THE ECOLOGICAL FOOTPRINT OF CONSUMPTION IN VICTORIA

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The Ecological Footprint of Consumption in Victoria

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1. Project Background

1.1. Ecological Footprint accounts for the State of the Environment Report

The Commissioner for Environmental Sustainability (CES) is required to report on the state of Victoria's environment at least once every five years. 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.

According to the Footprint Term Glossary of the Global Footprint Network the Ecological Footprint (EF) is "A measure of how much biologically productive land and water an individual, population or activity requires to produce all the resources it consumes and to absorb the waste it generates using prevailing technology and resource management practices" (GFN 2008b). 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 Victoria's residents. This land area sits both within and outside the borders of Victoria and therefore the Footprint is an indicator for the impacts of consumption of Victoria residents wherever the products and services are produced.

The Ecological Footprint documents what has occurred - it provides a snapshot in time. It does not predict future demand or capacity, nor prescribe allocation. The Ecological Footprint attempts to answer one central sustainability question: 'how much of the bioproductive capacity of the biosphere is used by human activities.'

The purpose of the State of the Environment Report 2008 is to inform the Government, and those involved in environmental management, in decision-making. In addition, stakeholders such as environmental non-government organizations, educators and community groups may use the information presented in the report to inform other projects.

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. 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.

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. There are 1.8 global hectares (gha) available per person. 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 is 2.2 gha per person but as this exceeds the 1.8 gha available it would takes 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 Victoria and to present the findings in a clear and concise format, such that they can be directly incorporated into the upcoming SoE Report. In addition, this more comprehensive report was produced in order to document the methodology and elaborate on the results of the study.

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 (Barrett et al. 2005; Barrett et al. 2007; Collins et al. 2006; DSE 2006a, b; GFN and ISA 2005; Lenzen and Murray 2001c; Lenzen and Murray 2001a; Wiedmann et al. 2006)[1]. This work also provides the basis for a future development of a Victoria-specific version of the software tool REAP (see http://www.sei.se/reap). The results presented in this report cover the financial year 2003/04 and meet standards in Ecological Footprinting (GFN 2006) (see also section 5).

1.2. Aim and Objectives

The aim of this project was to demonstrate, from a holistic perspective, the interconnectedness between local and global, whilst on the other hand getting across a clear message of how every day lifestyles in Victoria are, for the most part, far from ‘sustainable’, particularly in urban areas. The project had three main objectives:

1. To calculate the Ecological Footprint of the state of Victoria. The results are to inform the State of the Environment Report.
2. To illustrate the contribution of Melbourne’s Footprint and, in a metaphorical sense, to compile a detailed account of the direct and indirect environmental impacts of the consumption of their citizens.
3. To demonstrate how some of the most commonly consumed products vary in terms of their Ecological Footprint, with the help of environmental input-output analysis. The objective here was to clarify to the reader why their own Ecological Footprint might be the size it is, and how it could be reduced with the help of better-informed consumer choices.

The following main sections of the report present the results first and then provide a detailed description the methodology and data used.

[1] See also http://www.sei.se and http://www.isa.org.usyd.edu.au.

2. Ecological Footprint Results for Victoria

2.1. Overview and key findings

The average Victorian resident has an Ecological Footprint of 6.83 global hectares, more than three times higher than the world average. This equates to a total Footprint of 33 million global hectares, or 147% of the land area of Victoria. However, a part of Victoria'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 actual (real) land (arable land, pasture, forests, built land etc.) and "carbon land" (the land required to absorb the carbon dioxide emitted through the consumption patterns of a given population).

The EF land types

The Ecological Footprint distinguishes five different types of biologically productive land and water (GFN 2008a): cropland, grazing land, forest, fishing ground, and built-up land. **Cropland** is the land type with the greatest average bioproductivity per hectare and is used for growing crops for food, animal feed, fibre, oils and biofuels. **Grazing land** (or pastures) 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. **Fishing grounds** include both freshwater and marine areas where fish can be harvested. Finally, **carbon land** (also CO_2 area or CO_2 land) is the notional area within the Ecological Footprint that is required to sequester carbon dioxide emissions from human activity. Carbon land answers the question "how much woodland and forest area would we need to have in order to absorb all CO_2 emissions from the burning of fossil fuels?".

For Victoria, the majority of the Footprint is carbon land (56%). This is due to the heavy reliance on fossil fuels where the two "big hitters" are the consumption of electricity by households (27% of carbon land) and the purchase of petrol for cars (6% of carbon land). In terms of real land, cropland has the largest contribution with about 17% of the total Footprint. This reflects the impacts of agriculture with wheat accounting for 9% of the cropland Footprint in Victoria alone.

Table 1 and Figure 1 show the top level results by Footprint land type for the state, rural and urban parts and the whole of Australia. Victoria's Footprint is 4% bigger than the average for Australia.

Table 1: The Ecological Footprint of Victoria, Melbourne, areas outside of Melbourne and the whole of Australia by land type. Results are shown in absolute numbers (millions of global hectares, Mgha) and in per-capita numbers (gha/cap).

Absolute	Victoria	Melbourne	Victoria outside Melbourne	Australia	
Cropland	5.69	4.20	1.49	22.99	Mgha
Grazing land	3.71	2.76	0.95	17.11	Mgha
Forest	2.64	1.96	0.69	11.02	Mgha
Carbon	18.66	13.62	5.04	67.30	Mgha
Built-up land	1.37	1.03	0.34	5.51	Mgha
Fishing ground	1.40	1.05	0.35	5.45	Mgha
TOTAL	**33.5**	**24.6**	**8.88**	**129.4**	**Mgha**

Per capita	Victoria	Melbourne	Victoria outside Melbourne	Australia	
Cropland	1.16	1.18	1.12	1.17	gha/cap
Grazing land	0.76	0.77	0.71	0.87	gha/cap
Forest	0.54	0.55	0.51	0.56	gha/cap
Carbon	3.81	3.81	3.78	3.41	gha/cap
Built-up land	0.28	0.29	0.26	0.28	gha/cap
Fishing ground	0.28	0.29	0.26	0.28	gha/cap
TOTAL	**6.83**	**6.89**	**6.66**	**6.56**	**gha/cap**

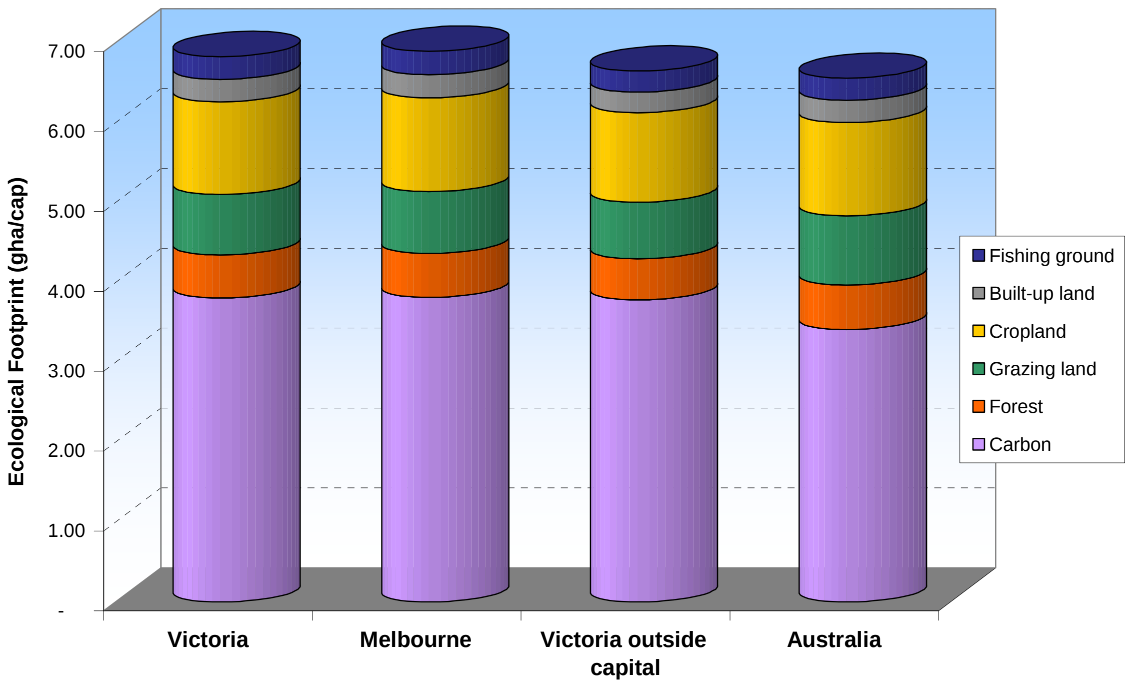


Figure 1: The per-capita Ecological Footprint of Victoria, Melbourne, areas outside of Melbourne and the whole of Australia by land type.

Globally, we are consuming more resources than the planet can regenerate each year, with a current "global overshoot" of 25%. The Victoria per capita Footprint contributes disproportionately to this global overshoot (6.8 gha/cap compared to 2.2 gha/cap world average and 1.8 gha/cap available). If everyone in the world had the same Footprint as the average Victoria resident, we would need 3.8 planets to live within ecological limits.

2.2. 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.

Figure 2: Comparison of Ecological Footprint consumption categories between Victoria and Australia.

Using these categories, the consumption of food and the demand for services have the most significant Ecological Footprint and account for half of the total. 39% of the food Footprint is from the consumption of meat (see below). 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 Victoria is similar to the national average, with a significant difference in the area of residential energy use where Victoria residents have a significantly (36%) higher Ecological Footprint (1.11 gha/cap) than the average Australian (0.82 gha/cap). This is due to Victoria's reliance on electricity from brown coal fired power stations which is well above the national average. Victoria's electricity Footprint alone is 0.96 gha/cap compared to 0.71 gha/cap for Australia as a whole.

Ecological Footprint results are often (and according to a guideline in the Footprint standards (GFN 2006)) displayed in the form of a "Consumption-Land-Use-Matrix (CLUM)" (Table 2). This table shows the consumption categories from Figure 2 in rows and the Footprint land types used in Figure 1 in columns. The CLUM also helps explain the difference between the terms 'carbon land' and 'residential energy use'. The latter one is a consumption category and comprises the use of electricity and fossil fuels by Victorian consumers in their homes. 'Carbon (land)' is a Footprint land type category and is sometimes called 'CO_2 land' or 'carbon footprint'. This is because it represents the (notional) area required to sequester the carbon dioxide emissions that we produce. 'Residential energy use' contributes most to the carbon land category as the consumption of electricity and fossil fuels leads to significant amounts of carbon dioxide being released into the atmosphere. However, all other consumption categories also contribute to carbon land as CO_2 emissions are indirectly 'embedded' in all goods and services that we buy, for example food products, cars and some services. For this reason the carbon land part of the Footprint is much higher (3.81 gha/cap) than the Footprint for the consumption category 'residential energy use' (1.11 gha/cap).

Table 2: The Ecological Footprint of Victoria broken down by consumption categories (rows) and Footprint land types (columns).

Consumption Land Use Matrix (CLUM) (all values in gha/cap)							
EF land types >	Cropland	Grazing land	Forest	Carbon	Built-up land	Fishing ground	**EF of Victoria**
Consumption categories							
Food	0.974	0.405	0.033	0.399	0.030	0.081	**1.92**
.plant-based	0.805	0.084	0.020	0.225	0.018	0.012	**1.16**
.animal-based	0.169	0.321	0.013	0.174	0.012	0.070	**0.76**
Housing	0.0030	0.0055	0.144	0.173	0.018	0.0025	**0.35**
.new construction	0.0030	0.0055	0.141	0.172	0.018	0.0025	**0.34**
.maintenance	0.00002	0.00003	0.00336	0.00072	0.00009	0.00001	**0.00**
Residential energy use	0.0007	0.0012	0.0035	1.102	0.002	0.002	**1.11**
..electricity	0.0003	0.0004	0.0014	0.957	0.001	0.001	**0.96**
..natural gas	0.0002	0.0004	0.0007	0.106	0.000	0.000	**0.11**
..fuelwood	0.00000	0.00000	0.00048	0.00000	0.00000	0.00000	**0.00**
..fuel oil, kerosene, LPG, coal	0.00019	0.00040	0.00086	0.03900	0.00026	0.00010	**0.04**
Mobility	0.008	0.015	0.026	0.600	0.017	0.005	**0.67**
.passenger cars and trucks	0.006	0.012	0.017	0.399	0.013	0.004	**0.45**
.motorcycles	0.0000	0.0001	0.0003	0.0026	0.0002	0.0000	**0.00**
.buses	0.001	0.001	0.002	0.044	0.001	0.000	**0.05**
.passenger rail transport	0.000	0.000	0.002	0.014	0.000	0.000	**0.02**
.passenger air	0.001	0.001	0.003	0.114	0.002	0.001	**0.12**
.passenger boats	0.000	0.001	0.002	0.026	0.001	0.000	**0.03**
Goods	0.071	0.170	0.175	0.496	0.041	0.013	**0.97**
.appliances	0.001	0.002	0.002	0.030	0.002	0.001	**0.04**
.furnishings	0.003	0.012	0.060	0.048	0.005	0.001	**0.13**
.computers & electrical equipm.	0.006	0.013	0.010	0.130	0.008	0.003	**0.17**
.clothing and shoes	0.020	0.101	0.009	0.085	0.010	0.003	**0.23**
.cleaning products	0.0007	0.0029	0.0005	0.0044	0.0004	0.0001	**0.01**
.paper products	0.003	0.006	0.080	0.045	0.004	0.001	**0.14**
.tobacco	0.0014	0.0018	0.0011	0.0052	0.0005	0.0003	**0.01**
.other misc. goods	0.036	0.030	0.013	0.147	0.012	0.004	**0.24**
Services	0.089	0.116	0.119	0.858	0.152	0.178	**1.51**
.water and sewage	0.000	0.000	0.001	0.023	0.002	0.057	**0.08**
.telephone and cable service	0.0011	0.0018	0.0051	0.0301	0.0018	0.0005	**0.04**
.solid waste	0.0000	0.0000	0.0001	0.0015	0.0000	0.0000	**0.00**
.financial and legal	0.0016	0.0027	0.0046	0.0225	0.0044	0.0012	**0.04**
.medical	0.026	0.008	0.009	0.078	0.022	0.003	**0.14**
.real estate and rental lodging	0.003	0.002	0.016	0.114	0.006	0.003	**0.14**
.entertainment	0.013	0.007	0.005	0.047	0.009	0.091	**0.17**
.Government	0.005	0.008	0.028	0.101	0.010	0.003	**0.15**
..non-military, non-road	0.004	0.005	0.024	0.074	0.008	0.003	**0.12**
..military	0.0012	0.0020	0.0039	0.0274	0.0019	0.0006	**0.04**
.other misc. services	0.039	0.086	0.050	0.441	0.098	0.018	**0.73**
Unidentified	0.016	0.044	0.039	0.179	0.021	0.003	**0.30**
TOTAL	**1.16**	**0.76**	**0.54**	**3.81**	**0.28**	**0.28**	**6.83**

2.3. The Big Hitters – Ecological Footprint analysis of commodities

Victoria's 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 Footprint. The high level consumption categories shown in Figure 2 can hide some of the finer details of Victoria's Footprint. Under these broad categories exists a breakdown of over 300 consumption activities (commodities). To calculate the Footprint, expenditure on every commodity by Victoria residents has been taken into account. This helps provide a focus on where to take action to achieve maximum reduction in the Ecological Footprint.

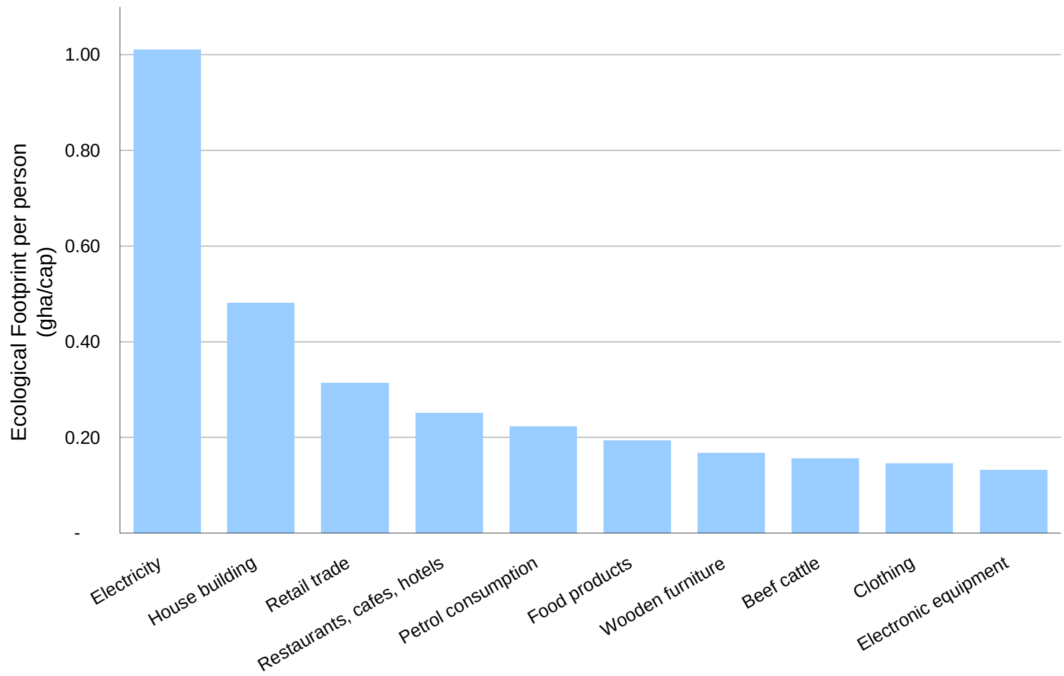


Figure 3: Top ten commodities in terms of per-capita Ecological Footprint in Victoria.

Just the ten top-ranking of these commodities account for almost half (45%) of Victoria's total Ecological Footprint. These ten 'big hitters' are shown in Figure 3. The first twenty out of the 300 commodities account for 61% of the total Ecological Footprint; they are listed in Table 3. At the top of the 'league table' is the impact of electricity consumption. Using electrical power alone adds around 15% (1.0 gha) to each persons Footprint every year! Electricity has a higher impact than other types of energy by a significant margin because of current production techniques and energy losses in transmission. Victoria meets its electricity needs mostly through brown coal fired power stations which have the highest carbon dioxide emissions of all forms of electricity generation and therefore contribute significantly to the Ecological Footprint.

In second place is house construction. Building new homes in Victoria adds around half a global hectare to each persons Footprint every year (0.48 gha/cap). 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.

The third biggest Footprint is created by the demand for retail good. The underlying cause of this is the fuel consumption of the vehicles used to distribute the goods, thus contributing significantly to the carbon Footprint.

Food consumption is another big hitter. 'Eating out' (restaurants etc.) and 'eating in' (food products) appear on place four and six, respectively. Production, processing, packaging and transport of food requires both land and energy, two natural resources which contribute to the overall Ecological Footprint. This is also reflected in the fact that the rearing of beef cattle is the largest single contributor to the Footprint of food production and comes at place eight of the top ten list. Food is also consumed in restaurants, cafes and hotels and this is the main reason why this service is also high up on the list (0.25 gha/cap, rank 4).

The use of petrol for driving cars, timber furniture, clothing and electronic equipment also all make it into the top ten. This information can be used to assist Victorians in determining where to take action to achieve maximum reduction in Victoria's Ecological Footprint.

Table 3: EF intensity, expenditure and per-capita EF of the 20 top-ranking commodities consumed in Victoria.

Rank	Commodities	EF intensity (gha/$)	Expenditure ($/cap)	EF per capita (gha/cap)
1	Electricity	0.0035	287	1.01
2	House building	0.0003	1,797	0.48
3	Retail trade	0.0002	1,949	0.31
4	Restaurants, cafes, hotels	0.0003	977	0.25
5	Petrol consumption	0.0002	1,257	0.22
6	Food products	0.0001	1,850	0.19
7	Wooden furniture	0.0006	280	0.17
8	Beef cattle	0.0022	70	0.16
9	Clothing	0.0002	838	0.15
10	Electronic equipment	0.0001	1,130	0.13
11	Ownership of dwellings	0.0000	2,635	0.13
12	Education	0.0001	1,733	0.13
13	Non-building construction	0.0001	1,039	0.13
14	Non-residential building construction	0.0001	1,072	0.12
15	Air and space transport	0.0001	841	0.12
16	Finished cars	0.0001	1,168	0.11
17	Wheat	0.0059	18	0.11
18	Gas supply	0.0002	649	0.100
19	Recorded media and publishing nec	0.0004	221	0.081
20	Wholesale trade	0.0001	779	0.080

The methodology applied in this project allows for a life-cycle analysis of over 300 commodities consumed by residents in different parts of Victoria, using the Ecological Footprint as the impact indicator. Figure 4 shows the relative contributions of the 20 commodities which have the highest individual Footprint. It is the same information as in Table 3, but now in graphical form. Each 'bubble' in the diagram represents one commodity (e.g. electricity). 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 $ per person, x-axis) and the relative intensity of the impact (EF per $ spent, y-axis).

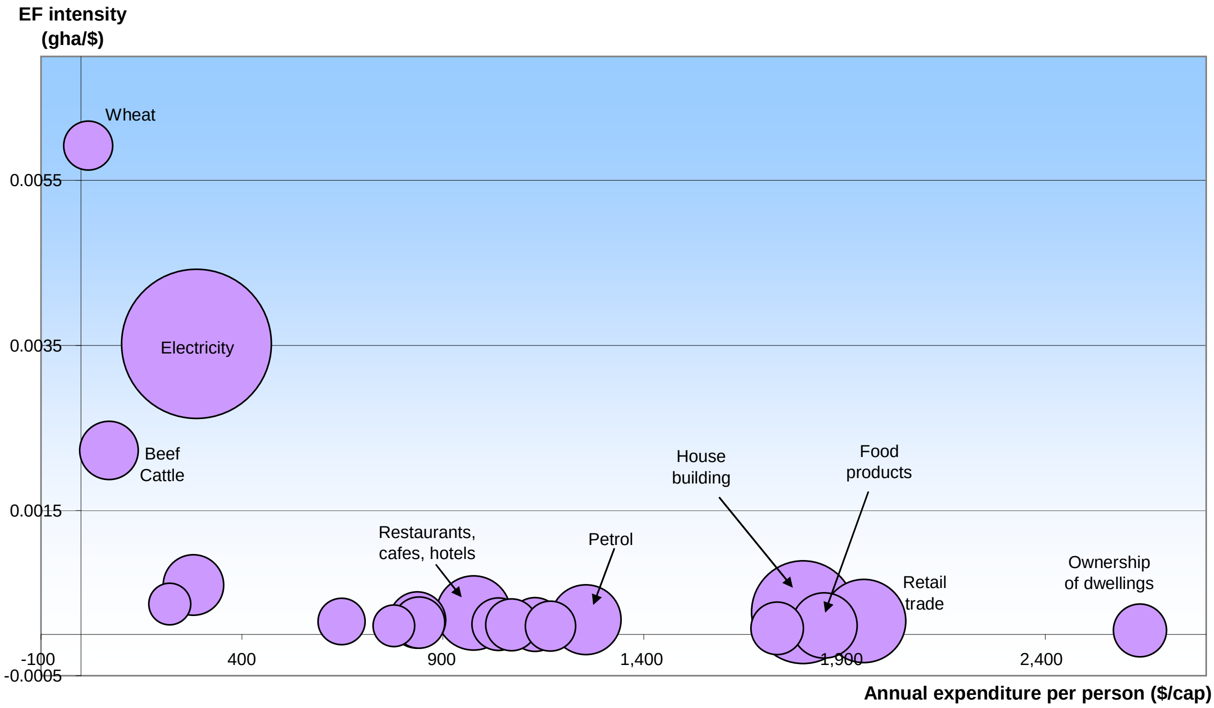


Figure 4: Ecological Footprints of the 20 top-ranking commodities in Victoria by expenditure (x axis, in $/cap)**, intensity** (y axis, in gha/$) **and absolute EF** (size of circles, in gha/cap)**.** Only some have been labelled.

This way of looking at detailed Footprint results can provide information on whether impacts are mainly due to the production process or whether they come from high levels of consumption. Commodities located in the top left part of Figure 4 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 process. Wheat, beef cattle and electricity are examples for this type in Victoria. 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. In Victoria, much money is spent on own dwellings, homes construction, food products and retail trade.

As can be seen from Figure 4, 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.

2.4. Spatial variations: Differences between urban and rural consumption impacts in Victoria

Not everyone consumes equally. Whilst some people consume more than others there are also regional differences in consumption. People in rural areas have completely different needs for transport, for example, and public services such as recycling, water supply or education are handled differently to urban areas.

We start with a comparison of the total Footprint area of Melbourne's residents with the actual area of Melbourne and Victoria. As can be seen in Figure 5 below, Melbourne's total Footprint of 6.9 gha/cap is 12% larger than the physical land area of the state is (25 million gha compared to 22 million ha) and 28 times larger than the actual area of Melbourne.

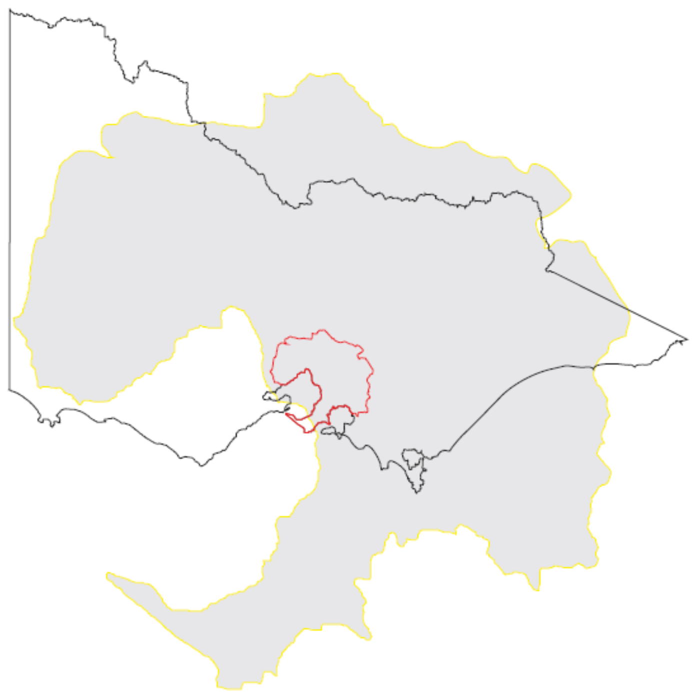


Figure 5: The relative size of Melbourne's Ecological Footprint (grey shaded area) compared to the actual size of Melbourne (red line) and Victoria (black line).

The following graphs and tables go on to show the regional variations in Ecological Footprint, organised by Statistical Divisions (Table 4), Statistical Sub-Divisions (Table 5) and Statistical Local Areas (Figure 6 and Figure 7). The breakdown of Ecological Footprint results by local area allows a more detailed spatial analysis of consumption related environmental impacts.

Table 4: Absolute and per-capita Ecological Footprint (EF) by Statistical Divisions (SD) in Victoria

Statistical Divisions	Total EF (Mgha)	Population	EF per person (gha/cap)
Melbourne	24.44	3,547,200	**6.89**
Barwon	1.70	250,222	**6.79**
Western District	0.67	99,789	**6.67**
Central Highlands	0.94	140,179	**6.71**
Wimmera	0.34	50,877	**6.67**
Mallee	0.59	90,650	**6.54**
Loddon	1.10	164,121	**6.69**
Goulburn	1.28	193,745	**6.59**
Ovens-Murray	0.65	97,814	**6.67**
East Gippsland	0.53	80,126	**6.57**
Gippsland	1.03	156,576	**6.59**
	33.3	**4,871,300**	**6.83**

Table 5: Absolute and per-capita Ecological Footprint (EF) by Statistical Sub-Divisions (SSD) in Victoria

Statistical Sub-Divisions	Total EF (Mgha)	Population	EF per person (gha/cap)
Inner Melbourne	2.31	274,184	**8.43**
Western Melbourne	2.88	431,780	**6.67**
Melton-Wyndham	0.90	144,351	**6.23**
Moreland City	0.95	138,408	**6.90**
Northern Middle Melbourne	1.73	250,845	**6.90**
Hume City	0.84	138,646	**6.06**
Northern Outer Melbourne	1.16	181,486	**6.37**
Boroondara City	1.27	158,295	**8.01**
Eastern Middle Melbourne	3.09	427,333	**7.24**
Eastern Outer Melbourne	1.63	251,165	**6.50**
Yarra Ranges Shire Part A	0.92	144,322	**6.34**
Southern Melbourne	2.87	393,603	**7.28**
Greater Dandenong City	0.86	131,219	**6.54**
South Eastern Outer Melbou	1.44	233,364	**6.19**
Frankston City	0.73	116,092	**6.30**
Mornington Peninsula Shire	0.86	132,106	**6.47**
Greater Geelong City Part A	1.07	157,370	**6.78**
East Barwon	0.38	54,478	**6.96**
West Barwon	0.25	38,374	**6.59**
Warrnambool City	0.20	29,800	**6.72**
Hopkins	0.22	32,891	**6.60**
Glenelg	0.25	37,098	**6.69**
Ballarat City	0.56	82,954	**6.76**
East Central Highlands	0.26	39,129	**6.66**
West Central Highlands	0.12	18,096	**6.60**
South Wimmera	0.24	36,334	**6.65**
North Wimmera	0.10	14,543	**6.71**
Mildura Rural City Part A	0.30	45,800	**6.54**
West Mallee	0.08	11,579	**6.68**
East Mallee	0.22	33,271	**6.48**
Greater Bendigo City Part A	0.52	78,596	**6.67**
North Loddon	0.32	48,562	**6.58**
South Loddon	0.25	36,963	**6.87**
Greater Shepparton City Part	0.29	44,303	**6.63**
North Goulburn	0.49	75,184	**6.56**
South Goulburn	0.21	32,130	**6.67**
South West Goulburn	0.28	42,129	**6.55**
Wodonga	0.30	45,394	**6.64**
West Ovens-Murray	0.20	30,112	**6.67**
East Ovens-Murray	0.15	22,307	**6.75**
East Gippsland Shire	0.26	39,410	**6.58**
Wellington Shire	0.27	40,716	**6.55**
La Trobe Valley	0.48	73,672	**6.57**
West Gippsland	0.21	32,374	**6.62**
South Gippsland	0.33	50,529	**6.60**
Total	**33.3**	**4,871,300**	**6.83**

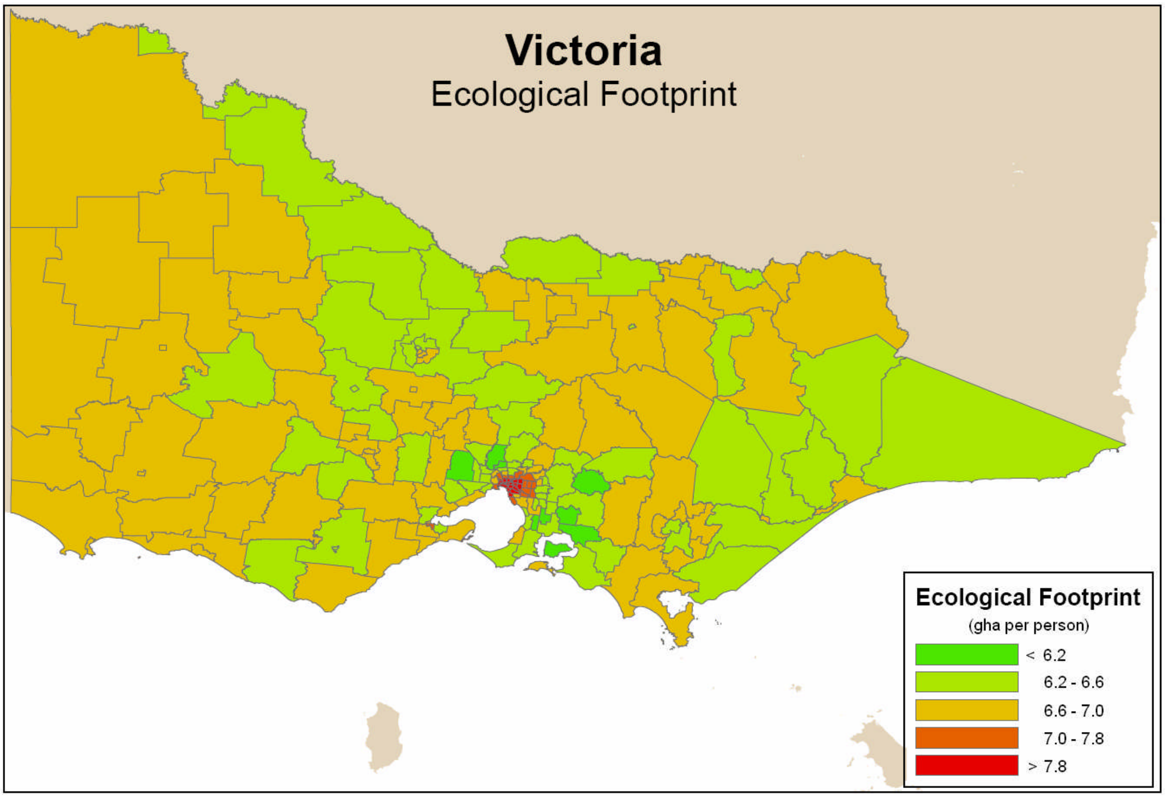


Figure 6: Per-capita Ecological Footprint of Statistical Local Areas (SLA) in Victoria

There are many factors that lead to a high Ecological Footprint. However, by far the most important appears to be income. More affluent areas tend to have higher Footprints although higher income households, on average, do purchase products that have a lower environmental impact. For example, spending money on activities such as entertainment and leisure generally has a lower impact. However, high income families generally spend more and also spend a lot of money on the high impact activities such as air travel, appliances and electricity.

Though people make greener choices with increasing income, their global environmental impact tends to increase as they buy more. Although wealthier people may buy better quality – and thus longer lasting – items, they also tend to buy bigger ones (and more). The steady increase in consumption of goods and services as wealth increases gives firm support to the correlation between wealth and environmental impact.

This correlation can also be depicted on a map showing local areas in Melbourne. The map on the left side of Figure 7 shows the Ecological Footprint per capita while the right hand map shows per capita income in these areas. Central areas of Melbourne are home to more wealthy people and show higher per capita Ecological Footprints, indicating higher levels of consumption and environmental impact. The choice of how income is spent can determine a positive or negative impact on the environment. Victorians who wish to reduce their footprint can consider investing in activities that protect or improve the natural environment, buying less, sharing more, buying smarter and reducing waste.

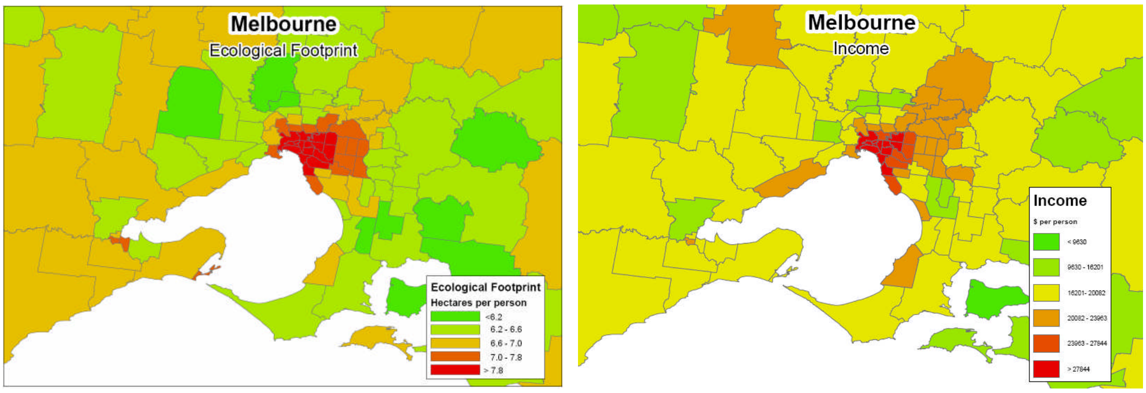


Figure 7: Statistical Local Areas in Melbourne and their Ecological Footprints (left) and levels of income (right).

When grouping together all local areas belonging to Melbourne on one hand and all areas outside of Melbourne on the other hand 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 8. A more detailed breakdown is shown in Figure 9.

Figure 8: Comparison of the relative contributions of main consumption categories in Melbourne and rural areas of Victoria

When comparing Melbourne with the rest of the state some differences in the Ecological Footprint become apparent. Melbourne residents have a slightly higher Footprint in the areas of food, housing and services whereas rural areas have a higher Footprint for residential energy use.

Figure 9 below provides more detail. City dwellers tend to eat out more which explains the higher food Footprint. There is also more housing construction in urban areas, raising the Footprint of 'housing'. The 'services' Footprint is higher in Melbourne due to 'real estate and rental lodging' and other services typical for an urban environment.

The higher energy Footprint for rural areas in Victoria can be attributed to a higher consumption of electricity there and is related to little access to piped gas in rural areas. The mobility Footprint for rural areas is slightly higher, mainly due to car driving, reflecting a higher dependency on private transport. Public transport is used less in rural areas.

In terms of durable and consumable goods, the Footprint of 'clothing and shoes' is slightly higher in the capital, but the urban Footprint is lower for 'furnishings'.

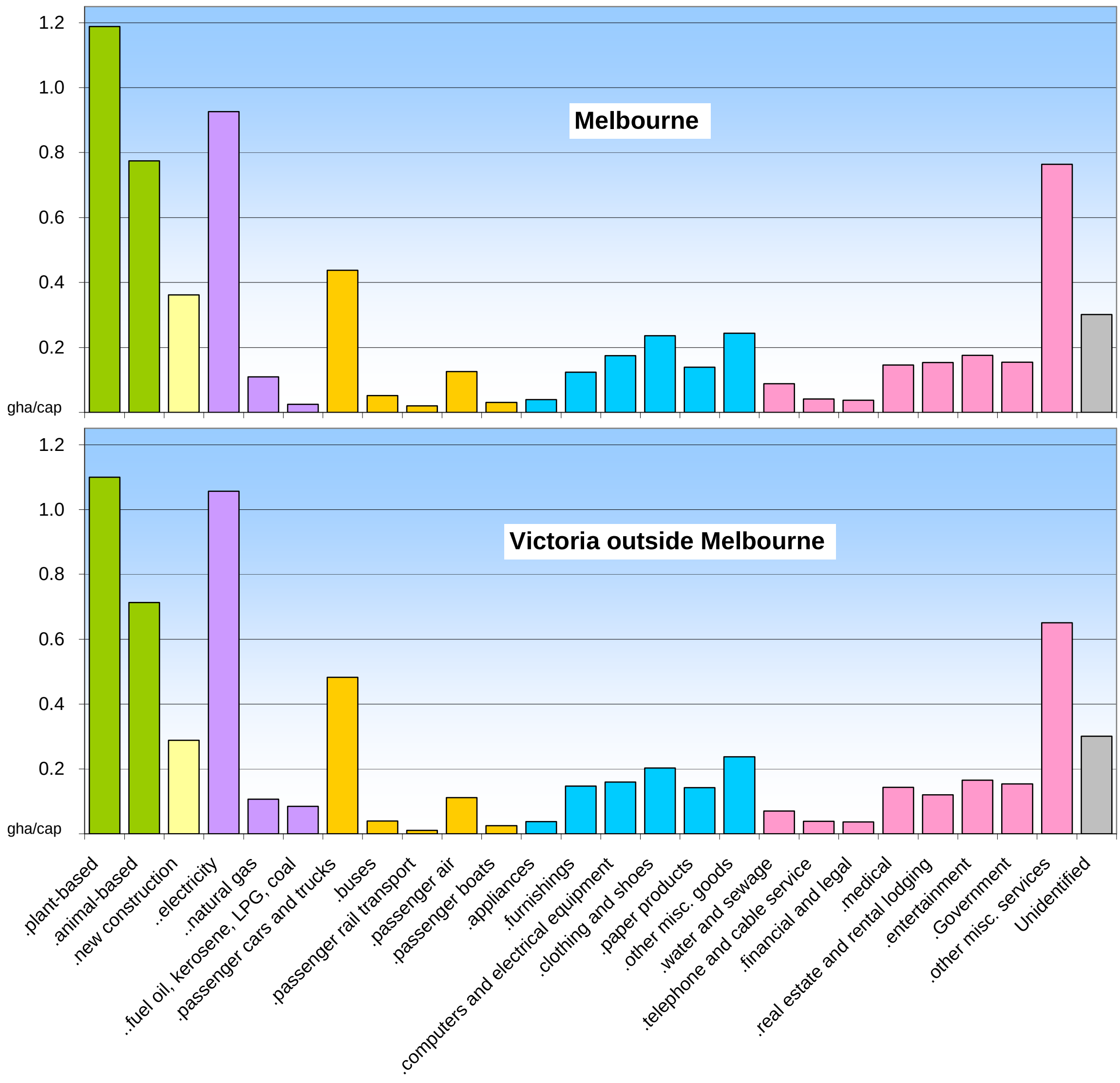


Figure 9: Per-capita Ecological Footprint of Melbourne and Victoria outside the capital by consumption category.

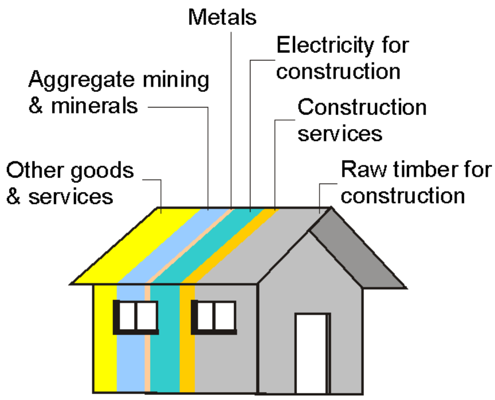
2.5. The Footprint of everyday household items

The environmental impacts that occur in the production and distribution of the goods and services we buy and consume far overshadow our direct household impacts (by roughly a factor of four). Use of electricity, petrol and water might be the most visible and most discussed areas of personal impact on the environment. However, while many Victorians are increasingly aware of the need to conserve water and reduce energy use, information about the hidden environmental costs of many products and services is much harder to come by.

People in Victoria buy goods and services every day and each of these adds a little bit to Victoria's total Ecological Footprint. Below, the life cycle impact of three commodities is examined.

A new house

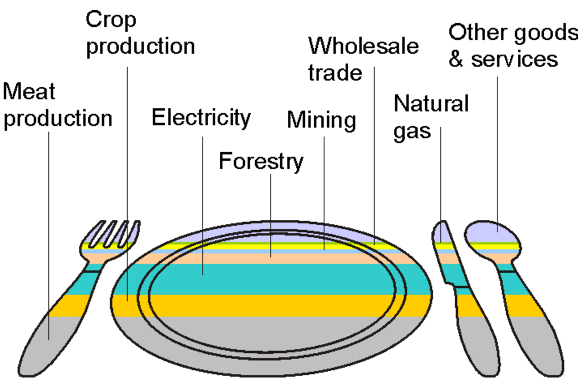
Almost 54,000 new houses were built in Victoria in 2003/04, each of which creates a footprint of 27 global hectares at the moment of construction. If the average house lasted for 90 years, then this impact would be equivalent to about 0.3 gha a year. This is the area and amount of biocapacity required to produce, transport and assemble all the construction materials, to provide all the energy and to deliver all the services that are needed to build a new house. Of all the different materials that go into constructing a home, timber is the biggest contributor to the Footprint of materials. 43% of the total house Footprint is from forest area that is needed to supply the timber. Other important contributors are electricity (16%), aggregate mining and minerals (14%) and construction services (14%).



Raw timber for construction	43.0%
Construction services	14.0%
Electricity for construction	15.5%
Metals	3.1%
Aggregate mining & minerals	14.4%
Other goods & services	10.0%
Total	100%

Figure 10: Main contributors to the Footprint of a new house

The total Ecological Footprint of residential construction in Victoria is 1.4 million global hectares, which is 6% of the 22.7 million hectares of actual land area in Victoria. This Footprint area is required year after year and clearly shows the high demand for natural resources used in residential building. The use of recycled construction materials is one possibility to ease this pressure.



Meat production	40.9%
Crop production	21.2%
Electricity	17.6%
Forestry	2.5%
Mining	2.3%
Wholesale trade	2.9%
Natural gas	1.3%
Other goods & services	11.3%
Total	100%

Figure 11: Main contributors to the Footprint of a restaurant meal

A restaurant meal

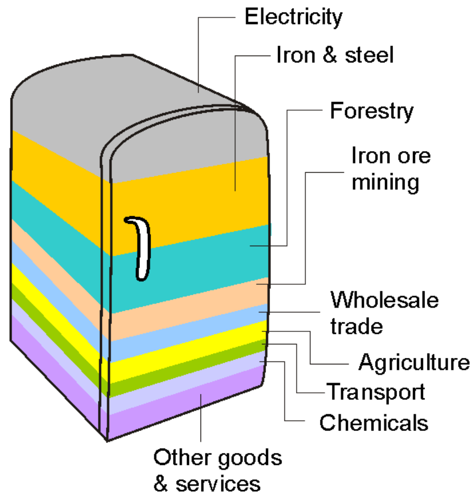
The Ecological Footprint of an average restaurant meal in Victoria is 60 global square metres, which is equivalent to the base area of a small house and a lot more than the actual space it takes up on the plate. The largest impact comes from the land area that is needed to grow the food in the first place, but all other 'upstream impacts' such as the energy needed for processing and transporting as well as for the restaurant itself have to be included.

The most important 'impact paths' in the production of a restaurant meal, derived by a comprehensive Footprint life cycle analysis, are the production of beef and agricultural crops. These are the main contributors and together make up 62% of the total Footprint. The third biggest contribution for the 'Footprint on the plate' comes from the use of electricity.

A household refrigerator

When looking at the life cycle stages of a household appliance such as a fridge the use phase is most important, followed by the production of the fridge, and then its disposal.

The annual electricity used to run a refrigerator for one year adds 0.16 gha to the footprint of each household in Victoria. Manufacturing the fridge has a smaller impact, about 0.021 gha per household per year. A detailed cradle-to-gate analysis of all resources required for the production of domestic refrigerators reveals that it is again the impact of electricity that comes in first place and makes up 48% of the fridge's production footprint. In second place (19%) is the footprint of producing steel for the fridge and in third place (6.3%) is the forest footprint, due substantially to the cardboard packaging used for shipping the fridge. Iron ore mining, wholesale trade, agriculture and transport each account for 4 to 5% of the total footprint.



Electricity	47.5%
Iron & steel	19.0%
Forestry	6.3%
Iron ore mining	4.8%
Wholesale trade	4.8%
Agriculture	4.7%
Transport	4.0%
Chemicals	3.2%
Other goods and services	5.8%
Total	100%

Figure 12: Main contributors to the Footprint of producing a household fridge

To make substantial reductions to a fridge's Ecological Footprint this analysis shows the need to address the carbon-intensity of electricity used in the production and use phase. Consumption of electricity during the use phase can be reduced substantially by buying the most energy-efficient appliances available.

2.6. Opportunities for change

What does it all mean? The analysis demonstrates that there is a need to consume less as well as consume differently. While it is important to exploit technologies that offer us a lower Footprint lifestyle, this will never be enough. Gains in energy and resource efficiency have always been 'eaten up' by increased and accelerated consumption. The issue of “time” becomes extremely important when trying to imagine what a low Footprint lifestyle might look like.

The less time we have as individuals, the more we rely on technology around us to do the jobs we don’t have time for. First, the introduction of timesaving devices often increases the energy input required for the production of one unit of service as they increase the capital intensity of consumption processes. A good example for the additional energy required by speeding-up a certain process might be transport, where faster modes are usually more energy intensive per mile travelled: bicycles need less energy than cars and planes more than trains or ships. Other examples are halogen down-lights, dishwashers, computers and plasma televisions. These appliances need electricity, Victoria's number one in the top ten Footprint list.

It is clear that Victorians need to move to a more sustainable lifestyle if the Ecological Footprint is to be reduced. To reduce our impact on the environment we will need to live smarter by using less electricity and choosing goods and services that have a low Footprint. This has not only positive environmental effects but also frees up more time for life, leading to healthier, more sustainable communities and improving quality of life.

3. Project Methodology

3.1. Overview

The results of this Ecological Footprint analysis of Victoria 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 at the level of local statistical areas in Victoria.

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. 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 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.[2] 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).

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

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

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]

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. This is followed by a mathematical exposition of the methodology.

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 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 2000b); (Moffatt 2000c); (Opschoor 2000c); (Rapport 2000c); (van Kooten and Bulte 2000a). 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[4], 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 2000b), and to formulate appropriate policy responses (Ayres 2000c); (Moffatt 2000b); (Opschoor 2000a); (van Kooten and Bulte 2000c). In response to the problems highlighted, the concept has undergone significant modification and improvement (Bicknell et al. 1998a), (Simpson et al. 2000a), (Lenzen and Murray 2001d).

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). 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

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

[4] 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.

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 (Wackernagel and Rees 1996), Canadians in 1991 had 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 et al. 2000c) all areas of land were included, irrespective of their productivity.

3.4. Input-output-based Ecological Footprinting – an approach growing worldwide

In the calculation of Ecological Footprints of populations by (Wackernagel and Rees 1996) and (Simpson et al. 2000b), 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.

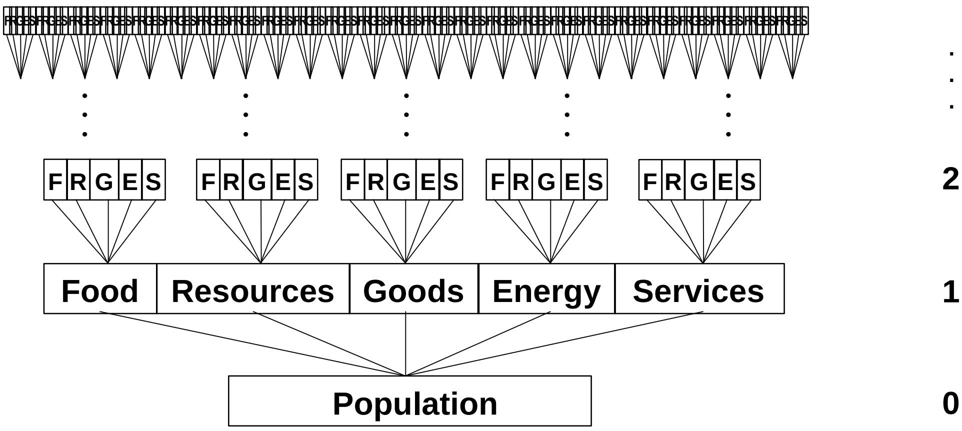

Figure 13: Industrial interdependence in a modern economy: a "tree" of upstream production layers.

Such a production "tree" is shown schematically in Figure 13: 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.

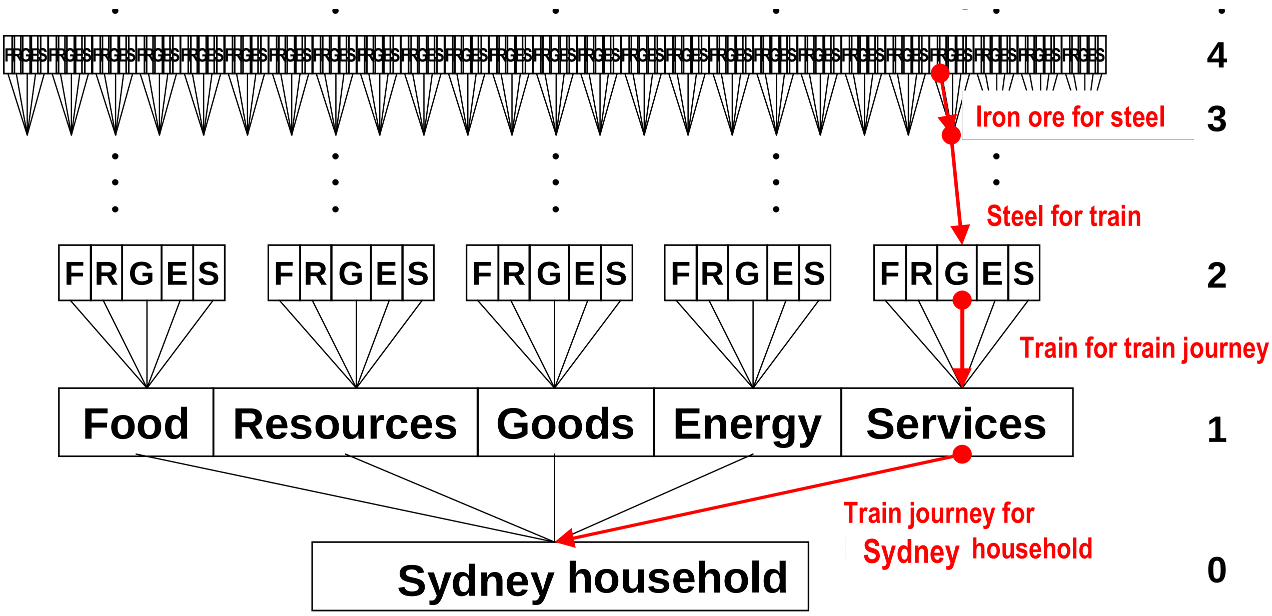

Figure 14: Production layers and input paths in the Ecological Footprint of a Sydney household (as an example).

A specific example for direct and indirect requirements in the Ecological Footprint of a Sydney household is shown in Figure 14. 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 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 13 and Figure 14 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 2001a). It was first applied by (Bicknell et al. 1998b) 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.[5] 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). The current Ecological Footprint standards explicitly allow the use of on input-output analysis as a means to break down national totals (GFN 2006) (see also section 5).

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.

4. 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

[5] (Albino and Kühtz 2002; Bagliani et al. 2002; Ferng 2001; Hubacek and Giljum 2003; Lenzen et al. 2003; Lenzen and Murray 2003; McDonald and Patterson 2003; Nichols 2003; Wiedmann and Barrett 2005; Wiedmann et al. 2007a; Wiedmann et al. 2007b; Wiedmann et al. 2006; Wood and Lenzen 2003).

[6] See, for example, studies of Vancouver (Rees and Wackernagel 1996b), 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

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 1996a). 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 iven population (Rapport 2000a), and to formulate appropriate policy responses (Ayres 2000a); (Moffatt 2000a); (Opschoor 2000b); (van Kooten and Bulte 2000b). Furthermore, Ecological Footprints on sub-national scales underestimate indirect requirements (Bicknell et al. 1998c; Lenzen and Murray 2001b). 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, 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 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

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(Barrett and Scott 2001), Guernsey (Barrett 2001), and the Isle of Wight (Best Foot Forward and Imperial College 2001).

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.

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

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

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*.

Its elements $\{Q_{ij}^{\text{hh}}\}_{i=1,\dots,f\,;\,j=1,\dots,s}$ describe the usage by private households of factor *i* per A$ value of final consumption of commodity *j*. $\mathbf{Q}^{\text{hh}}$ 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[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.

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

Its elements $\{Q_{ij}^{\text{emb}}\}_{i=1,\dots,f\,;\,j=1,\dots,s}$ 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,

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

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 2001b)).

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 $\{Y_{ij}\}_{i=1,\dots,s;\, j=1,\dots,h}$ 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*

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

The variables in equation 2 are:

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

Its elements $\{Q_{ij}^{\text{ind}}\}_{i=1,\dots,f;\, j=1,\dots,s}$ 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 $\{I_{ij}\}_{i=1,\dots,s;\, j=1,\dots,s}$ 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 $\{A_{ij}\}_{i=1,\dots,s;\, j=1,\dots,s}$ 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 et al. 1972), (Herendeen 1978b), (Miller and Blair 1985b), (Proops 1988), (Miller et al. 1989), (Hawdon and Pearson 1995), and (Forssell 1998). For a description of the assembly of an Australian input-output framework, see (Lenzen 2001e).

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

[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.

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

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 1999a, b); see also (Lenzen 2001d).

The baseline year 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 2006a) was supplemented with Produce Price Indices (Australian Bureau of Statistics 2006b) 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.

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

[12] (Tarancon and Del Rio 2005).

- 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 National Footprint Account 2006 Edition for Australia was used as a starting point for subsequent calculations.

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 2001c), and a CSIRO report on landcover disturbance across the Australian continent (Graetz et al. 1995); (Lenzen and Murray 2001e).

Other data

State specific figures were taken from (Australian Greenhouse Office 2004). The full fuel-cycle emission factor for electricity in Victoria is 1.392 kg CO2-e/kWh.

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 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 2001a). 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 2001c). 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 2001b).

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 1969a), 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 1969b), 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*.

4.5. Structural path analysis

The general decomposition approach described in the following was introduced into economics and regional science in 1984 under the name *Structural Path Analysis* (Crama et al. 1984; Defourny and Thorbecke 1984), and applied in life-cycle assessment by Treloar and Lenzen (Lenzen 2002; Treloar 1997; Treloar et al. 2000; Treloar 1998). The total factor multipliers as in Eq. 2 can be decomposed into contributions from structural paths, by "unravelling" the Leontief inverse using its series expansion

$$\mathbf{Q}^{\mathrm{ind}}\,(\mathbf{I}\text{-}\mathbf{A})^{-1} = \mathbf{Q}^{\mathrm{ind}} + \mathbf{Q}^{\mathrm{ind}}\mathbf{A} + \mathbf{Q}^{\mathrm{ind}}\mathbf{A}^2 + \mathbf{Q}^{\mathrm{ind}}\mathbf{A}^3 + \ldots \quad . \qquad (4)$$

Expanding Equation 4, indirect requirements $Q^{\mathrm{emb}}{}_i \times Y_i$ as in Equation 1 can be written as

$$Q_i^{\text{emb}} Y_i = Y_i \sum_{j=1}^{s} Q_j^{\text{ind}} \left(I_{ji} + A_{ji} + (\mathbf{A}^2)_{ji} + (\mathbf{A}^3)_{ji} + \ldots \right)$$

$$= Y_i \sum_{j=1}^{s} Q_j^{\text{ind}} \left(I_{ji} + A_{ji} + \sum_{k=1}^{s} A_{jk} A_{ki} + \sum_{l=1}^{s} \sum_{k=1}^{s} A_{jl} A_{lk} A_{ki} + \ldots \right)$$

$$= Q_i^{\text{ind}} Y_i + \sum_{j=1}^{s} Q_j^{\text{ind}} A_{ji} Y_i + \sum_{k=1}^{s} Q_k^{\text{ind}} \sum_{j=1}^{s} A_{kj} A_{ji} Y_i + \sum_{l=1}^{s} Q_l^{\text{ind}} \sum_{k=1}^{s} A_{lk} \sum_{j=1}^{s} A_{kj} A_{ji} Y_i + \ldots \quad (5)$$

where *i*, *j*, *k*, and *l* denote industries. ${Q^{\text{emb}}}_i Y_i$ is thus a sum over a direct factor input ${Q^{\text{ind}}}_i Y_i$, occurring in industry *i* itself, and higher-order input paths. An input path from industry *j* (domestic or foreign) into industry *i* of first order is represented by a product ${Q^{\text{ind}}}_j A_{ji} Y_i$, while an input path from industry *k* via industry *j* into industry *i* is represented by a product ${Q^{\text{ind}}}_k A_{kj} A_{ji} y_i$, and so on. There are *s* input paths of first order, s^2 paths of second order, and, in general, s^N paths of N^{th} order. An index pair (*ij*) shall be referred to as a *vertex*.

5. Standard compliance

This section briefly describes how compliance with EF standards was achieved. We refer to the current set of standards which were released on 16th of June 2006 (GFN 2006).

- Standard 1 - Consistency with National Footprint Accounts: the national total from the National Footprint Accounts (2006ed) was broken down using IO analysis as an appropriate technique.
- Standard 2 - Definition of Study Boundaries: the study uses the same boundaries as the NFA and it has been made clear that the Footprint of consumption is presented.
- Standard 3 - Sub-National Population Calculations: sub-national results have been presented in the NFA-consistent CLUM format.
- Standard 4 - (Place holder for organizational and product studies: Not released): n/a
- Standard 5 - Derivative Conversion Factors: primary conversion factors have implicitly accepted by adopting the NFA total; secondary conversion factors have implicitly been calculated by using IO analysis; this technique has been amply described in the methodology chapter.
- Standard 6 - Consistency of Components: the same components as in the latest NFA for Australia have been used.
- Standard 7 - Use of Non-Standard Elements in Footprint studies: no elements for added or omitted.
- Standard 8 - (Place Holder for calculation methods Not Released): n/a
- Standard 9 - Error Estimates (GUIDELINE): the estimation of error margins was not included in the scope of the project.
- Standard 10 - Traceability to National Footprint Accounts: the analysis was undertaken with the latest National Footprint Accounts edition that was available at the time when the assessment was initiated – the 2006 edition; this is clearly stated in the report.

- Standard 11 - Glossary, Definitions and Versions: definitions from the current Footprint Term Glossary were used and quoted (GFN 2008a).
- Standard 12 - Separation of Analytical Footprint Results from Normative or Values-based Interpretations: standards compliant language was used.
- Standard 13 - Footprint Scenarios: the Ecological Footprint is presented as an ecological accounting tool, and not as a predictive model; scenarios were not included in the scope of the project.
- Standard 14 - Footprint Study Limitations: the method is extensively described above, pointing out limitations either directly or indirectly by quoting adequate literature.
- Standard 15 - Explanation of Link between Sustainability and Footprint: the report does not state or imply that the Footprint is a complete measure of sustainability and it uses text suggested by the Footprint standards in the introduction.
- Standard 16 - Citation of sources and description of methodologies: the report references relevant other work that is used to support the analysis and conclusions; the report references all data sources used in compiling the Consumption Land Use Matrix.
- Standard 17 - Reference to Standards and Certifying Bodies: we herewith confirm that this report is compliant to the Ecological Footprint Standards 2006 (GFN 2006) to the best of our knowledge and ability. For further information on Footprint standards and certification see www.footprintstandards.org. Our contact details for any questions are:

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- Standard 18 - Communication style (GUIDELINE): partly followed, but not slavishly.

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