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New Developments in Ecological Footprint Methodology, Policy & Practice

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Modelling Ecological Footprints for sub-regional Levels: A Detailed Footprint of Consumption in Local Areas of Melbourne and Victoria

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ABSTRACT The Ecological Footprint has been identified as a useful concept and effective tool to communicate key messages in the State of the Environment (SoE) Report in Victoria. By presenting the concept and results in a visually engaging way, 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. This contribution presents preliminary findings of an ongoing project undertaken by the Stockholm Environment Institute in collaboration with the ISA team at the University of Sydney on behalf of EPA Victoria and the Commissioner for Environmental Sustainability. The aim is to produce a detailed account of environmental headline indicators (energy, water, land disturbance / biodiversity impacts, bioproductivity impacts, GHG emissions) that together provide an expanded and multi-facetted picture of the Footprint of consumption in all Local Areas of Victoria. It will illustrate the contribution of Melbourne's Footprint and show, in a metaphorical sense, the 'metabolism' of the capital. We will also demonstrate, with the help of environmental input-output and life cycle analysis, how some of the most commonly consumed products vary in terms of their Ecological Footprint. The results will be published in the State of the Environment Report of Victoria.

Conference Theme: Applications and Case Studies

Keywords: Ecological Footprint, land disturbance, biodiversity, regional input-output analysis, household consumption, Victoria, Australia

Contents

1. Introduction

The Commissioner for Environmental Sustainability (CES) is required to report on the state of Victoria's environment at least once every five years (Commissioner for Environmental Sustainability, 2005). Victoria's first State of the Environment (SoE) Report is due for publication in late 2008 and the Ecological Footprint is going to be one of the key indicators for environmental impacts of consumption. The purpose of these reports is to advise the Government of current conditions and trends to enable informed decision-making, and to raise awareness of those involved in environmental management and the community. In addition, actors such as environmental non-government organizations, educators and community groups may use the information presented in the report to inform other projects.

Part 3 ("Production, Consumption and Waste") of the SoE Report will represent Victoria as an integrated system having inputs of energy, water and materials and outputs of goods and services, pollution and waste. The processes of extracting, processing and consuming resources will be examined through a range of activities and sectors. Environmental pressures which result from these processes and activities will be identified (see Figure 1).

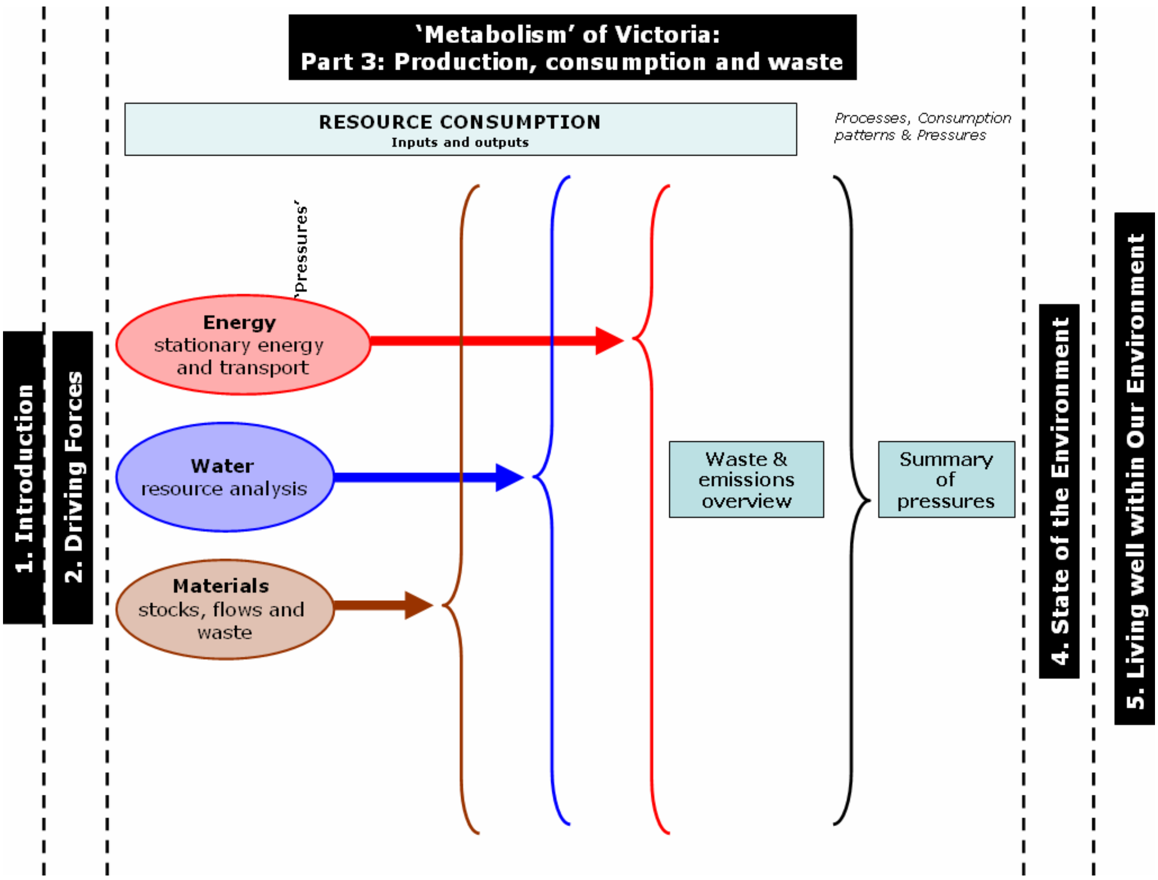

Figure 1: Contents of Part 3 of the Victorian State of the Environment Report

The specific focus of Part 3 will be in identifying those pressures that result from production and consumption of energy, water and material resources, and the waste that is generated from using those resources. This resource consumption analysis will identify the natural resource stocks available in Victoria and describe broad consumption patterns. An Ecological Footprint analysis will be presented to illustrate the impact of consumption on the natural environment.

The Ecological Footprint has been identified as a useful concept and effective tool to communicate key messages in the SoE report, in order to provide the reader with a broad overview of the present environmental situation in Victoria. By presenting the concept and results in a visually engaging way, this project has the potential to illustrate, symbolically, the links between topical environmental issues such as climate change, and every day individual or local life styles. For instance, the total Ecological Footprint area of Melbourne might exceed the productive land surface area of Victoria – meaning that current consumption levels in Melbourne require a land surface area far beyond the city's own, and its state's, limits and capacity to meet this demand.

EPA Victoria as a partner to the Commissioner has therefore commissioned a study aimed at determining the Ecological Footprint and other environmental headline indicators (such as energy, water, land disturbance / biodiversity impacts, GHG emissions) of Victoria and to present the findings in a clear and concise format, such that they can be directly incorporated into the upcoming SoE Report.

The Stockholm Environment Institute (SEI) at the University of York, in collaboration with 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 very positive experience from previous projects in Australia, Victoria, the UK, Wales and Scotland (Lenzen, M. and Murray 2001; Barrett et al. 2005; GFN and ISA 2005; Collins et al. 2006; DSE 2006a; DSE 2006b; Wiedmann et al. 2006; Barrett et al. 2007)

The aim of this paper is to present ongoing work to calculate the Ecological Footprint consumption in the state of Victoria and its local areas in high level of spatial and commodity detail.

2. Methodology

2.1. Background to Ecological Footprints

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 et al. 1997), (Wackernagel and Silverstein 2000).

Since the formulation of the Ecological Footprint, however, a number of researchers have criticised the method as originally proposed (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[1], 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 et al. 1998), (Simpson et al. 2000), (Lenzen and Murray 2001).

2.2. Original concept

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 1995). 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' 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. For example, the land that was needed in 1991 to support the lifestyle of an average Canadian was calculated by (Wackernagel and Rees 1995), p. 83) to be 2.34 ha energy land, 0.2 ha degraded land, 0.02 ha garden, 0.66 ha crop land, 0.46 ha pasture, and 0.59 ha forest, giving a total Ecological Footprint of 4.27 ha per capita.

The total Ecological Footprint for a population can also be subtracted from the ‘productive’ area that a 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 (Wackernagel and Rees 1995), p. 97), Canadians in 1991 had an ecological remainder of 10.94 ha per capita.

[1] 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.

2.3. 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 1995). 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 et al. 2000) all areas of land were included, irrespective of their productivity. Similarly, (Venetoulis and Talberth 2007) include the entire surface of the Earth in their modified biocapacity and Footprint calculations of nations and allocate space for other species.

2.4. Including indirect requirements by using input-output analysis

In the calculation of Ecological Footprints of populations by (Wackernagel and Rees 1995) and (Simpson 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.

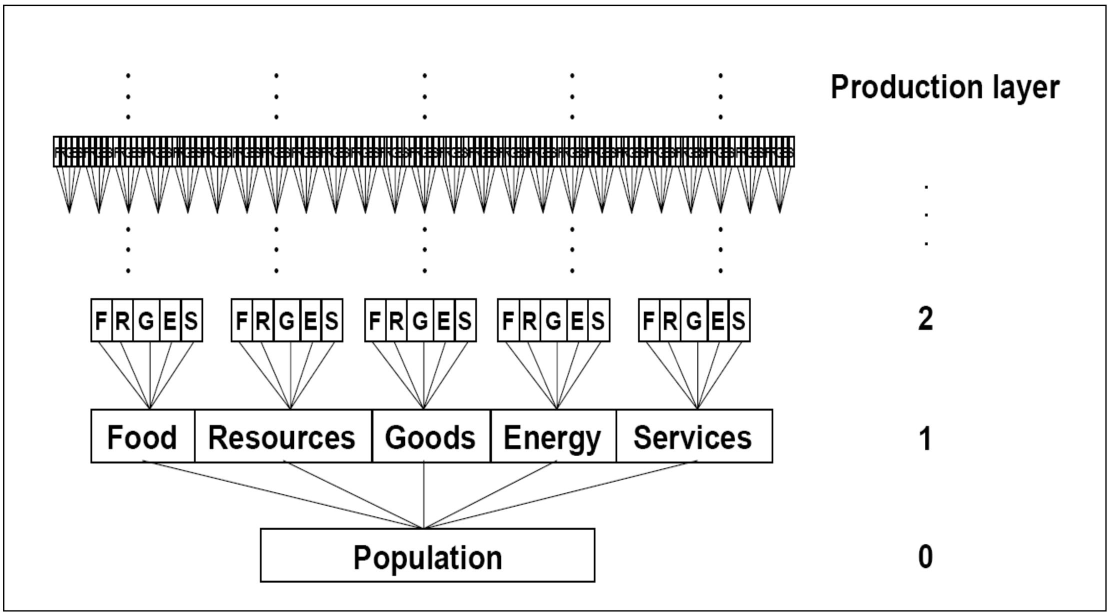

Figure 2: Industrial interdependence in a modern economy: a "tree" of upstream production layers.

Such a production "tree" is shown schematically in Fig. 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.

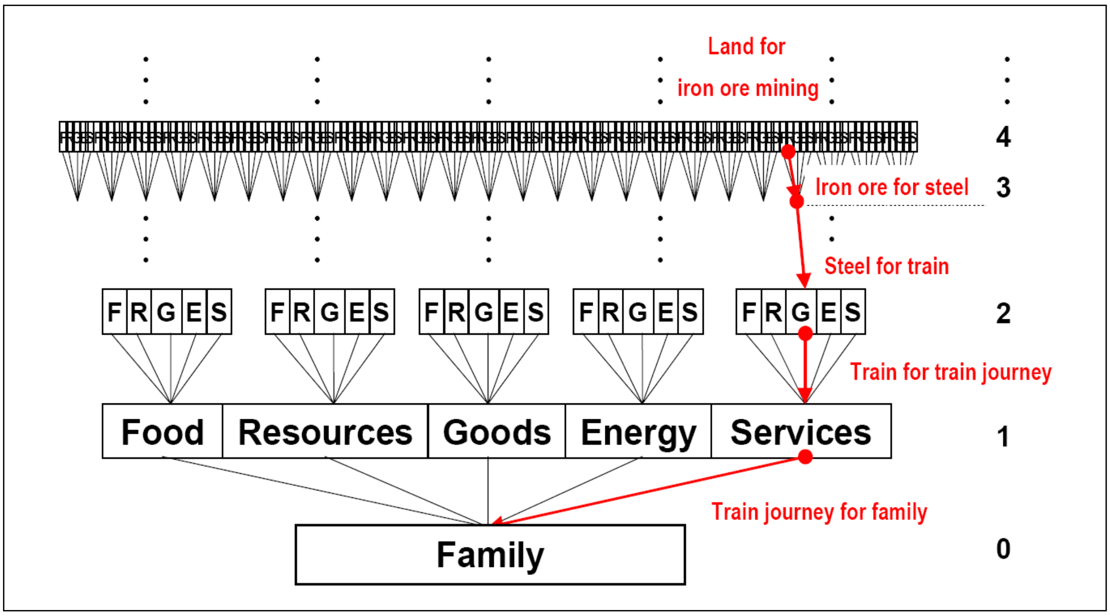

Figure 3: Production layers and input paths in the Ecological Footprint of a household.

A specific example for direct and indirect requirements in the Ecological Footprint of a household is shown in Fig. 2. Direct requirements in production layer zero are represented by the land required for the household'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 household's Ecological Footprint could be a train journey. The household 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 of 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. Figs. 1 and 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 et al. 1998) to calculate an Ecological Footprint for New Zealand. Since then, the users of input-output analysis for Ecological Footprint analysis has grown continuously, to include research organisations all over the world (Lenzen, Manfred and Murray 2003; Wiedmann et al. 2006). Recently, a pilot study has been completed for Victoria, comparing the original method with an input-output-based method (http://www.epa.vic.gov.au/eco-footprint/docs/vic_ecofootprint_demand.pdf) (GFN and ISA 2005).

In addition, input-output analysis draws on detailed data sets which are regularly collected by government statistical agencies, such as the input-output tables (Australian Bureau of Statistics 2001) and the household expenditure survey (Australian Bureau of Statistics 2000). Using Australian data, input-output-based Ecological Footprints can be calculated for more than 300 industry sectors and product groups, for states, local areas and cities, and for companies and households.

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.

2.5. Method employed in this study

The Integrated Sustainability Analysis (ISA) group 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[6], and is therefore the most robust approach of assessing environmental impacts of populations. In this work, we additionally use multiple regression in order to estimate Ecological Footprints for local areas, based on both Household Expenditure and Census data.

Final Ecological Footprints were 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.[2] The methodology has been successfully piloted in a range of Australian company and government applications (see http://www.isa.org.usyd.edu.au), a pilot program on TBL reporting (http://www.isa.org.usyd.edu.au/research/TBLEPA.shtml), and in the widely publicised nation-wide whole-economy TBL study *Balancing Act* (http://www.isa.org.usyd.edu.au/publications/balance.shtml).

Results can then be interpreted *ex-post*, that is as answers to the questions: "What Ecological Footprint would have been assigned to the user's entity, 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?"[3]

3. Data preparation

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 Statistical Sub-Division (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 necessarily been estimated. This has been performed by creating an initial estimate from the 1998-99 data and then subsequently constraining the estimate by the 2003-04 state data, with a further constraint utilising a breakdown between capital city and rest of state. Hence the implicit assumption is that there has not been a change in relative expenditure levels between SSDs since 1998-99, apart from the explicit changes modelled for states, capital cities and non-capital regions.

The baseline year of data for the 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, due to data availability from the ABS. The importance of state based price indices was particularly evident for such consumer items as automotive fuel, which not only forms a significant component of the population's Ecological Footprint, but is also quite volatile over time and across locations.

3.1. Correlation to input-output categories

In order to explicitly model the Ecological Footprint from a consumer induced perspective and in order to be comprehensive in capturing all impacts, input-output analysis has been

[2] Foran et al. (2005), see also United Nations Department for Economic and Social Affairs (1999) and Lenzen (2001).

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

utilised in this study. The ISA team at the University of Sydney has a breakdown of 344 input-output sectors, and the HES data needed to be remapped to these categories. Furthermore, the HES data published by the ABS does not match the level and type of household expenditure published in the national accounts (and hence in the input-output tables). Thus a mapping process was carried out that not only re-categorised the HES data, but also readjusted absolute levels so as to be compatible within the input-output framework. The level of readjustment was firstly performed for 1998-99 Australian HES data, as there are currently no input-output tables available for 2003-04. The readjustment was then performed identically across all HES data. The consequence of this is that the explicit detail of the HES between regions is maintained, whilst results are also consistent with modelling the Ecological Footprint at the national level.

3.2. Calculation of intensities

For the most part, Ecological Footprint intensities (impact per $ spent) were calculated at the national level. This is a consequence of a) lack of detailed and robust data at the regional level and b) the fluidity of trade between states of consumer items (regional based intensities are only of value if the consumption and production of goods are explicitly known and linked). There are, however, some particular commodities that have significantly different impacts in different states, and where consumption is generally confined to the production in its own state. These commodities have been explicitly modelled, as set out below.

Impacts from electricity production vary from state to state, primarily because of the fuel or technology used (e.g. black coal versus brown coal). State figures can thus be adjusted by the state-based full fuel-cycle emission factors available from the (Australian Greenhouse Office 2004).

Within the land disturbance methodology, the changing amount of land clearing and land for grazing is highly different for each state, and has also changed considerably over time. The ABS publish data on agricultural operations on a state level (Australian Bureau of Statistics 2005) and earlier), with grazing area able to be inferred from total farm area minus cropping area. State based intensities were only used for modelling the first two production layers, with national intensities used for the third and higher production layer where the source of impact is less clear. The changing rates of greenhouse emissions from land clearing for cattle farming were obtained from time series data of the National Greenhouse Gas Inventory (Australian Greenhouse Office 2006). These adjustments were only relevant to the disturbance based approach, as the bio-productivity approach uses global average bio-productivity hectares. The significant change in area used in farming over time, was, however, included in order to update the 1998-99 intensities to 2003-04 intensities.

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.

4. Methodology – mathematical exposition

Some of the more popular studies dealing with the sustainability of cities are Ecological Footprints[4]. 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, W. 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 et al. 1998; Lenzen, M. 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.

4.1. 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 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

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

local input-output coefficients for the multi-regional modelling 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.[5] The technique of combining input-output and household expenditure data has been used previously by a number of authors[6], 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

$$\mathbf{F} = \left(\mathbf{Q}^{\mathrm{emb}} + \mathbf{Q}^{\mathrm{hh}}\right) \times \mathbf{Y} . \qquad (1)$$

The variables in Equation 1 are:

F Matrix of *household factor requirements*. Its elements $\left\{F_{ij}\right\}_{i=1,\ldots,f\,;\,j=1,\ldots,g}$ 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 $\mathbf{Q}^{\mathrm{hh}}\times\mathbf{Y}$ used directly by the household (in the house or by using private vehicles), and (2) factors $\mathbf{Q}^{\mathrm{emb}}\times\mathbf{Y}$ 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.

$\mathbf{Q}^{\mathrm{hh}}$ Matrix of *household factor multipliers*. Its elements $\left\{Q_{ij}^{\mathrm{hh}}\right\}_{i=1,\ldots,f\,;\,j=1,\ldots,s}$ describe the usage by private households of factor *i* per A$ value of final consumption of commodity *j*. $\mathbf{Q}^{\mathrm{hh}}$ has dimensions $f\times s$, 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[7] and industry sectors. These range from primary industries such as agriculture and mining, via

[5] 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).

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

[7] 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).

secondary industries such as manufacturing and electricity, gas and water utilities, to tertiary industries such as commercial services, health, education, defence and government administration.

$\mathbf{Q}^{\text{emb}}$ Matrix of *embodied factor multipliers*. Its elements $\left\{Q_{ij}^{\text{emb}}\right\}_{i=1,\ldots,f;\,j=1,\ldots,s}$ 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. $\mathbf{Q}^{\text{emb}}$ thus captures the *total factor requirements* of industries in the entire economy that are needed to produce commodities consumed by households. $\mathbf{Q}^{\text{emb}}$ has dimensions $f\times s$.

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

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

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

The variables in equation 2 are:

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

I The *unity matrix*. Its elements $\left\{I_{ij}\right\}_{i=1,\ldots,s;\,j=1,\ldots,s}$ are $I_{ij}=1$ if $i=j$, and $I_{ij}=0$ if $i\neq j$. **I** has dimensions $s\times s$.

A Matrix of *direct requirements*. Its elements $\left\{A_{ij}\right\}_{i=1,\ldots,s;\,j=1,\ldots,s}$ 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[8] – 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 et al. 1972), (Herendeen, R. A. 1978), (Miller and Blair 1985), (Proops 1988), (Miller et al.

[8] 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 (see Section 2.3).

1989), (Hawdon and Pearson 1995), and (Forssell 1998). For a description of the assembly of an Australian input-output framework, see (Lenzen, M. 2001).

4.2. 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[9], and optimisation techniques[10]. As a consequence, small flows (monetary and physical) are associated with large uncertainties, as indicated in some of the results sheets.

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, M. 2001).

The industrial Ecological Footprint multipliers $\mathbf{Q}_{\mathrm{ef}}^{\mathrm{ind}}$ as well as household Ecological Footprint multipliers $\mathbf{Q}_{\mathrm{ef}}^{\mathrm{hh}}$ 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 et al. 1995); (Lenzen, M. and Murray 2001).

4.3. 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

[9] (Gretton and Cotterell 1979); (Junius and Oosterhaven 2003).

[10] (Tarancon and Del Rio 2005).

different products supplied by one industry, and (7) the truncation of the "gate-to-grave" component of the full life cycle (see (Bullard et al. 1978) and (Lenzen, M. 2001). Standard errors $\Delta Q_{ij}^{\text{emb}}$ of elements in the embodied factor multiplier matrix $\mathbf{Q}^{\text{emb}}$ due to the above sources defy analytical treatment, and can therefore only be determined using stochastic analysis. The $\Delta Q_{ij}^{\text{emb}}$ as used in this article were calculated by Monte-Carlo simulations of the propagation of normally distributed perturbations from $\mathbf{Q}^{\text{ind}}$ and $\mathbf{A}$ through to $\mathbf{Q}^{\text{emb}}$ (see (Lenzen, M. 2001). Given the standard errors $\Delta\left(Q^{\text{emb}}+Q^{\text{hh}}\right)_{ik}$ of $\mathbf{Q}^{\text{emb}}+\mathbf{Q}^{\text{hh}}$, 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

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

The uncertainty ranges of $\mathbf{Q}^{\text{emb}}+\mathbf{Q}^{\text{hh}}$ given in ISA's software output cover raw data uncertainty and allocation uncertainty only, as described in (Lenzen, M. 2001).

4.4. Multiple regression

Multiple regression seeks to establish the relationship between an explained variable y, and a number of explanatory variables x_i. The explained variable is of course household expenditure (on 344 commodities). The explanatory variables appraised in this work are household characteristics:

inc annual per-capita before-tax household income,

size number of household members,

edu index of highest qualification of household members aged 15 and over with a qualification (1 basic vocational; 2 skilled vocational; 3 Associate Diploma; 4 Undergraduate Diploma; 5 Bachelor degree; 6 Postgraduate Diploma; 7 Higher than 1-6),

htype index of house type (1 caravan, cabin, houseboat or other; 2 flat, unit or apartment; 3 semi-detached, row or terrace house; 4 separate house)

urb population density in people per km^2,

age average age,

kid percentage of household members aged 18 and below,

empl percentage of household members aged 18-64 working,

prov provenance: percentage of people in region born overseas,

ten tenure type (1 rent-free, 2 renting, 3 purchasing with mortgage, 4 owning),

car car ownership (cars per person),

wktrv percentage of people travelling to work by car,

State dummy variable indicating location of SLA by State (8 dummies).

We have omitted one of pair-wise correlated variables (such as house type and population density, or number of children and age) in our multiple regression, because the respective variables are mutually surrogate drivers of the explained variable. The decision of which variable to exclude can be based on an exogenously stated, sequential causal structure (see for example (Poulsen and Forrest 1988), or based on a series of regression models in order to establish the combination of variables with the strongest explanatory power. The latter approach was taken in this work.

A particular feature of the ABS Household Expenditure Survey is that the observations of expenditure apply to groups of households rather than single households. Expenditure and socio-demographic-economic characteristics of an observation h are therefore really group *means* $\overline{x_i^h}$, derived from sums $\overline{x_i^h} = \sum_{j=1}^{n_h} x_{ij}^h$ taken over n_h single-household observation x_{ij}. Unfortunately, in general, the number of observations n_h is not the same in each group h. This fact has to be taken into account in the multiple regression as follows: Assume that the observations x_{ij}^h and y_j^h satisfy the regression equation $y_j^h = \beta_0 + \sum_i \beta_i x_{ij}^h + \varepsilon_j^h$ $\forall h, j=1,\ldots,n_h$, with ε_j^h being the error term with zero mean and constant variance $\mathrm{var}\left(\varepsilon_j^h\right) = \sigma^2$ (homoskedasticity). Summation over j shows in a straightforward manner that the same regression equation $\overline{y^h} = \beta_0 + \sum_i \beta_i \overline{x_i^h} + \overline{\varepsilon^h}$ also holds for the group means $\overline{y^h} = \frac{1}{n_h}\sum_j y_j^h$, $\overline{x_i^h} = \frac{1}{n_h}\sum_j x_{ij}^h$, and $\overline{\varepsilon^h} = \frac{1}{n_h}\sum_j \varepsilon_j^h$. The disturbance $\overline{\varepsilon^h}$ has zero mean, but its variance is not constant anymore over group observations h, because each group contains a different number n_h of single-household observations: the regression becomes *heteroskedastic*. This means that the estimation of the regression coefficients β_i requires the group means to be *weighted* inversely proportional to the disturbance variances. Since the latter are $\mathrm{var}\left(\overline{\varepsilon^h}\right) = \frac{\sigma^2}{n_h}$, all group means must be weighted with the number of single-household observations n_h in each group (Cramer 1969), p. 144).

Using multiple regression, and taking into account the varying sample sizes of the Household Expenditure Survey sample groups (and resulting heteroskedasticity), the expenditure on the 344 ISAPC expenditure items was estimated from explanatory variables sourced from the census data pertaining to the SLAs examined. A stepwise multiple regression was followed, consisting of

- establishing correlation coefficients between the expenditure of samples on each of the 344 commodities, and all explanatory variables, starting with commodity 1;
- selecting the variable with the highest correlation coefficient as the first regression variable;
- selecting the variable with the next highest correlation coefficient as the second regression variable, and so on;
- calculating an adjusted R^2 value for each subsequent regression, and checking whether the adjusted R^2 increases more than 0.1%;
- if not, terminating the addition of further explanatory variables to the regression model, and moving on to the next commodity.

This stepwise regression procedure is data-driven, as opposed to the theory-driven hierarchical multiple regression, where a model is specified based on purely theoretical considerations. The stepwise procedure was chosen because it is preferred if the purpose of regression is simple prediction of expenditure (Cramer 1969), and because a sound theoretical reason for a dependence of the consumption of a particular commodity on socio-demographic-economic variables can in general not be established *a priori*.

5. Results

Note: The project is still in progress and therefore no headline results can be presented yet. The Victorian Commissioner for Environmental Sustainability will publish the headline results in the SoE Report and EPA Victoria will make the detailed results publicly available through a technical report.

For this reason we present selected preliminary findings in a qualitative format that does not allow a deduction of final headline results. We concentrate on the comparison of urban and rural consumption patterns in Victoria and the relative impact of various commodities.

5.1. Differences between urban and rural consumption impacts in Victoria

The breakdown of Ecological Footprint results by local area allows a detailed spatial analysis of consumption related environmental impacts. We have calculated absolute and per capita Ecological Footprints by SLA (Statistical Local Areas) for Melbourne and the whole of Victoria and will present the results in coloured maps in the final report.

A similar analysis on SSD (statistical sub-division) level was undertaken before by the University of Sydney (DSE 2006a). The results of this study are shown in the following map.

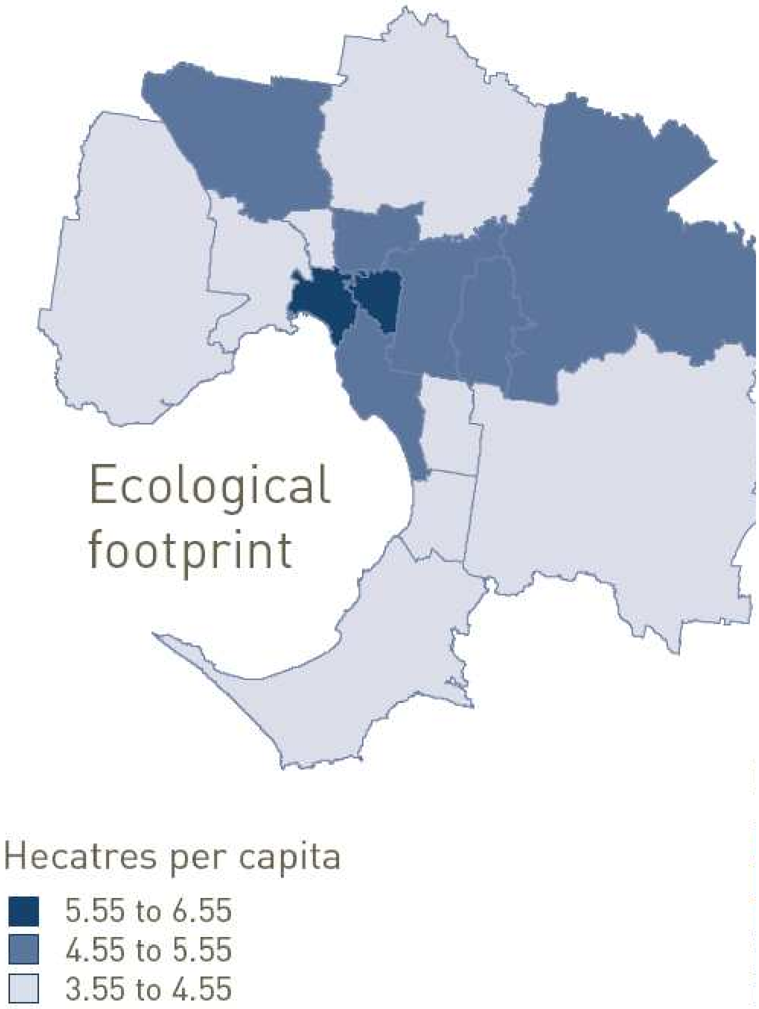

Figure 4: Per capita Ecological Footprint of statistical sub-divisions in Melbourne (taken from the Melbourne Atlas, DSE 2006a)

Central areas of Melbourne show higher per capita EFs, suggesting higher levels of consumption and related impacts. We expect similar results in the current study and will analyse the pattern of consumption of over 300 commodities in order to gain an understanding of underlying causes for differences.

When grouping together all local areas belonging to Melbourne on the one hand and all areas outside of Melbourne on the other we are able to compare the Ecological Footprint of urban and rural areas in Victoria. The relative contribution of main consumption categories in these two areas are shown in Figure 5.

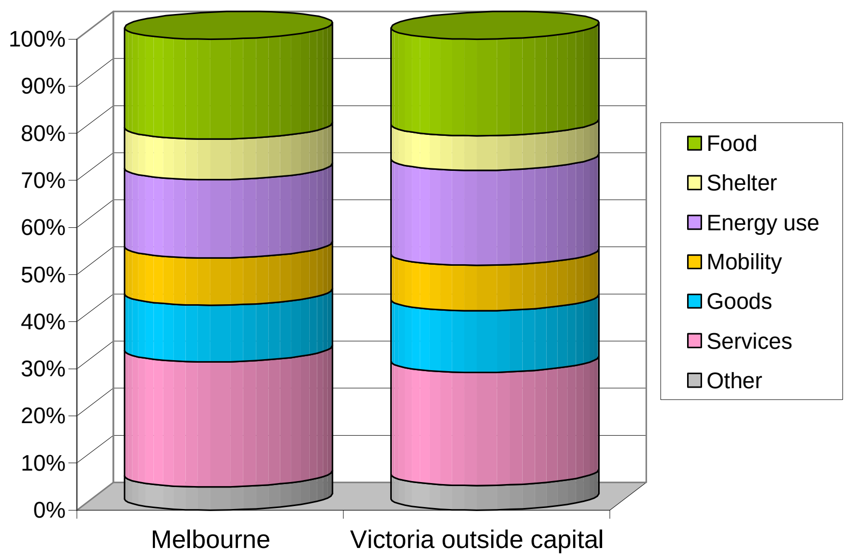

Figure 5: Comparison of the relative contributions of main consumption categories in Melbourne and rural areas of Victoria

Differences are in the areas of food, shelter and services (where Melbourne has a higher EF) as well as energy use (where rural areas have a higher EF). When looking at the impacts of single commodities it is possible to pinpoint at the underlying causes for differences. We have performed detailed analyses of Footprint patterns in different local areas in Victoria that will provide further insights into consumption related impacts. The Commissioner and EPA Victoria will publish the detailed findings in late 2008.

5.2. Ecological Footprint analysis of commodities

The methodology applied in this project allows the full life-cycle analysis of EFs of over 300 commodities consumed by residents in different parts of Victoria. Detailed results cannot be revealed at this stage of the project but Figure 6 gives a glimpse at the relative contributions of individual commodities. Each 'bubble' in the diagram represents one commodity (e.g. petrol). The size is proportional to the per-capita Ecological Footprint. The location of the bubble is determined by the level of consumption (expenditure on the commodity in $) and the relative intensity of the impact (EF per $ spent).

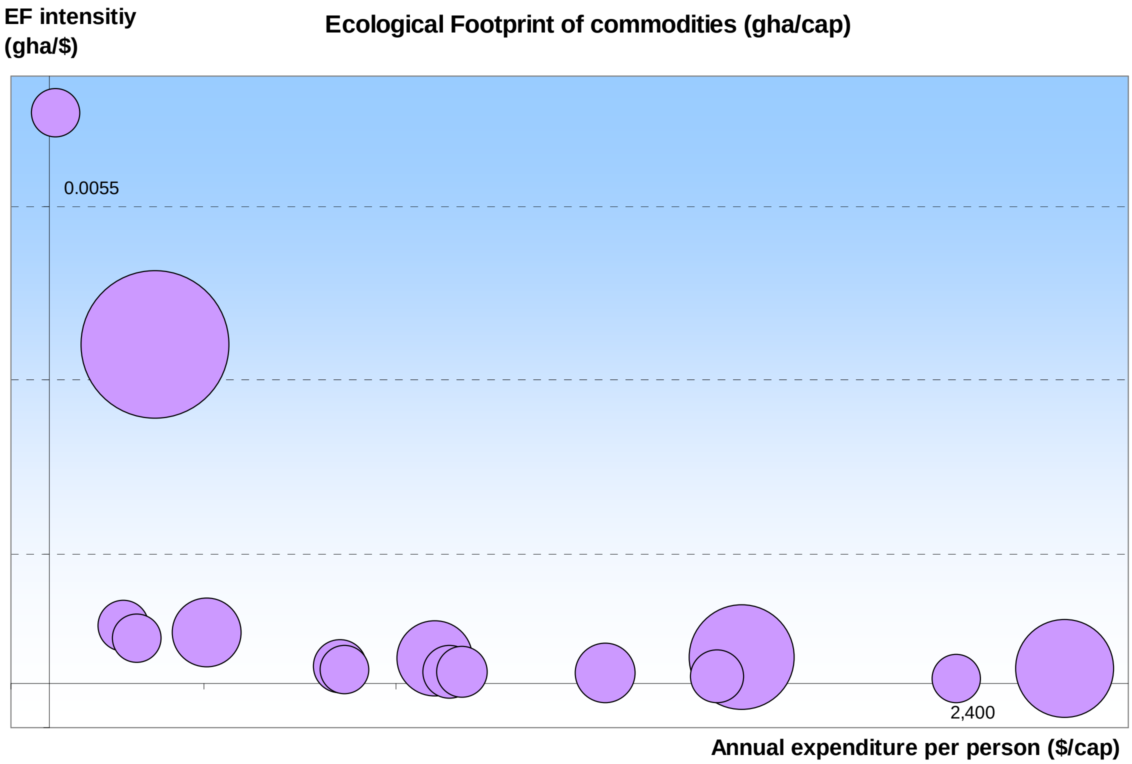

Figure 6: Ecological Footprints of some commodities by expenditure (x axis), intensity (y axis) and absolute EF (size of circles) (identities and values not revealed for confidentiality reasons)

This method of looking at detailed Footprint results can provide information on whether impacts are mainly due to the production process or come from high levels of consumption. Commodities located in the top left part of Figure 6 have high intensities per $ which means that a relatively high 'load' of EF related impacts is embodied per value of product, most likely because of Footprint intensive production processes. If, on the other hand, the commodity is located towards the right part of the diagram, impacts are increasingly due to the level of consumption as expenditure increases. As can be seen from Figure 6, we did not find commodities that had both, high intensity and high expenditure values and thus the top right part of the diagram is empty.

A previous commodity Footprint analysis, undertaken by the University of Sydney and published by the Department of Sustainability and Environment (DSE 2006b) yields the results presented in Table 1. Note that about half of the total Ecological Footprint is caused by the consumption of the top five products and services.

Table 1: Ecological Footprint of 15 top-ranking commodities consumed in Melbourne, 1998-99 (taken from the Melbourne Atlas, DSE 2006b)

2 Commodity breakdown for Melbourne
Melbourne Statistical Division, 1998-99

Rank	Commodity	Impact (hectare per capita)	Per cent of total Eco footprint
1	Clothing	0.68	14.41
2	Retail trade	0.55	11.66
3	Accommodation, cafes and restaurants	0.54	11.40
4	Beef products	0.46	9.73
5	Electricity supply	0.20	4.20
6	Raw sugar, animal feeds, processed seafoods & other food products	0.19	3.96
7	Ownership of dwellings	0.14	2.97
8	Dairy products	0.13	2.86
9	Carpets, curtains, tarpaulins, sails, tampons and other textile products	0.13	2.71
10	Bread, cakes, biscuits and other bakery products	0.10	2.19
11	Petrol	0.10	2.09
12	Footwear	0.08	1.60
13	Wholesale trade	0.07	1.58
14	Motor vehicles and parts, other transport equipment	0.07	1.44
15	Banking	0.06	1.35

6. Preliminary Conclusion

Work in this project is still in progress and results cannot be revealed at this stage. Once finished, the method presented here will provide a detailed picture of Ecological Footprints by local areas in Victoria, allowing a distinction between rural and urban areas, as well as a detailed breakdown by commodity and thus fine consumption patterns. We have shown with qualitative results and findings from previous studies the potential for policy-relevant conclusions across the whole area of sustainable consumption.

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