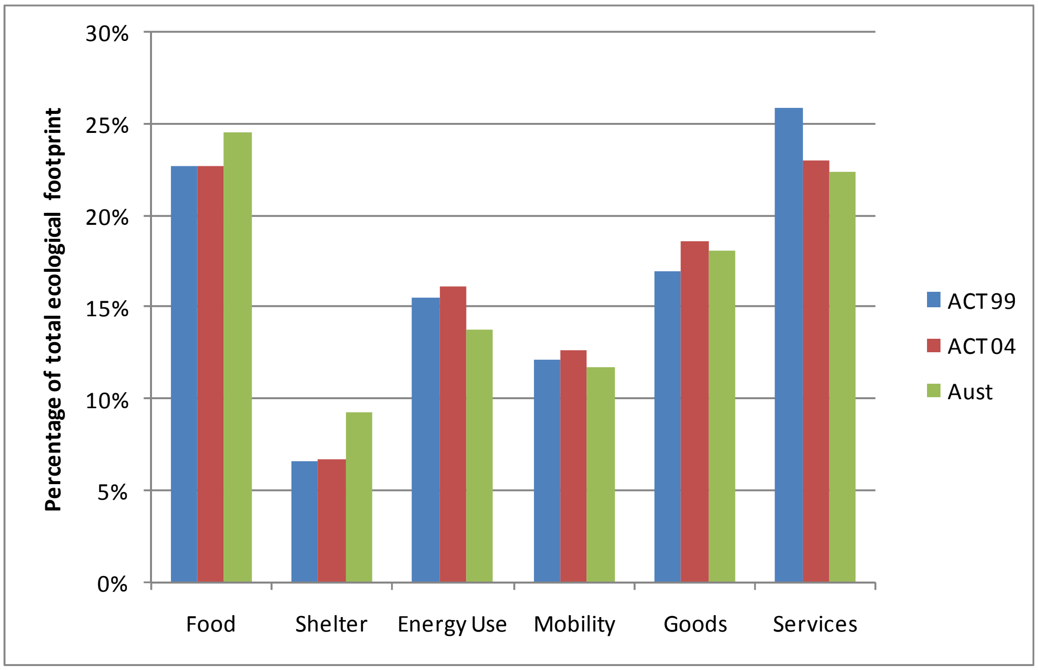


Figure 4: Comparison of Ecological Footprint consumption categories between the ACT and Australia, 2003-04.

Using these categories, the consumption of food and the demand for services have the most significant Ecological Footprint. Fifty-seven percent of the food impact (1.1 gha) is due to plant based food products, whilst the remainder (0.7 gha) is due to animal based products. The "services" category includes a large number of commodities including telecommunication services, financial services, medical, entertainment and government services. The main pattern of consumption in the ACT is reasonably similar to the national average, with slightly lower food and shelter impacts, but higher impacts in the more tertiary sectors.

To give an idea of the difference in impacts embodied within the production practices of each category, Figure 5 compares the Ecological Footprint of each consumption category (in blue) to the expenditure in each consumption category of ACT residents (in red).

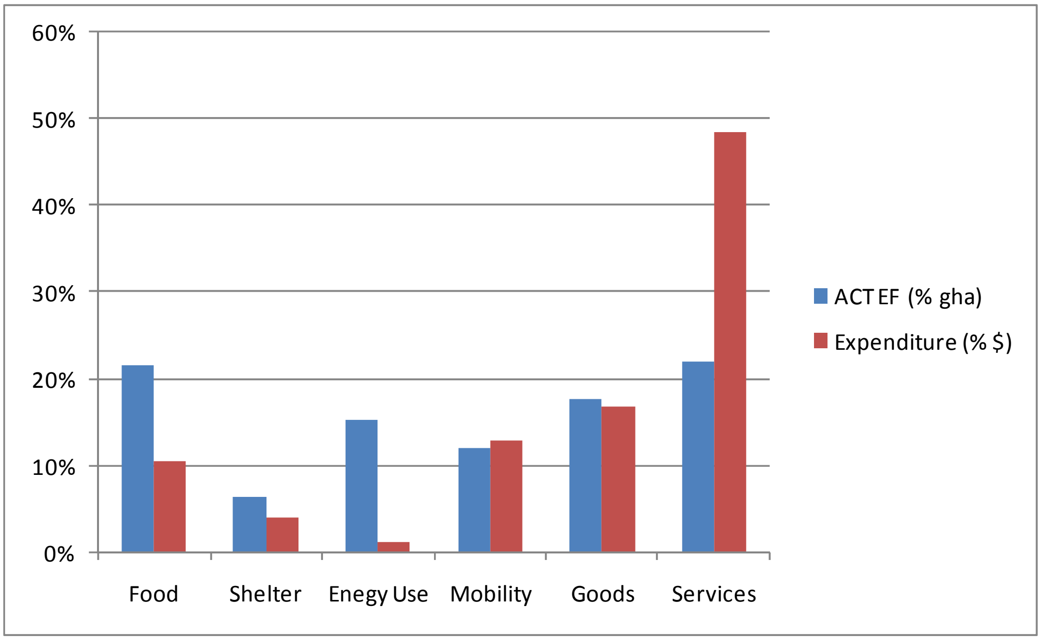


Figure 5: Comparison of consumption categories by Ecological Footprint and Expenditure, ACT 2003-04.

Hence, whilst food accounts for over 20% of the ACT Ecological Footprint, it is due to only roughly 10% of an ACT resident's expenditure ("Expenditure" includes imports, government and capital expenditure). In significant contrast, is the expenditure on services, making up almost 50% of total expenditure, but having an impact of slightly less than 20%. The issue of cheap electricity in Australia coupled with the environmental impact of the considerable carbon emissions is most evident in the Energy Use category of Figure 5.

4.3. Ecological Footprint analysis of commodities

The ACT's Ecological Footprint is a measure of land used to provide goods and services for activities such as building cities, growing fruit and vegetables, grazing cows to provide dairy and beef products, growing trees for paper and wood products, and absorbing carbon dioxide produced from using electric appliances, driving cars, operating machinery, etc. Each of these contributes to the Ecological Footprint. The high level consumption categories shown in Figure 4 can hide some of the finer details of the ACT's Ecological Footprint. Under these broad categories exists a breakdown of over 300 consumption activities (commodities). To calculate the Ecological Footprint, expenditure on every commodity by ACT residents has been taken into account. This helps provide a focus on where to take action to achieve maximum reduction in the Ecological Footprint.

Rank	Commodity	Impact (gha/capita)	% of Total
1	Electricity supply	1.1	13%
2	Residential building construction	0.5	6%
3	Retail trade	0.4	5%
4	Hotels, clubs, restaurants and cafes	0.4	5%
5	Petrol	0.3	4%
6	Air and space transport	0.3	4%
7	Other food products	0.3	3%
8	Wooden furniture	0.2	3%
9	Ownership of dwellings	0.2	3%
10	Electronic equipment	0.2	2%
11	Clothing	0.2	2%
12	Beef cattle	0.2	2%
13	Gas supply	0.1	2%
14	Non-building construction	0.1	2%
15	Education	0.1	2%
16	Finished cars	0.1	2%
17	Non-residential building construction	0.1	2%
18	Wheat	0.1	1%
19	Recorded media and publishing nec	0.1	1%
20	Wholesale trade	0.1	1%
21	Federal government	0.1	1%
22	Pharmaceutical goods for human use	0.1	1%
23	Community services and religious organisations	0.1	1%
24	Beer and malt	0.1	1%
25	Sport and recreation services	0.1	1%

Table 2: Top 25 commodities in terms of per-capita Ecological Footprint in the ACT in 2003-04.

These first twenty-five out of the 300 commodities account for more than two thirds (68%) of the total Ecological Footprint; they are listed in Table 2. All figures reported are in per-capita terms. Error margins for values quoted are in the order of 10-20%. At the top of the table is the impact of electricity consumption. Using electrical power alone adds around 13% (1.1 gha) to each person's Ecological Footprint every year. The ACT meets its electricity needs mostly through coal fired power stations which have one of the highest carbon dioxide emissions of all forms of electricity generation and therefore contributes significantly to the Ecological Footprint.

The second biggest Ecological Footprint is created by house construction. Building new homes in the ACT adds around half a global hectare to each person's Ecological Footprint every year. In this case it is mainly the forest area needed to grow timber for construction as well as the carbon Footprint of generating energy used in construction that creates this Footprint impact.

Other major contributors are retail trade (3rd) and hospitality (4th). Retail trade reflects the industry sector that sells us our goods and services. The underlying cause of this impact is the fuel consumption of the vehicles used to distribute the goods, and this is why it contributes to the energy Footprint. Food consumption (and waste) in restaurants, cafes and hotels is the main reason why this service is also high up on the list (0.4 gha/cap, rank 4). Private transportion is also a significant contributor, with the use of petrol in private automobiles ranked 5th, closely followed by airplane flights (6th).

For comparative purposes, the commodity ranking of the 1998-99 Ecological Footprint of the ACT has been calculated according to the current methodology (Table 3). Results at this level of detail are considerably different from the previous report mainly due to a) change in comparative weightings of impacts; b) change in classification to a more detailed data set. For more information, please refer to Section 3.6.

Rank	Commodity	Impact (gha/capita)	% of Total
1	Electricity supply	1.0	13%
2	Retail trade	0.4	6%
3	Residential building construction	0.4	5%
4	Hotels, clubs, restaurants and cafes	0.4	5%
5	Petrol	0.3	4%
6	Ownership of dwellings	0.2	3%
7	Wooden furniture	0.2	3%
8	Air and space transport	0.2	2%
9	Beef cattle	0.1	2%
10	Clothing	0.1	2%
11	Wholesale trade	0.1	2%
12	Finished cars	0.1	2%
13	Non-building construction	0.1	2%
14	Wheat	0.1	2%
15	Other food products	0.1	2%
16	Education	0.1	2%
17	Beer and malt	0.1	2%
18	Non-residential building construction	0.1	1%
19	Community services and religious organisations	0.1	1%
20	Electronic equipment	0.1	1%
21	Gas supply	0.1	1%
22	Federal government	0.1	1%
23	Sport and recreation services	0.1	1%
24	Pharmaceutical goods for human use	0.1	1%
25	Recorded media and publishing nec	0.1	1%

Table 3: Top 25 commodities in terms of per-capita Ecological Footprint in the ACT in 1998-99.

4.4. Conclusion

In 2003-04 the ACT Ecological Footprint was 8.5 global hectares (gha) per capita, a growth of approximately 15% from the ACT Ecological Footprint of 1998-99. The average ACT resident has a Ecological Footprint some 17% larger than the Australian average, and 11% larger than the average Melbourne resident. The total Ecological Footprint of all ACT residents is approximately 2,677,000 global hectares, eleven times the geographical area of the ACT. Fifty eight percent of the Ecological Footprint is “energy land” – which mainly reflects the biocapcity required to absorb carbon emissions. Eighteen percent of the Ecological Footprint is in Forests – primarily used within the residential construction industry. In comparison, only 3% of the ACT Ecological Footprint is in Built Land.

Food is responsible for the majority of the ACT Ecological Footprint, closely followed by the provision of services to ACT residents. Of the food Footprint, 57% is plant based whilst the remainder is animal based food products. At a more detailed level, the highest ranking commodities contributing to the ACT Ecological Footprint are electricity use, residential building construction, retail trade, hospitality, petrol use and aviation.

The ACT per-capita Ecological Footprint has grown 15% in 5 years. It is clear that if ACT residents want to move away from having one of the highest Ecological Footprints in Australia they will need to follow a more sustainable lifestyle including living smarter by using less electricity and choosing goods and services with low embodied Ecological Footprints.

5. Mathematical Exposition of the Methodology

Some of the more popular studies dealing with the sustainability of cities are Ecological Footprints[6]. This concept adopts the idea of carrying capacity, and by inverting the standard carrying capacity ratio, seeks to characterise an area of land that is needed to sustain a given population indefinitely, wherever on earth this land is located. The obvious result of most Ecological Footprint calculations is that cities appropriate an area of productive land that by far exceeds their physical size, and that therefore they cannot be sustainable (Rees and Wackernagel 1996). While Ecological Footprints are an instructive educational resource for raising awareness about global unsustainability, they have been criticised, for example, because the aggregated form of the final value makes it difficult to understand the specific reasons for the unsustainability of the consumption of a given population (Rapport 2000), and to formulate appropriate policy responses (Ayres 2000); (Moffatt 2000); (Opschoor 2000); (van Kooten and Bulte 2000). Furthermore, Ecological Footprints on sub-national scales underestimate indirect requirements (Bicknell, Ball et al. 1998; Lenzen and Murray 2001). In this work, we therefore focused on providing a disaggregated description of the environmental impact of city dwellers, both in terms of impact types (fuel use, greenhouse gas emissions, land use, etc.) and consumption type (goods, services, energy, water etc.). Furthermore, we take into account indirect requirements from all upstream production layers by using input-output analysis.

5.1. Input-output analysis

Input-output analysis is a macroeconomic technique that uses data on inter-industrial monetary transactions to account for the complex interdependencies of industries in modern economies. Since its introduction by (Leontief 1936; Leontief 1941), it has been applied to numerous economic and environmental issues, and input-output tables are now compiled on a regular basis for most industrialised, and also many developing countries.

The first input-output tables to be compiled for a city are those constructed by (Hirsch 1959), who surveyed large- and medium-sized companies operating in the St. Louis area, USA, and presents sectoral income, employment, fiscal and land multipliers (Hirsch 1963). (Smith and Morrison 1974), and (Morrison and Smith 1974) review methods to compile input-output tables for cities, based on survey and non-survey techniques. They conclude that non-survey techniques are the most attractive, because of the savings of time and resources they provide to the urban planner, and because they produce reliable results. Based on a comparison of a survey-based input-output table

[6] See, for example, studies of Vancouver (Rees and Wackernagel 1996), various cities surrounding the Baltic Sea (Folke, Jansson et al. 1997) and in the UK (Simmons and Chambers 1998), Santiago de Chile (Wackernagel 1998), Canberra (Close and Foran 1998), Malmö (Wackernagel, Lewan et al. 1999), Liverpool (Barrett and Scott 2001), Guernsey (Barrett 2001), and the Isle of Wight (Best Foot Forward and Imperial College 2001).

for the city of Peterborough, UK with semi- and non-survey versions, they conclude that the RAS method "proved to be far superior to all the other techniques which were tested" with regard to the similarity of the simulated input-output coefficients to the "true" survey-based ones. (Gordon and Ledent 1980) suggest using such local input-output coefficients for the multi-regional modeling of a system of metropolitan areas.

In this work we use a different approach for regionalisation: we combine the national Australian input-output tables and national data on resource use and pollution (modified by regionalising some important effects) with regional household expenditure data. The assumption inherent in this approach is that products purchased by regional households are produced regionally and nationally using a similar production recipe.[7] The technique of combining input-output and household expenditure data has been used previously by a number of authors[8], with only one study (Moll and Norman 2002) applying this approach to cities.

The Ecological Footprint of households in the SLAs and SSDs examined in this work is determined via

$$\mathbf{F} = \left(\mathbf{Q}^{\text{emb}} + \mathbf{Q}^{\text{hh}}\right) \times \mathbf{Y} \quad (1)$$

The variables in Equation 1 are:

F Matrix of household factor requirements.

Its elements $\{F_{ij}\}_{i=1,\dots,f\,;\,j=1,\dots,g}$ describe the total amount of factor *i* required by household group *j*. The term *factor* represents resource and Ecological Footprint components (land disturbance; fuel consumption; greenhouse gas emissions). **F** comprises (1) factors $\mathbf{Q}^{\text{hh}}\times\mathbf{Y}$ used directly by the household (in the house or by using private vehicles), and (2) factors $\mathbf{Q}^{\text{emb}}\times\mathbf{Y}$ used by Australian and foreign industries, that are required indirectly to provide goods and services purchased by the household. The latter are also called *embodied factor requirements*. **F** has dimensions $f\times g$, where *f* is the number of factors (f = 47), and *h* is the number of household groups. For the city of Sydney for example, the Australian Household Expenditure Survey conducted by the Australian Bureau of Statistics (ABS) distinguishes h = 240 household groups, categorised according to 18 household characteristics (mainly family type) and the 14 SSDs.

$\mathbf{Q}^{\text{hh}}$ Matrix of household factor multipliers.

---

7 Note that this study is not an analysis of regional but of national impacts. As such, the limitations in the use of national input-output tables for regional studies (Czamanski and Malizia 1969) do not apply here. In contrast, the analysis of local impacts or interregional flows requires the estimation of a set of regional input-output tables (Tiebout 1960).

8 See (Herendeen and Tanaka 1976; Herendeen 1978; Herendeen, Ford et al. 1981; Peet, Carter et al. 1985; Aoyagi, Kondo et al. 1992; Breuil 1992; Weber and Fahl 1993; Aoyagi, Moriguchi et al. 1995; Vringer and Blok 1995; Weber, Fahl et al. 1995; Kondo, Moriguchi et al. 1996; Lenzen 1998; Biesiot and Noorman 1999; Munksgaard, Pedersen et al. 2000; Weber and Perrels 2000; Munksgaard, Pedersen et al. 2001; Wier, Lenzen et al. 2001; Carlsson-Kanyama, Karlsson et al. 2002; Cohen, Lenzen et al. 2005; Lenzen, Wier et al. 2006).

Its elements $\left\{Q_{ij}^{\mathrm{hh}}\right\}_{i=1,...,f\,;\,j=1,...,s}$ describe the usage by private households of factor *i* per A$ value of final consumption of commodity *j*. $\mathbf{Q}^{\mathrm{hh}}$ has dimensions *f*×*s*, where *s* is the number of classified commodities. This number is also equal to the number of classified industry sectors. The version of the Australian *input-output tables* compiled by the ABS used in this work distinguishes *s* = 344 commodities[9] and industry sectors. These range from primary industries such as agriculture and mining, via secondary industries such as manufacturing and electricity, gas and water utilities, to tertiary industries such as commercial services, health, education, defence and government administration.

$\mathbf{Q}^{\mathrm{emb}}$ Matrix of embodied factor multipliers.

Its elements $\left\{Q_{ij}^{\mathrm{emb}}\right\}_{i=1,...,f\,;\,j=1,...,s}$ describe the usage of factor *i* per A$ value of final consumption of commodity *j*, (1) by the industry sectors producing commodity *j*, (2) by all upstream industry sectors supplying industry sectors producing commodity *j*, (3) by all upstream industry sectors supplying industry sectors that supply industry sectors producing commodity *j*, and (4) so on, infinitely. $\mathbf{Q}^{\mathrm{emb}}$ thus captures the *total factor requirements* of industries in the entire economy that are needed to produce commodities consumed by households. $\mathbf{Q}^{\mathrm{emb}}$ has dimensions *f*×*s*.

Y Matrix of household expenditure.

Its elements $\left\{Y_{ij}\right\}_{i=1,...,s\,;\,j=1,...,h}$ describe the amount of A$ spent on commodity *i* by household group *h* during the reference year. **Y** has dimensions *s*×*h*.

$\mathbf{Q}^{\mathrm{emb}}$ can be calculated according to the *basic input-output relationship*

$$\mathbf{Q}^{\mathrm{emb}} = \mathbf{Q}^{\mathrm{ind}}\left(\mathbf{I}-\mathbf{A}\right)^{-1} \qquad (2)$$

The variables in equation 2 are:

$\mathbf{Q}^{\mathrm{ind}}$ Matrix of industrial factor multipliers.

Its elements $\left\{Q_{ij}^{\mathrm{ind}}\right\}_{i=1,...,f\,;\,j=1,...,s}$ describe the usage of factor *i* by industry sector *j* per A$ value of total output by industry sector *j*. In contrast to $\mathbf{Q}^{\mathrm{emb}}$, $\mathbf{Q}^{\mathrm{ind}}$ represents only factors used directly in each industry, but not in upstream supplying industries. $\mathbf{Q}^{\mathrm{ind}}$ has dimensions *f*×*s*.

I The unity matrix.

Its elements $\left\{I_{ij}\right\}_{i=1,...,s\,;\,j=1,...,s}$ are I_{ij}=1 if *i*=*j*, and I_{ij}=0 if *i*≠*j*. **I** has dimensions *s*×*s*.

A Matrix of direct requirements.

---

9 The so-called ISAPC sector classification is a non–confidential subset of the Australian Bureau of Statistics' 8-digit Input-Output Product Classification (IOPC8; (Australian Bureau of Statistics 2001)).

Its elements $\{A_{ij}\}_{i=1,\ldots,s;\, j=1,\ldots,s}$ describe the amount of input in Australian Dollars (A$) of industry sector *i* into industry sector *j*, per A$ value of total output of industry sector *j*. **A** has dimensions $s \times s$. It comprises imports from foreign industries and transactions for capital replacement and growth. **A** captures the interdependence of industries in the Australian economy and their dependence on foreign industries, and – assuming that imports are produced using Australian technology[10] – thus enables the translation of industrial factor multipliers $\mathbf{Q}^{\text{ind}}$ into embodied factor multipliers $\mathbf{Q}^{\text{emb}}$.

For an introduction into input-output theory, see articles by (Leontief and Ford 1970), (Duchin 1992), and (Dixon 1996). For a history of the development of input-output analysis, see (Carter and Petri 1989), and (Forssell and Polenske 1998). For examples and reviews of input-output studies applied to environmental issues, see (Leontief and Ford 1971), (Isard, Choguill et al. 1972), (Herendeen 1978), (Miller and Blair 1985), (Proops 1988), (Miller, Polenske et al. 1989), (Hawdon and Pearson 1995), and (Forssell 1998). For a description of the assembly of an Australian input-output framework, see (Lenzen 2001).

5.2. Data sources

The main difficulties encountered during the data collection and preparation were due to differences in industry sector classification and differences in data reference year. It was necessary to confront and reconcile data sets documented according to the Australian and New Zealand Standard Industrial Classification (ANZSIC), the Input-Output Product Classification (IOPC), the Australian land use (ALUMC) classification, the Household Expenditure Survey commodity classification, and the reporting format prescribed by the Intergovernmental Panel on Climate Change (IPCC).

Surveys of industries, households and farms are not conducted in identical intervals. Hence, the input-output, household expenditure, resource use and pollution data refer to different years between 1998 and 2003. In order to minimise discrepancies, input-output and factor data was assembled for years closely around 1998-99, where data availability was best. Data were reconciled using RAS matrix balancing[11], and optimisation techniques[12]. As a consequence, small flows (monetary and physical) are associated with large uncertainties, as indicated in some of the results sheets.

Household Expenditure Survey data

---

10 For example, in this study, Australian energy intensities were also applied to imported items (about 10% of total Australian output), which equivalent to assuming that they are produced using Australian technology. This assumption carries an uncertainty into energy multipliers.

11 (Gretton and Cotterell 1979); (Junius and Oosterhaven 2003).

12 (Tarancon and Del Rio 2005).

The source of the household expenditure data was the *Household Expenditure Survey (HES),* published by the Australian Bureau of Statistics, Catalogue No. 6540.0 . Data was available at the SSD level for 1998-99. An updated data set was made available in 2006 for the 2003-04 year, however, the ABS would not release data at the SSD level. Hence household expenditure data at the SSD level for 2003-04 has been estimated by creating an initial estimate from the 1998-99 data and subsequently constraining by 2003-04 state data, with a further constraint utilising a breakdown between capital city and rest of state.

The household expenditure matrix Y was derived from the 1998-99 Household Expenditure Survey (Australian Bureau of Statistics 2000), while the direct requirements matrix A was constructed from the Australian input-output tables (Australian Bureau of Statistics 1999; Australian Bureau of Statistics 1999); see also (Lenzen 2001).

The baseline year for the Ecological Footprint model is 1998-99, hence all prices were deflated to 1999 levels. To do this, the ABS published Consumer Price Index (Australian Bureau of Statistics 2006) was supplemented with Produce Price Indices (Australian Bureau of Statistics 2006) where necessary, and subsequently correlated with the HES data. Price indices were created at a state level, with the assumption that the published price indices in capital cities were similar across each respective state. The importance of state based price indices is particularly evident for such consumer items as automotive fuel, which not only forms a significant component of the population's Ecological Footprint, is also quite volatile over time and across locations.

Data refer to the financial year 1998-99. Since then, especially petrol and gas prices and tariffs may have experienced high variability, which has to be accounted for by continuously and manually adjusting intensities in order to keep them up-to-date. The most accurate way of doing this is to proceed as follows:

- Petrol, GHG: obtain current petrol price (by State) in $/L. Invert, and multiply by 34.2 MJ/L and by 0.066 kg/MJ. Add to the indirect intensity in table below for the respective category.
- Gas, GHG: obtain gas price (by State) in $/GJ. Divide by 1000, invert, and multiply by 0.051 kg/MJ. Add to the indirect intensity in table below for the respective category.
- There is no information on margins and other mark-ups to convert basic prices into purchasers' prices on a state basis. National data was hence used.

Ecological Footprint data

The industrial Ecological Footprint multipliers $\mathbf{Q}_{ef}^{ind}$ as well as household Ecological Footprint multipliers $\mathbf{Q}_{ef}^{hh}$ were obtained by consulting a range of sources such as fuel statistics (Australian Bureau of Agricultural and Resource Economics 1999), (Australian Bureau of Agricultural and Resource Economics 2000), the Australian National Greenhouse Gas Inventory (Australian Greenhouse Office 1999), (George Wilkenfeld & Associates Pty Ltd and Energy Strategies 2002), the ABS' Integrated Regional Database ((Australian Bureau of Statistics 2001), and a CSIRO report on landcover disturbance across the Australian continent (Graetz, Wilson et al. 1995); (Lenzen and Murray 2001).

Other data

State specific figures were taken from (Australian Greenhouse Office 2004). The full fuel-cycle emission factor for electricity in the ACT is 1.054 kg CO2-e/kWh.

5.3. Uncertainties

Input-output analysis suffers from uncertainties arising from the following sources: (1) uncertainties of basic source data due to sampling and reporting errors, and uncertainties resulting from (2) the assumption made in single-region input-output models, that foreign industries producing competing imports exhibit the same factor multipliers as domestic industries, (3) the assumption that foreign industries are perfectly homogeneous, (4) the assumption of proportionality between monetary and physical flow, (5) the aggregation of input-output data over different producers, (6) the aggregation of input-output data over different products supplied by one industry, and (7) the truncation of the "gate-to-grave" component of the full life cycle (see (Bullard, Penner et al. 1978) and (Lenzen 2001). Standard errors $\Delta Q_{ij}^{\mathrm{emb}}$ of elements in the embodied factor multiplier matrix $\mathbf{Q}^{\mathrm{emb}}$ due to the above sources defy analytical treatment, and can therefore only be determined using stochastic analysis. The $\Delta Q_{ij}^{\mathrm{emb}}$ can be calculated by Monte-Carlo simulations of the propagation of normally distributed perturbations from $\mathbf{Q}^{\mathrm{ind}}$ and $\mathbf{A}$ through to $\mathbf{Q}^{\mathrm{emb}}$ (see (Lenzen 2001). Given the standard errors $\Delta\left(Q^{\mathrm{emb}}+Q^{\mathrm{hh}}\right)_{ik}$ of $\mathbf{Q}^{\mathrm{emb}}+\mathbf{Q}^{\mathrm{hh}}$, and ΔY_{kj} of $\mathbf{Y}$, the total standard error ΔF_{ij} of an element F_{ij} in the household factor requirement $\mathbf{F}$ in Equation 1 is

$$\Delta F_{ij}=\sqrt{\sum_{k=1}^{s}\Delta\left(Q^{\mathrm{emb}}+Q^{\mathrm{hh}}\right)_{ik}^{2} Y_{kj}^{2}+\sum_{k=1}^{s}\left(Q^{\mathrm{emb}}+Q^{\mathrm{hh}}\right)_{ik}^{2}\Delta Y_{kj}^{2}} . \quad (3)$$

The uncertainty ranges of $\mathbf{Q}^{\mathrm{emb}}+\mathbf{Q}^{\mathrm{hh}}$ cover raw data uncertainty and allocation uncertainty only, as described in (Lenzen 2001).

6. References

Albino, V. and S. Kühtz (2002). Environmental footprint of industrial districts using input-output tables based on production processes. 14th International Conference on Input-Output Techniques, Montréal, Canada, Internet site http://www.io2002conference.uqam.ca/abstracts_papers/new16janv03/Montreal_final_paper.doc.

Aoyagi, M., Y. Kondo, et al. (1992). Analysis of differences of CO_2 emission structure by consumption expenditures of households. 9th Energy System / Economics Conference, Tokyo, Japan.

Aoyagi, M., Y. Moriguchi, et al. (1995). "Characteristics of households' energy consumption." Energy and Resources **16**(6): 59-67 (in Japanese).

Australian Bureau of Agricultural and Resource Economics (1999). Australian energy consumption and production. Canberra, Australia, Commonwealth of Australia.

Australian Bureau of Agricultural and Resource Economics. (2000). "Australian energy consumption and production, Table C1AUST, Historical data update."

Australian Bureau of Statistics (1999). Australian National Accounts, Input-Output Tables, 1994-95. Canberra, Australia, Australian Bureau of Statistics.

Australian Bureau of Statistics. (1999). "Australian National Accounts, Input-Output Tables, 1994-95, Commodity Details."

Australian Bureau of Statistics. (2000). "1998-99 Household Expenditure Survey - Detailed Expenditure Items, Confidentialised Unit Record File."

Australian Bureau of Statistics (2001). Australian National Accounts, Input-Output Tables, 1996-97. Canberra, Australia, Australian Bureau of Statistics.

Australian Bureau of Statistics (2001). Australian National Accounts, Input-Output Tables, Product Details, 1996-97. Canberra, Australia, Australian Bureau of Statistics.

Australian Bureau of Statistics. (2001). "Integrated Regional Data Base."

Australian Bureau of Statistics (2006). Consumer Price Index, Australia. ABS Catalogue No. 6401.0. Canberra, Commonwealth of Australia.

Australian Bureau of Statistics (2006). Producer Price Index, Australia. ABS Catalogue No. 6427.0. Canberra, Commonwealth of Australia.

Australian Greenhouse Office. (1999). "Australia's National Greenhouse Gas Inventory."

Australian Greenhouse Office (2004). AGO Factors and Methods Workbook. Canberra, Australia, Australian Government.

Ayres, R. U. (2000). "Commentary on the utility of the ecological footprint concept." Ecological Economics **32**: 347-349.

Bagliani, M., F. Ferlaino, et al. (2002). Ecological footprint and input-output methodology: the analysis of the environmental sustainability of the economic sectors of Piedmont Region (Italy). 14th International Conference on Input-Output Techniques, Montréal, Canada, Internet site http://www.io2002conference.uqam.ca/abstracts.pdf.

Barrett, J. (2001). "Component ecological footprint: developing sustainable scenarios." Impact Assessment and Project Appraisal **19**(2): 107-118.

Barrett, J. and A. Scott. (2001). "An Ecological footprint of Liverpool: A Detailed Examination of Ecological Sustainability."

Best Foot Forward and Imperial College. (2001). "Ecological footprint of the Isle of Wight."

Bicknell, K. B., R. J. Ball, et al. (1998). "New methodology for the ecological footprint with an application to the New Zealand economy." Ecological Economics **27**(2): 149-160.

Biesiot, W. and K. J. Noorman (1999). "Energy requirements of household consumption: a case study of The Netherlands." Ecological Economics **28**(3): 367-383.

Breuil, J.-M. (1992). "Input-output analysis and pollutant emissions in France." Energy Journal **13**(3): 173-184.

Bullard, C. W., P. S. Penner, et al. (1978). "Net energy analysis - handbook for combining process and input-output analysis." Resources and Energy **1**: 267-313.

Carlsson-Kanyama, A., R. Karlsson, et al. (2002). Household metabolism in the Five Cities - Swedish National Report - Stockholm. Stockholm, Sweden, Forskningsgruppen för Miljöstrategiska Studier.

Carter, A. P. and P. A. Petri (1989). "Leontief's contribution to economics." Journal of Policy Modeling **11**(1): 7-30.

Close, A. and B. Foran (1998). Canberra's ecological footprint. Canberra, Australia, Resource Futures Program, CSIRO Wildlife and Ecology.

Cohen, C. A. M. J., M. Lenzen, et al. (2005). "Energy requirements of households in Brazil." Energy Policy **55**: 555-562.

Costanza, R. (2000). "The dynamics of the ecological footprint concept." Ecological Economics **32**: 341-345.

Czamanski, S. and E. E. Malizia (1969). "Applicability and limitations in the use of national input-output tables for regional studies." Papers of the Regional Science Association **23**: 65-77.

Dixon, R. (1996). "Inter-industry transactions and input-output analysis." Australian Economic Review **3'96**(115): 327-336.

Duchin, F. (1992). "Industrial input-output analysis: implications for industrial ecology." Proceedings of the National Academy of Science of the USA **89**: 851-855.

Ferng, J.-J. (2001). "Using composition of land multiplier to estimate ecological footprints associated with production activity." Ecological Economics **37**: 159-172.

Folke, C., Å. Jansson, et al. (1997). "Ecosystem appropriation by cities." Ambio **26**(3): 167-172.

Foran, B., M. Lenzen, et al. (2005). Balancing Act - A Triple Bottom Line Account of the Australian Economy. Canberra, ACT, Australia, CSIRO Resource Futures and The University of Sydney.

Foran, B., M. Lenzen, et al. (2005). "Integrating Sustainable Chain Management with Triple Bottom Line Reporting." Ecological Economics **52**(2): 143-157.

Forssell, O. (1998). "Extending economy-wide models with environment-related parts." Economic Systems Research **10**(2): 183-199.

Forssell, O. and K. R. Polenske (1998). "Introduction: input-output and the environment." Economic Systems Research **10**(2): 91-97.

George Wilkenfeld & Associates Pty Ltd and Energy Strategies (2002). Australia's National Greenhouse Gas Inventory 1990, 1995 and 1999 - end use allocation of emissions. Canberra, Australia, Australian Greenhouse Office.

Global Footprint Network (2006). Living Planet Report 2006. WWF. Gland, Switzerland.

Gordon, P. and J. Ledent (1980). "Modeling the dynamics of a system of metropolitan areas: a demoeconomic approach." Environment and Planning A **12**(2): 125-133.

Graetz, R. D., M. A. Wilson, et al. (1995). Landcover disturbance over the Australian continent. Canberra, Australia, Department of the Environment, Sport and Territories Biodiversity Unit.

Gretton, P. and P. Cotterell (1979). The RAS method for compiling input-output tables - Australian Bureau of Statistics experience. Eighth Conference of Economists, La Trobe University.

Hawdon, D. and P. Pearson (1995). "Input-output simulations of energy, environment, economy interactions in the UK." Energy Economics **17**(1): 73-86.

Herendeen, R. (1978). "Total energy cost of household consumption in Norway, 1973." Energy **3**: 615-630.

Herendeen, R., C. Ford, et al. (1981). "Energy cost of living, 1972-1973." Energy **6**: 1433-1450.

Herendeen, R. and J. Tanaka (1976). "Energy cost of living." Energy **1**: 165-178.

Herendeen, R. A. (1978). "Input-output techniques and energy cost of commodities." Energy Policy **6**(2): 162-165.

Hirsch, W. Z. (1959). "Interindustry relations of a metropolitan area." Review of Economics and Statistics **41**(4): 360-369.

Hirsch, W. Z. (1963). Application of input-output techniques to urban areas. Structural Interdependence and Economic Development. T. Barna. London, UK, MacMillan & Co Ltd**:** 151-168.

Hubacek, K. and S. Giljum (2003). "Applying physical input-output analysis to estimate land appropriation (ecological footprints) of international trade activities." Ecological Economics **44**: 137-151.

Isard, W., C. L. Choguill, et al. (1972). Ecologic-economic analysis for regional development. New York, NY, USA, The Free Press.

Junius, T. and J. Oosterhaven (2003). "The solution of updating or regionalizing a matrix with both positive and negative entries." Economic Systems Research **15**(1): 87-96.

Kondo, Y., Y. Moriguchi, et al. (1996). "Analysis of the trend of CO_2 emission structure by consumption expenditures of households." Transactions of the Society of Environmental Science **9**(2): 231-240 (in Japanese).

Lenzen, M. (1998). "The energy and greenhouse gas cost of living for Australia during 1993-94." Energy **23**(6): 497-516.

Lenzen, M. (2001). "Errors in conventional and input-output-based life-cycle inventories." Journal of Industrial Ecology **4**(4): 127-148.

Lenzen, M. (2001). "A generalised input-output multiplier calculus for Australia." Economic Systems Research **13**(1): 65-92.

Lenzen, M., S. Lundie, et al. (2003). "Assessing the ecological footprint of a large metropolitan water supplier - lessons for water management and planning towards sustainability." Journal of Environmental Planning and Management **46**(1): 113-141.

Lenzen, M. and S. A. Murray (2001). "A modified ecological footprint method and its application to Australia." Ecological Economics **37**(2): 229-255.

Lenzen, M. and S. A. Murray (2003). The ecological footprint - issues and trends. Sydney, Australia, ISA The University of Sydney.

Lenzen, M., M. Wier, et al. (2006). "A comparative multivariate analysis of household energy requirements in Australia, Brazil, Denmark, India and Japan." Energy **31**: 181-207.

Leontief, W. (1936). "Quantitative input and output relations in the economic system of the United States." Review of Economics and Statistics **18**(3): 105-125.

Leontief, W. (1941). The Structure of the American Economy, 1919-1939. Oxford, UK, Oxford University Press.

Leontief, W. and D. Ford (1970). "Environmental repercussions and the economic structure: an input-output approach." Review of Economics and Statistics **52**(3): 262-271.

Leontief, W. and D. Ford (1971). Air pollution and the economic structure: empirical results of input-output computations. Fifth International Conference on Input-Output Techniques, Geneva, Switzerland, North-Holland Publishing Company.

Levett, R. (1998). "Footprinting: a great step forward, but tread carefully." Local Environment **3**(1): 67-74.

McDonald, G. and M. Patterson (2003). Ecological Footprints of New Zealand and its Regions. Wellington, New Zealand, Ministry for Environment New Zealand.

Miller, R. E. and P. D. Blair (1985). Input-Output Analysis: Foundations and Extensions. Englewood Cliffs, NJ, USA, Prentice-Hall.

Miller, R. E., K. R. Polenske, et al., Eds. (1989). Frontiers of Input-Output Analysis. New York, USA, Oxford University Press.

Moffatt, I. (2000). "Ecological footprints and sustainable development." Ecological Economics **32**: 359-362.

Moll, H. C. and K. J. Norman (2002). Towards sustainable development at city level: evaluating and changing the household metabolism in five European cities. Lifecycle Approaches to Sustainable Consumption, Laxenburg, Austria, International Institute for Applied Systems Analysis (IIASA), National Institute for Advanced Industrial Science and Technology (AIST), and Sustainable Consumption and Production Unit of the United Nations Environment Programme (UNEP).

Morrison, W. I. and P. Smith (1974). "Nonsurvey input-output techniques at the small area level: an evaluation." Journal of Regional Science **14**(1): 1-14.

Munksgaard, J., K. A. Pedersen, et al. (2000). "Impact of household consumption on CO_2 emissions." Energy Economics **22**: 423-440.

Munksgaard, J., K. A. Pedersen, et al. (2001). "Changing consumption patterns and CO_2 reduction." International Journal of Environment and Pollution **15**(2): 146-158.

Nichols, M. (2003). An application of the Ecological Footprint method to an eco-tourism resort: A case study of Kingfisher Bay resort and Village, Fraser Island. Faculty of Science. Maroochydore, Australia, University of the Sunshine Coast.

Opschoor, H. (2000). "The ecological footprint: measuring rod or metaphor?" Ecological Economics **32**: 363-365.

Peet, N. J., A. J. Carter, et al. (1985). "Energy in the New Zealand household, 1974-1980." Energy **10**(11): 1197-1208.

Proops, J. L. R. (1988). Energy intensities, input-output analysis and economic development. Input-Output Analysis - Current Developments. M. Ciaschini. London, UK, Chapman and Hall**:** 201-216.

Rapport, D. J. (2000). "Ecological footprints and ecosystem health: complementary approaches to a sustainable future." Ecological Economics **32**: 381-383.

Rees, W. and M. Wackernagel (1996). "Urban ecological footprints: why cities cannot be sustainable - and why they are a key to sustainability." Environmental Impact Assessment Review **16**(4-6): 223-248.

Rees, W. E. (1992). "Ecological footprints and appropriated carrying capacity: what urban economics leaves out." Environment and Urbanization **4**(2): 121-130.

Simmons, C. and N. Chambers (1998). "Footprinting UK households: how big is your ecological garden?" Local Environment **3**(3): 355-362.

Simpson, R. W., A. Petroeschevsky, et al. (2000). "An ecological footprint analysis for Australia." Australian Journal of Environmental Management **7**: 11-18.

Smith, P. and W. I. Morrison (1974). Simulating the urban economy. London, UK, Pion Limited.

Tarancon, M. and P. Del Rio (2005). "Projection of input-output tables by means of mathematical programming based on the hypothesis of stable structural evolution." Economic Systems Research **17**(1): 1-23.

Tiebout, C. M. (1960). Regional and interregional input-output models: an appraisal. The techniques of urban economic analysis. R. W. Pfouts. West Trenton, NJ, USA, Chandler-Davis Publishing Co.**:** 395-407.

United Nations Department for Economic and Social Affairs Statistics Division (1999). Handbook of Input-Output Table Compilation and Analysis. New York, USA, United Nations.

van den Bergh, J. C. J. M. and H. Verbruggen (1999). "Spatial sustainability, trade and indicators: an evaluation of the 'ecological footprint'." Ecological Economics **29**(1): 61-72.

van Kooten, G. C. and E. H. Bulte (2000). "The ecological footprint: useful science or politics?" Ecological Economics **32**: 385-389.

Vringer, K. and K. Blok (1995). "The direct and indirect energy requirements of households in the Netherlands." Energy Policy **23**(10): 893-910.

Wackernagel, M. (1997). "Ranking the ecological footprint of nations."

Wackernagel, M. (1998). "The ecological footprint of Santiago de Chile." Local Environment **3**(1): 7-25.

Wackernagel, M., L. Lewan, et al. (1999). "Evaluating the use of natural capital with the ecological footprint." Ambio **28**(7): 604-612.

Wackernagel, M., L. Onisto, et al. (1997). The Ecological Footprint of Nations. Xalapa, Mexico, Centro de Estudios para la Sustentabilidad.

Wackernagel, M. and W. E. Rees (1996). Our Ecological Footprint - Reducing Human Impact on the Earth. Gabriola Island, B.C., Canada, New Society Publishers.

Wackernagel, M. and J. Silverstein (2000). "Big things first: focusing on the scale imperative with the ecological footprint." Ecological Economics **32**: 391-394.

Weber, C. and U. Fahl (1993). "Energieverbrauch und Bedürfnisbefriedigung." Energiewirtschaftliche Tagesfragen **43**(9): 605-612.

Weber, C., U. Fahl, et al. (1995). "Freizeit, Lebensstil und Energieverbrauch." VDI Berichte **1204**: 15-38.

Weber, C. and A. Perrels (2000). "Modelling lifestyle effects on energy demand and related emissions." Energy Policy **28**: 549-566.

Wiedmann, T. and J. Barrett (2005). The Use of Input-Output Analysis in REAP to allocate Ecological Footprints and Material Flows to Final Consumption Categories. York, United Kingdom Stockholm Environment Institute, WWF UK.

Wiedmann, T., J. Barrett, et al. (2007). Companies on the Scale - Comparing and Benchmarking the Footprints of Businesses. International Ecological Footprint Conference, Cardiff, Wales, UK, ESRC BRASS Research Centre, Cardiff University.

Wiedmann, T., M. Lenzen, et al. (2007). Multiregional input-output modelling opens new opportunities for the estimation of Ecological Footprints embedded in international trade. International Ecological Footprint Conference, Cardiff, Wales, UK, BRASS Research Centre, Cardiff University.

Wiedmann, T., J. Minx, et al. (2006). "Allocating ecological footprints to final consumption categories with input-output analysis." Ecological Economics **56**(1): 28-48.

Wier, M., M. Lenzen, et al. (2001). "Environmental effects of household consumption pattern and lifestyle." Economic Systems Research **13**(3): 259-274.

Wood, R. and M. Lenzen (2003). "An application of an improved ecological footprint method and structural path analysis in a comparative institutional study." Local Environment **8**(4): 365-384.