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SYDNEY

The 2008-09 Ecological Footprint of the population of the ACT



**Prepared by
Integrated Sustainability Analysis (ISA)
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**The 2008-09 Ecological Footprint
of the population of the Australian Capital Territory**

Report on consultancy work carried out for the
Office of the Commissioner for Sustainability and the Environment

by

Integrated Sustainability Analysis Research Group
The University of Sydney

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1. Executive summary

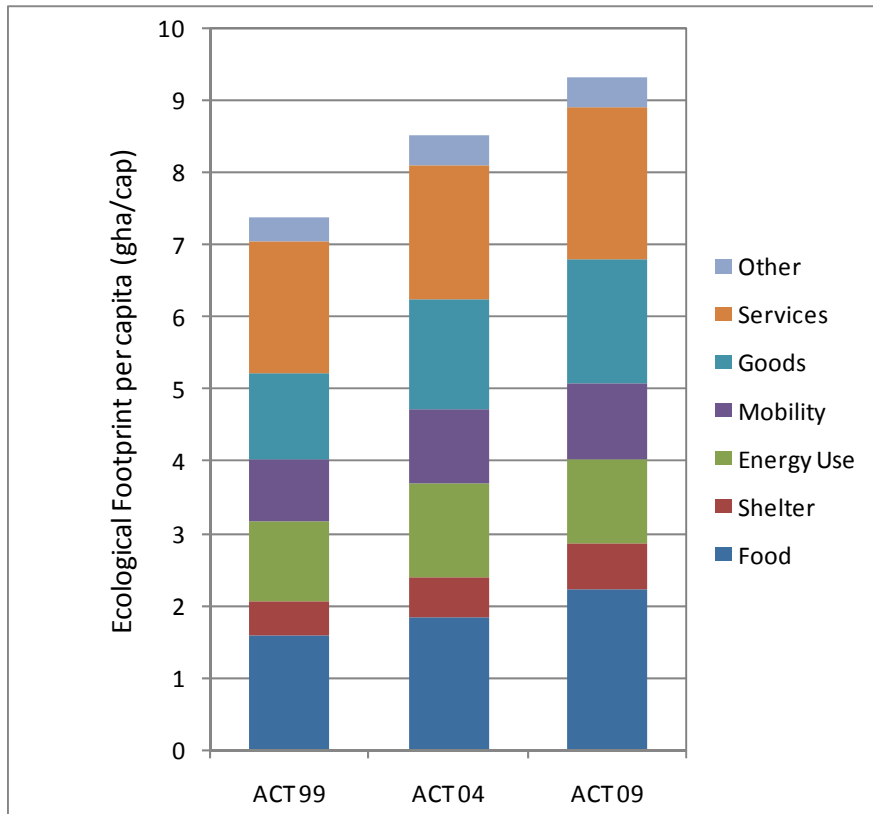
This report presents results of calculations of the Ecological Footprint of the population of the ACT. The Ecological Footprint is a concept for assessing the sustainability of resource use and pollution of households, cities, and entire nations. For example, applied to households, the Ecological Footprint represents the land area equivalence (in hectares) of all the resources required to support the lives of the people in the household, and to absorb their pollution. Although a single indicator, the Ecological Footprint is a powerful concept when compared to the total available productive area on Earth. Globally at present, humanity is already in 'ecological overshoot': meaning we are running down renewable resources faster than they can be regenerated by ecosystems and producing CO₂ faster than it can be absorbed (WWF - World Wide Fund for Nature 2010).

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

The main results are that, on average, the Ecological Footprint of a person living in the ACT in 2008-09 is 9.2 global hectares (gha). With a population of 349,000 people, this amounts to a total area of 3,200,000 global hectares, roughly fourteen times the area of the ACT. This figure includes all upstream impacts, capital requirements, imports, and capital imports. That the Ecological Footprint of the ACT is many times larger than its administrative area represents the fact that impacts of consumption go well beyond arbitrary borders, drawing on productive areas all over Australia and around the World.

ISA has also calculated the Ecological Footprint of the ACT for 1998-99 and 2003-04. Due to methodological changes in the development of the Ecological Footprint, later results are not directly comparable to the 2004 report. Hence a recalculation of 1998-99 data according to current methodology yields an Ecological Footprint of 7.4 global hectares. The overall ecological footprint for the ACT in 2003-04 was 8.5 gha. We have thus seen a growth in the per-capita Ecological Footprint for the ACT of 15% between 1998-99 and 2003-04, and a further 8% increase over the following 5 years. The average Australian's Ecological Footprint is 8.1 gha, or about 13% lower than that for the average resident of the ACT.

The graph on the following page shows the three Ecological Footprint results for the ACT as well as the main components of the footprints. With direct energy use steady or falling in the ACT in the last 5 years, the main contributions to the increasing overall footprint are steadily rising consumption of goods and services. In turn, this increasing consumption is related to strong growth in ACT household income. It is a commonly observed trend in affluent societies, whether at the level of whole nations or at an individual household, that total environmental pressures tend to continue to grow with income, even if the immediate or direct impacts are steady or falling. This trend presents a clear challenge for us to examine closely our consumption patterns and what it means to live in societies with high incomes.



Breakdown of the average per-capita Ecological footprint of the ACT for the three years according to different categories of consumption.

2. Project background

2.1. The Ecological Footprint

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

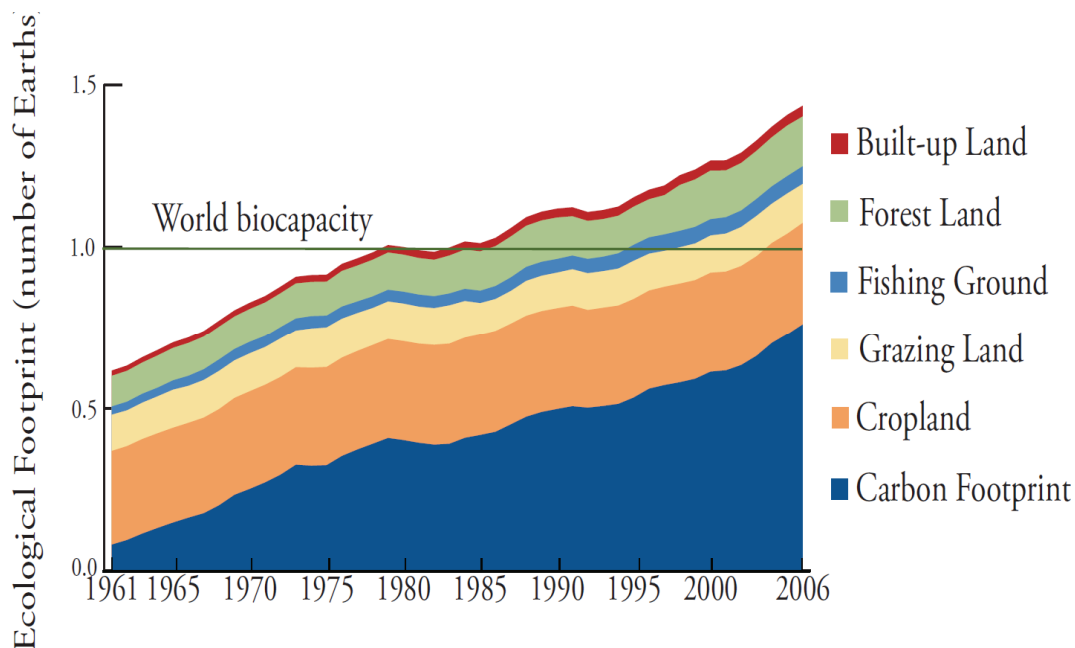
The purpose of the Ecological Footprint is to inform governments of all levels, and others involved in environmental management and decision-making. Stakeholders such as environmental non-government organizations, educators, community groups and individuals may use the information for awareness-raising,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

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

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

What exactly is an Ecological Footprint? Let's start with the basic premise that there is a limited amount of productive space on the Earth to sustain life. This bioproductive land area can be measured in global hectares (gha) which represent the average yield of all biologically productive areas on Earth. In 2006 there were 1.8 gha available per person (Global Footprint Network 2006; Global Footprint Network 2009). The Ecological Footprint measures the human demand on this area and contrasts it with 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 Footprints show 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 was 2.2 gha per person in 2003, and grew to 2.6 gha per person in 2006 (Global Footprint Network 2009) and 2.7 gha in 2007 (WWF - World Wide Fund for Nature 2010). But as this exceeds the 1.8 gha per person available, it would take 1.4 years to regenerate what humanity consumes in a year. So, in other words, average resource consumption globally results in an 'ecological overshoot' of about 40%. The figure below clearly shows this growing *unsustainability* of the impact of humans on the planet (Global Footprint Network 2009).



2.2. Purpose and aims

The purpose of this project was to carry out the necessary calculations for determining the consumption Ecological Footprint of the ACT and to present the findings in a clear and concise format. The Integrated Sustainability Analysis (ISA) research group at the University of Sydney has employed environmentally extended input-output analysis to perform the calculations. This work builds on the experience from previous projects in other parts of Australia and the ACT.

The aim of this project was to estimate the 2008-09 Ecological Footprint report for the ACT in order to investigate the progress towards or away from sustainability in the ACT. The project has five main objectives:

- To calculate the total Ecological Footprint of the ACT for 2008-09.
- To calculate the Ecological Footprint per-capita of the ACT population.
- To give a comparison to the Australian average.
- To give a breakdown of the most important goods and services contributing to the ACT Footprint.
- To provide a comparison with previous Ecological Footprints.

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

3. Project methodology

3.1. Overview

The results of this Ecological Footprint analysis of the ACT cover the financial year 2008-09 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 and household income data collected by the Australian Bureau of Statistics. By matching the expenditure and income data with the results of the input-output analysis for various categories of goods and services, we are able to assess the per-capita environmental impacts of household consumption.

The 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 ISA guarantees full 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 years⁸, and is the most robust approach of assessing environmental impacts of populations.

Final Ecological Footprints are based on a static, single-region, open, basic-price, industry-by-industry input-output model of the domestic Australian economy as of 1998-99, coupled with an extensive database on environmental indicators.¹ The methodology has been successfully employed in a range of Australian company and government applications, a pilot program on triple

¹ Foran, B., M. Lenzen, et al. (2005). *Balancing Act - A Triple Bottom Line Account of the Australian Economy*. Canberra, ACT, Australia, CSIRO Resource Futures and The University of Sydney.

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

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

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

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

The following sections provide a detailed exposition of the methodology applied in this work. They are aimed at readers who are unfamiliar with the concept of the Ecological Footprint, and who wish to learn about recent developments. A mathematical exposition of the methodology is included later.

3.2. Background to the Ecological Footprint

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

Since the formulation of the Ecological Footprint, however, a number of researchers have criticised the originally proposed method (Levett 1998); (van den Bergh and Verbruggen 1999); (Ayres 2000); (Moffatt 2000); (Opschoor 2000); (Rapport 2000); (van Kooten and Bulte 2000). The criticisms largely refer to the oversimplification in Ecological Footprints of the complex task of measuring sustainability of consumption, leading to comparisons among populations becoming meaningless³, 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

² For interpretation of static input-output models see Miller, R. E. and P. D. Blair (1985). Input-Output Analysis: Foundations and Extensions. Englewood Cliffs, NJ, USA, Prentice-Hall.

³ For example, as a result of calculations by Wackernagel, M. (1997). "Ranking the ecological footprint of nations."

Some countries with 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.

significant modification and improvement (Bicknell, Ball et al. 1998), (Simpson, Petroschevsky et al. 2000), (Lenzen and Murray 2001).

The original Ecological Footprint is defined as the land area that would be needed to meet the consumption of a population and to absorb all their waste (Wackernagel and Rees 1996). Consumption is divided into 5 categories: food, housing, transportation, consumer goods, and services. Land is divided into 8 categories: energy land, degraded or built land, gardens, crop land, pastures and managed forests, and 'land of limited availability', considered to be untouched forests and 'non-productive areas', which the authors defined as deserts and ice-caps. The 'non-productive' areas are not included further in the analysis. Data are collected from disparate sources such as production and trade accounts, state of the environment reports, and agricultural, fuel use and emissions statistics. The Ecological Footprint is calculated by compiling a matrix in which a land area is allocated to each consumption category. In order to calculate the per-capita Ecological Footprint, all land areas are added up, and then divided by the population, giving a result in hectares per capita.

The total Ecological Footprint for a population can also be subtracted from the 'productive' area that population inhabits. If this gives a positive number, it is taken to indicate an ecological 'remainder', or remaining ecological capacity for that population. A negative figure indicates that the population has an ecological 'deficit'. According to the first Ecological Footprint calculation (Wackernagel and Rees 1996), Canadians in 1991 had an Ecological Footprint of 4.3 ha per capita and an ecological remainder of 10.9 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, Petroschevsky et al. 2000) all areas of land were included, irrespective of their productivity.

3.4. Input-output-based Ecological Footprinting

In the calculation of Ecological Footprints of populations by (Wackernagel and Rees 1996) and (Simpson, Petroschevsky 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.

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

Even though indirect requirements, production layers and structural paths can be very complex, there exists a method for their calculation: input-output analysis. This is a macroeconomic technique that relies on data on inter-industrial monetary transactions, as documented for example in the Australian input-output tables compiled by the (Australian Bureau of Statistics 2001). It was first applied by (Bicknell, Ball et al. 1998) to calculate an Ecological Footprint for New Zealand. Since its first application in New Zealand, the use of input-output analysis for Ecological Footprint analysis has grown continuously, to include research organisations all over the world.⁴ In 2008, a

⁴ Ferng, J.-J. (2001). "Using composition of land multiplier to estimate ecological footprints associated with production activity." *Ecological Economics* **37**: 159-172.

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, Wood, R. and M. Lenzen (2003). "An application of an improved ecological footprint method and structural path analysis in a comparative institutional study." *Local Environment* **8**(4): 365-386.

pilot study was completed for Victoria, for the first time comparing the original method with an input-output-based methodology

(<http://www.epa.vic.gov.au/ecologicalfootprint/ausFootprint/default.asp>). Recently, the Ecological Footprint methodology has been standardised (<http://www.footprintstandards.org/>), with a strong focus on input-output analysis (Global Footprint Network 2009).

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, in more comprehensive studies input-output-based Ecological Footprints allow valid trade-offs with other sustainability indicators, thus placing the Ecological Footprint within the broader context of the Triple Bottom Line.

3.5. Ecological footprint land types

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

3.6. Methodological changes

As previously mentioned, the Ecological Footprint methodology has been standardised (<http://www.footprintstandards.org/>). Although not perfect, the standard represents an advance on the previous situation where there were several general footprint approaches with some important

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

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

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differences. Despite the move to a standard approach, or in fact partly because of this, previous Ecological Footprint calculations may not be directly comparable to current calculations. In this section, we refer specifically to the major methodological changes that have occurred from the first calculation of the ACT Ecological Footprint in 2004 to the current calculation.

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

For the particular case of greenhouse emissions, the previously used disturbance methodology related greenhouse emissions to the projected loss of land area due to climate change. In the bioproductivity approach, emissions are instead calculated by the biocapacity required to sequester carbon emissions through photosynthesis. Such land has been called ‘energy land’ in the past and is now sometimes referred to as the ‘carbon footprint’ component of the ecological footprint. Care must be exercised here as this is not the same as other users of the term carbon footprint which refers to the actual greenhouse gas emissions in CO₂-equivalents.

The second major change in methods used in this report is the updating and expansion of the Australian database from a baseline year of 1995 to 1999. The expansion of the database draws from detailed economic commodity reports, allowing the incorporation of a greater number of real physical data points for environmentally sensitive economic sectors. The disaggregation of a number of these sectors adds greater precision to results. The baseline year has been further updated in this report with important aspects such as inflation and major changes in physical accounts such as the national greenhouse gas inventory.

The overall effect of all these changes is usually small at the aggregate level, and more pronounced at the highly detailed commodity level, dependant on the particular consumption patterns of a population. Hence, in order to allow meaningful comparisons to be made from reports for ACT Footprint report for 1998-99 and 2003-04 to this current report, the 1998-99 dataset of consumption practices in the ACT has been expanded to the higher level of detail and processed according to the current methodology. This report, therefore, can be seen to supersede the first report such that previous results can be interpreted against current Ecological Footprint standards.

Finally, it should be noted that gaining full consistency across multiple data sources, years, and methodologies is difficult and not completely achievable given various data availabilities and limitations, changes in definitions and so on. Great care is taken in the work of ISA to achieve as high a consistency as possible.

4. Ecological Footprint results for the ACT

4.1. Overview and key findings

In 2009, it is estimated that the average ACT resident has an Ecological Footprint of 9.2 global hectares (Table 1), three and a half times higher than the world average and five times higher than the average available biocapacity (see Section 2.1). The ACT's 2009 footprint is 13% higher than the Australian average (8.1 gha) in 2009, in turn up from the average of 7.3 in 2004.

The 2009 total Ecological Footprint of 3.2 million global hectares is nearly 14 times the land area of the ACT. Most of the ACT's Ecological Footprint is located in other parts of the world that provide the wide range of goods and services consumed by ACT residents. The Ecological Footprint consists of both "Real Land" (arable land, pasture, forests, built land etc.) and "Energy Land" (the land required to absorb the carbon dioxide emitted through the consumption patterns of a given population)⁵.

ACT 09						
Ecological Footprint ('000 gha)						
Cropland	Pasture	Forests	Energy land	Built land	Water	TOTAL
329	344	610	1,828	87	1	3,200
AUS 09						
Ecological Footprint ('000 gha)						
Cropland	Pasture	Forests	Energy land	Built land	Water	TOTAL
18,054	20,031	36,006	97,229	4,610	47	175,977
ACT 09						
Ecological Footprint (gha)						
Cropland	Pasture	Forests	Energy land	Built land	Water	TOTAL
0.94	0.99	1.75	5.24	0.25	0.00	9.2
AUS 09						
Ecological Footprint (gha)						
Cropland	Pasture	Forests	Energy land	Built land	Water	TOTAL
0.83	0.92	1.66	4.47	0.21	0.00	8.1

Table 1: The Ecological Footprint of the ACT and the whole of Australia by land type for 2008-09. Results are shown in absolute terms (thousands of global hectares, '000 gha) and per-capita (gha/cap).

For the ACT, the majority of the Ecological Footprint is "Energy Land" (57%). This is due to the heavy reliance on fossil fuels where the major impacts are from the consumption of electricity by households (12% of total), the use of flights and the purchase of petrol for cars (both 4% each of total, see below). In terms of "Real Land", the forest Footprint has the largest contribution with

⁵ Refer Section 3.5

about 19% of the total Ecological Footprint. This largely reflects the use of wood in the construction of new houses and for heating.

The Ecological Footprint on farming lands (Cropland and Pasture) in the ACT (0.94 and 0.99 gha respectively) is slightly higher than for the average Australian (0.83 and 0.92 gha respectively), reflecting a higher than average consumption of foodstuffs and the fibres embodied in clothing and housing within the ACT. Combined, the Ecological Footprint of the farming lands account for 21% of the ACT Ecological Footprint compared to 22% of the Australian Ecological Footprint. Built land contributes only 3% to the Ecological Footprint of the average ACT resident, again reflecting just how little of a person’s Ecological Footprint is contained within the urban environment.

A comparison of the latest ACT Ecological Footprint to the Australian average (Figure 3) shows a similar breakdown. The average Australian has a per-capita Ecological Footprint of 7.3 gha in 2003-04, rising to 8.1 in 2008-09. The average ACT footprint in 2003-04 was 8.5 gha rising to 9.2 gha in 2008-09.

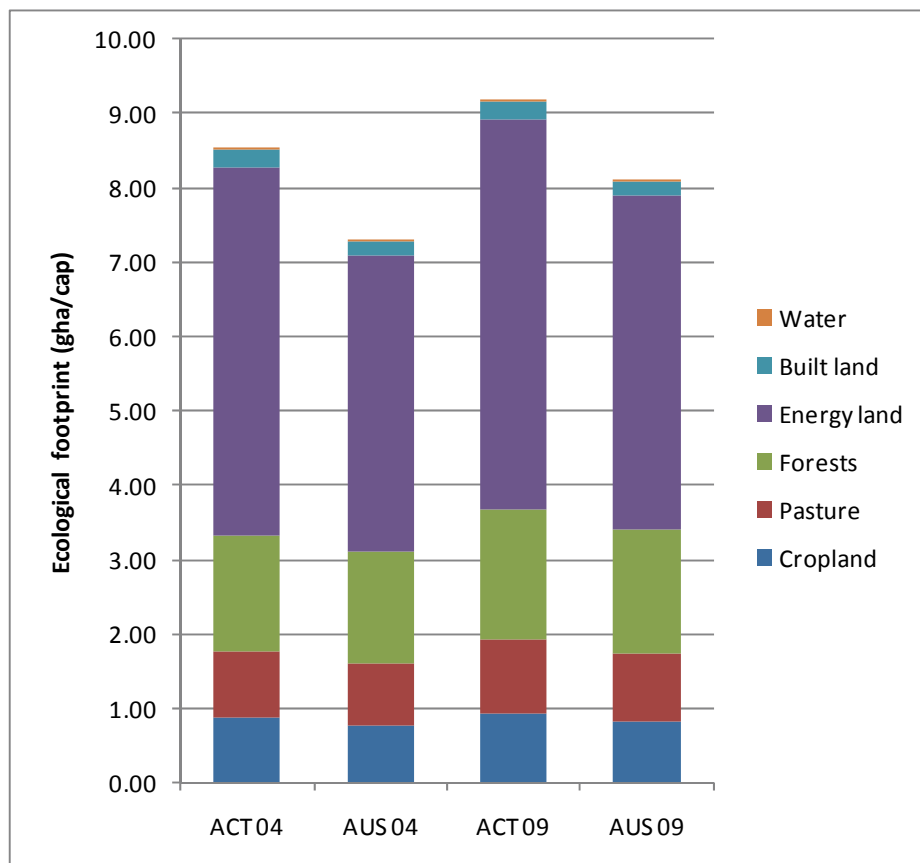


Figure 3: The per-capita Ecological Footprint of the ACT and the whole of Australia by land type for 2003-04 and 2008-09.

4.2. Ecological Footprint by consumption category

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

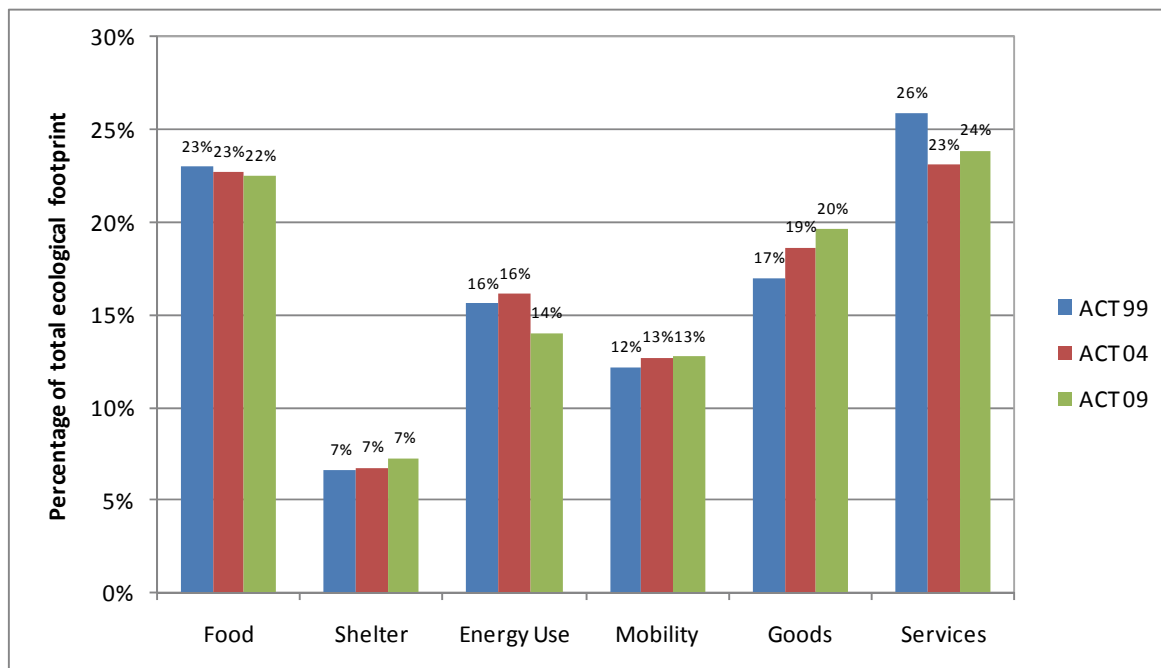


Figure 4: Comparison of Ecological Footprint consumption categories for the ACT for the three years.

Using these categories, the consumption of food and the demand for services have the most significant Ecological Footprint. Fifty-eight percent of the food impact (1.2 gha) is due to plant based food products, whilst the remainder (0.9 gha) is due to animal based products. The “services” category includes a large number of commodities including telecommunication services, financial services, medical, entertainment and government services. The main pattern of consumption in the ACT is reasonably similar to the national average, with slightly lower percentage of food and shelter impacts, but higher impacts in the more tertiary sectors. Energy use impacts are falling absolutely, and more so relatively, as per capita incomes continue to rise.

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

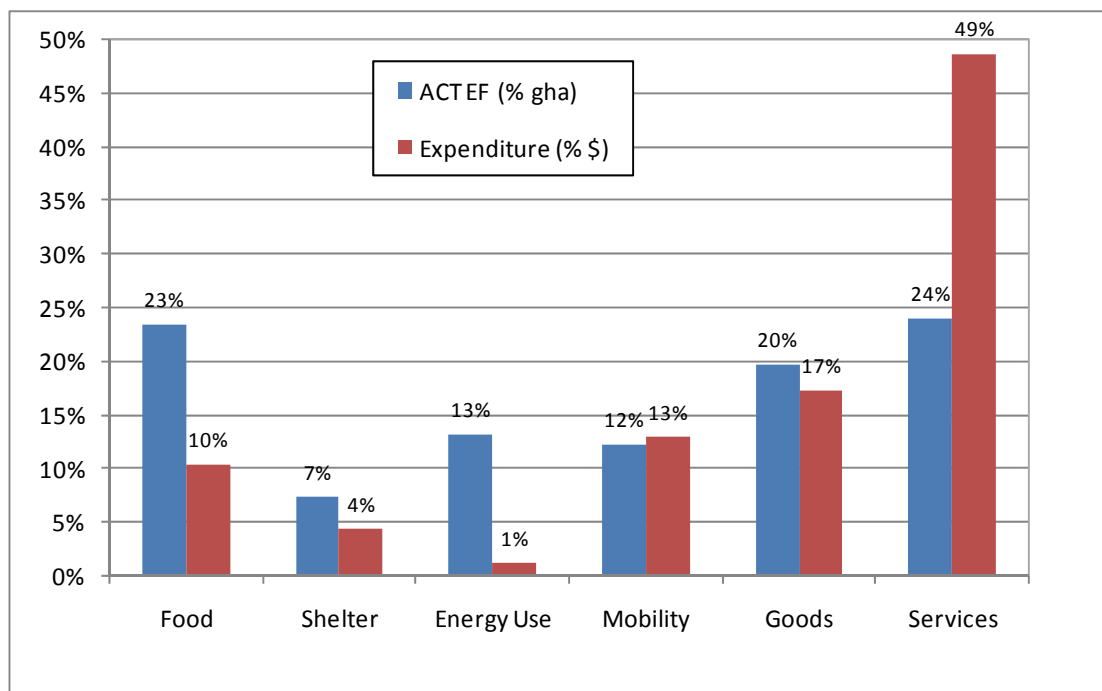


Figure 5: Comparison of consumption categories by Ecological Footprint and Expenditure, ACT 2008-09.

Hence, whilst food accounts for over 22% of the ACT Ecological Footprint, it is due to only roughly 10% of an ACT resident’s expenditure (“Expenditure” includes imports, government and capital expenditure). In significant contrast, is the expenditure on services, making up almost 50% of total expenditure, but having an impact of 24%, compared with 21%. Relative to the 2003-04 breakdown, goods and services are becoming more important. This is again due to the continual increase in incomes, and therefore expenditure.

4.3. Ecological Footprint analysis of commodities

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

Rank	Commodity	Impact (gha/capita)	% of Total
1	Electricity supply	1.07	12%
2	Residential building construction	0.56	6%
3	Retail trade	0.51	6%
4	Hotels, clubs, restaurants and cafes	0.44	5%
5	Air and space transport	0.35	4%
6	Petrol	0.32	4%
7	Other food products	0.29	3%
8	Wooden furniture	0.25	3%
9	Ownership of dwellings	0.24	3%
10	Clothing	0.21	2%
11	Electronic equipment	0.20	2%
12	Beef cattle	0.17	2%
13	Finished cars	0.16	2%
14	Education	0.15	2%
15	Non-building construction	0.14	2%
16	Gas supply	0.14	2%
17	Non-residential building construction	0.14	1%
18	Wheat	0.12	1%
19	Recorded media and publishing nec	0.10	1%
20	Pharmaceutical goods for human use	0.09	1%
21	Community services and religious organisations	0.09	1%
22	Wholesale trade	0.09	1%
23	Federal government	0.09	1%
24	Beer and malt	0.08	1%
25	Sport and recreation services	0.08	1%

Table 2: Top 25 commodities in terms of per-capita Ecological Footprint in the ACT in 2008-09.

These first twenty-five out of the 300 commodities account for two thirds (66%) of the total Ecological Footprint; they are listed in Table 2. All figures reported are in per-capita terms. Error margins for values quoted are in the order of 10-15%. At the top of the table is the impact of electricity consumption. Using electrical power alone adds around 12% (1.07 gha) to each person's Ecological Footprint every year. The ACT meets its electricity needs mostly through coal fired power stations which have one of the highest carbon dioxide emissions of all forms of electricity generation and therefore contributes significantly to the Ecological Footprint. The trend with electricity is for average per capita consumption decreasing by 6% between 2003-04 and 2007-08 (ACT Independent Competition and Regulatory Commission 2009).

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

Other major contributors are retail trade (3rd) and hospitality (4th). Retail trade reflects the industry sector that sells us our goods and services. The underlying cause of this impact is the fuel consumption of the vehicles used to distribute the goods and the electricity used in shops, and this is why it contributes to the energy Footprint. Food consumption in restaurants, cafes and hotels is the main reason why this service is also high up on the list (0.4 gha/cap, rank 4). Private transportation is also a significant contributor, with air travel ranked 5th and the use of petrol in private automobiles closely following in 6th. Fuel use in passenger vehicles appears to have plateaued in the last few years.

For comparative purposes, the commodity ranking of the 2003-04 Ecological Footprint of the ACT has been calculated according to the current methodology (Table 3). Results at this level of detail are similar to the current year's results. The main difference is that the direct contributions of electricity and petrol are slightly less important: a result of real achievements in limiting electricity use and vehicle kilometres. However, these contributions amount to less than 20% of the total footprint.

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

Table 3: Top 25 commodities in terms of per-capita Ecological Footprint in the ACT in 2003-04.

4.4. Other data and trends

It is instructive to examine some trends in other ACT data in order to test the validity of these modelling results. The main influence on both the magnitude and increases in Ecological Footprints in development countries is increases in consumption. Consumption is highly correlated with increases in income. The ACT has the highest mean household income of all Australian states, being 28% higher than the Australian average in 2007-08 (ABS 2009). The last decade has seen a considerable increase in the average income of ACT households compared to Australia as a whole (Figure 6).

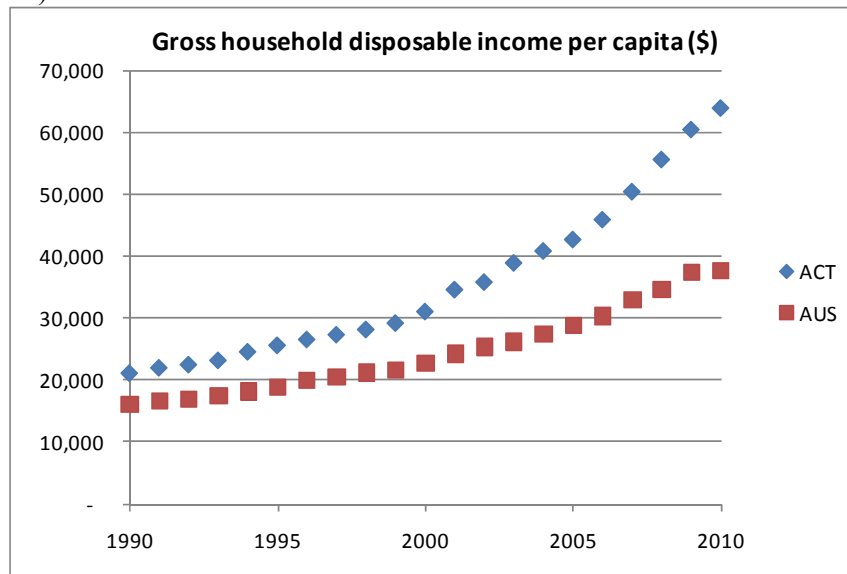


Figure 6: Average gross household disposable income per capita for Australian and the ACT.

Higher incomes generally result in higher expenditures. Figure 7 shows the household final consumption expenditure history for the ACT and Australia. As with income, there is a widening gap between the average expenditures. Note that these data are not exactly consistent with the expenditure data used in the Ecological Footprint calculations, but are indicative of the strong overall trend to higher consumption in the ACT.

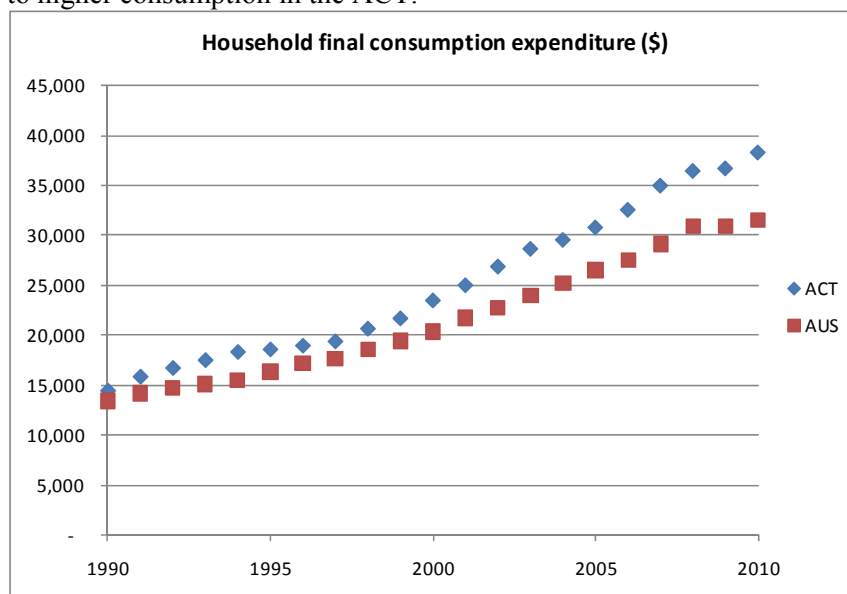


Figure 7: Comparison of average final consumption expenditure.

There has been a small but steady fall in electricity use per household each year from 2003-04 to 2007-08 (ACT Independent Competition and Regulatory Commission 2009), shown in Figure 8. The difference between these two years amounts to a 6% reduction in emissions (Department of Climate Change 2010). Similarly, there has been a 7% reduction in natural gas usage per household from 2003-04 to 2007-08 (Figure 9). Whilst the annual gas data appears to fluctuate more than the electricity usage, there is a general trend downwards in the last 6 years.

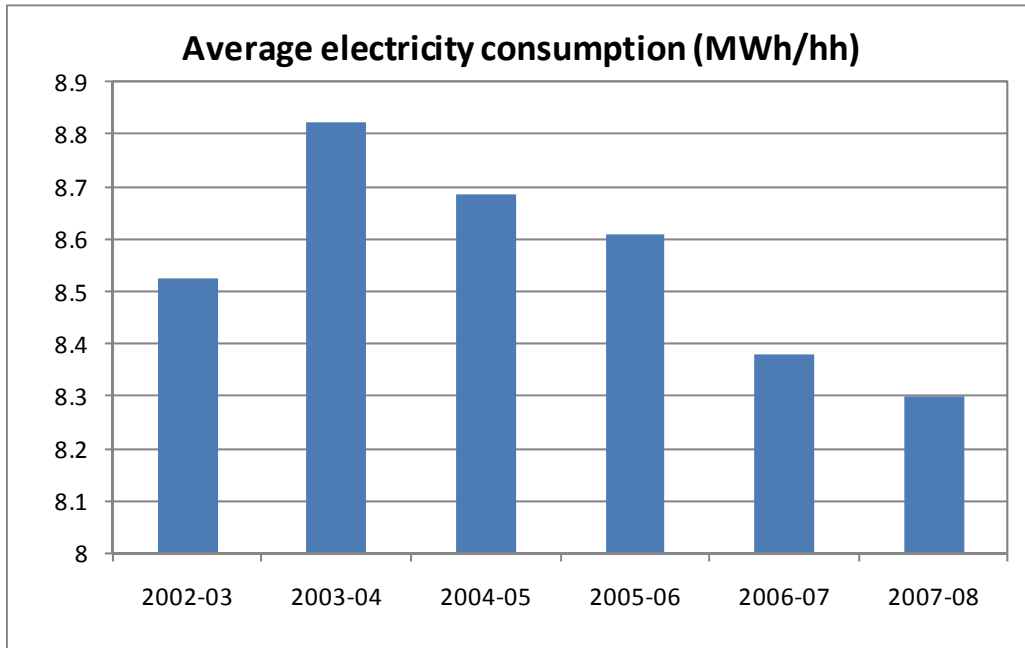


Figure 8: Average annual household (hh) electricity consumption. Emissions from electricity follow the same trend.

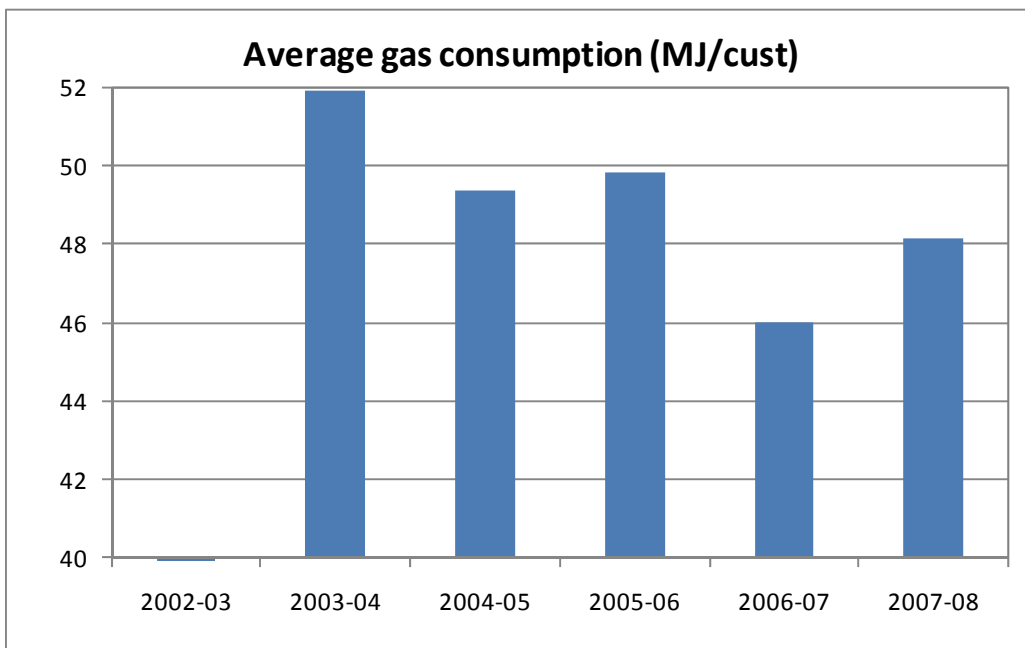


Figure 9: Average annual household (per gas customer) natural gas consumption.

Passenger car travels appears to have levelled off over the last 5 years, but the Bureau of Transport and Regional Economics still predicts the total passenger car equivalent kilometres to increase by 29% in Canberra between 2005 and 2020 (Bureau of Transport and Regional Economics 2007). The following two figures show the absolute and per capita passenger vehicle distances. There is a clear trend in reductions in average passenger vehicle distances per capita.

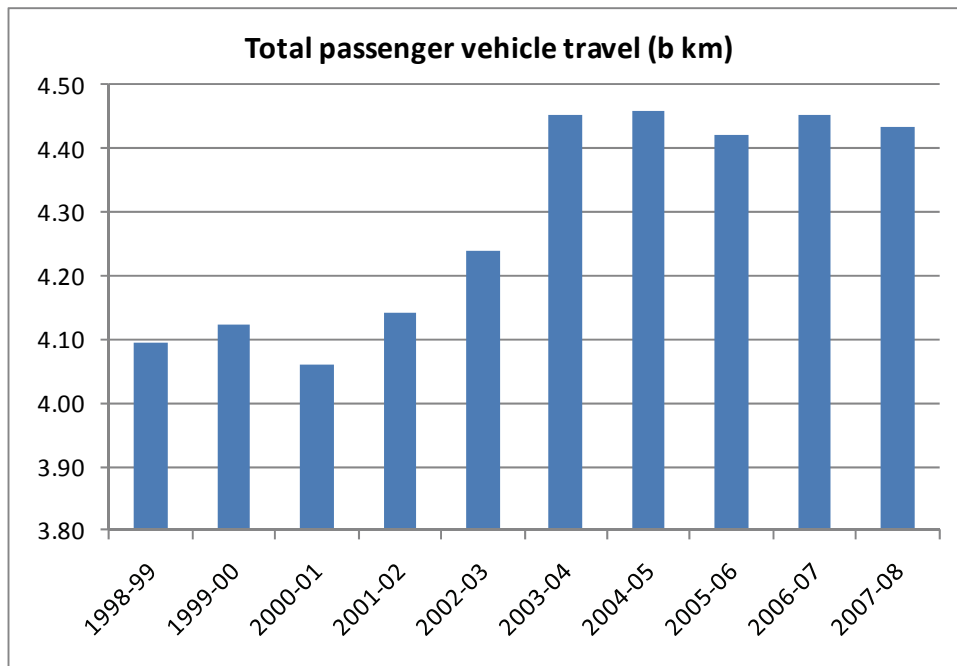


Figure 10: Total vehicle kilometres for ACT passenger vehicles.

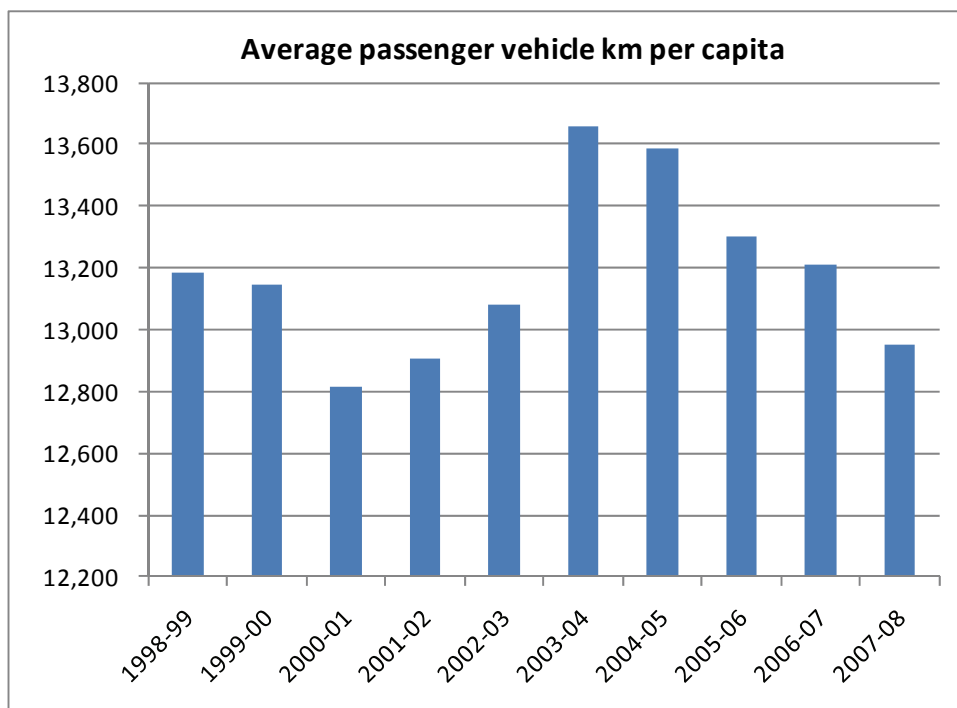


Figure 11: Average per capita vehicle kilometres for ACT passenger vehicles.

4.5. Conclusion

In 2008-09 the ACT Ecological Footprint was 9.2 global hectares (gha) per capita, a growth of approximately 8% from the ACT Ecological Footprint of 2003-04, which in turn was approximately 15% higher than the footprint in 1998-99. In 2008-09, the average ACT resident has a Ecological Footprint some 13% larger than the Australian average. The total Ecological Footprint of all ACT residents is approximately 3,200,000 global hectares, nearly 14 times the geographical area of the ACT. Fifty seven percent of the Ecological Footprint is “energy land” – which mainly reflects the biocapacity required to absorb carbon emissions. Nineteen percent of the Ecological Footprint is in Forests – primarily used within the residential construction industry. In comparison, only 3% of the ACT Ecological Footprint is in Built Land.

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

The ACT per-capita Ecological Footprint has grown steadily in the last 10 years, though at a slightly decreasing rate. It is clear that if ACT residents want to move away from having one of the highest Ecological Footprints in Australia they will need to make changes in their consumption habits. Despite showing some positive trends in reducing electricity, gas and fuel use, which have contributed to a slight reduction in these components in the footprint, the significant increase in consumption has meant that the ecological footprint associated with Goods and Services has increased. This is the main driving force behind the overall increase in the ACT’s Ecological Footprint.

5. Mathematical exposition of the methodology

Some of the more popular studies dealing with the sustainability of cities are Ecological Footprints⁶. This concept adopts the idea of carrying capacity, and by inverting the standard carrying capacity ratio, seeks to characterise an area of land that is needed to sustain a given population indefinitely, wherever on earth this land is located. The obvious result of most Ecological Footprint calculations is that cities appropriate an area of productive land that by far exceeds their physical size, and that therefore they cannot be sustainable (Rees and Wackernagel 1996). While Ecological Footprints are an instructive educational resource for raising awareness about global unsustainability, they have been criticised, for example, because the aggregated form of the final value makes it difficult to understand the specific reasons for the unsustainability of the consumption of a given population (Rapport 2000), and to formulate appropriate policy responses (Ayres 2000); (Moffatt 2000); (Opschoor 2000); (van Kooten and Bulte 2000). Furthermore, Ecological Footprints on sub-national scales underestimate indirect requirements (Bicknell, Ball et al. 1998; Lenzen and Murray 2001). In this work, we therefore focused on providing a disaggregated description of the environmental impact of city dwellers, both in terms of impact types (fuel use, greenhouse gas emissions, land use, etc.) and consumption type (goods, services, energy, water etc.). Furthermore, we take into account indirect requirements from all upstream production layers by using input-output analysis.

5.1. Input-output analysis

Input-output analysis is a macroeconomic technique that uses data on inter-industrial monetary transactions to account for the complex interdependencies of industries in modern economies.

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

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

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

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

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 local input-output coefficients for the multi-regional modeling of a system of metropolitan areas.

In this work we use a different approach for regionalisation: we combine the national Australian input-output tables and national data on resource use and pollution (modified by regionalising some important effects) with regional household expenditure data. The assumption inherent in this approach is that products purchased by regional households are produced regionally and nationally using a similar production recipe.⁷ The technique of combining input-output and household expenditure data has been used previously by a number of authors⁸, with only one study (Moll and Norman 2002) applying this approach to cities.

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

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

⁸ See Herendeen, R. and J. Tanaka (1976). "Energy cost of living." Energy **1**: 165-178.
 , Herendeen, R. (1978). "Total energy cost of household consumption in Norway, 1973." Energy **3**: 615-630.
 , Herendeen, R., C. Ford, et al. (1981). "Energy cost of living, 1972-1973." Energy **6**: 1433-1450.
 , Peet, N. J., A. J. Carter, et al. (1985). "Energy in the New Zealand household, 1974-1980." Energy **10**(11): 1197-1208.
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 , Weber, C. and U. Fahl (1993). "Energieverbrauch und Bedürfnisbefriedigung." Energiewirtschaftliche Tagesfragen **43**(9): 605-612.
 , Aoyagi, M., Y. Moriguchi, et al. (1995). "Characteristics of households' energy consumption." Energy and Resources **16**(6): 59-67 (in Japanese).

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

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

The variables in Equation 1 are:

F Matrix of household factor requirements.

Its elements $\{F_{ij}\}_{i=1,\dots,f; j=1,\dots,g}$ describe the total amount of factor i required by household group j .

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

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

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, Kondo, Y., Y. Moriguchi, et al. (1996). "Analysis of the trend of CO₂ emission structure by consumption expenditures of households." Transactions of the Society of Environmental Science **9**(2): 231-240 (in Japanese).

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

\mathbf{Q}^{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}^{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 $s = 344$ commodities⁹ 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}^{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, infinitely. \mathbf{Q}^{emb} thus captures the *total factor requirements* of industries in the entire economy that are needed to produce commodities consumed by households. \mathbf{Q}^{emb} has dimensions $f \times s$.

\mathbf{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. \mathbf{Y} has dimensions $s \times h$.

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

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

The variables in equation 2 are:

\mathbf{Q}^{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}^{emb} , \mathbf{Q}^{ind} represents only factors used directly in each industry, but not in upstream supplying industries. \mathbf{Q}^{ind} has dimensions $f \times s$.

\mathbf{I} The unity matrix.

⁹ The so-called ISAPC sector classification is a non-confidential subset of the Australian Bureau of Statistics' 8-digit Input-Output Product Classification (IOPC8; Australian Bureau of Statistics (2001). Australian National Accounts, Input-Output Tables, Product Details, 1996-97. Canberra, Australia, Australian Bureau of Statistics.

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 technology¹⁰ – thus enables the translation of industrial factor multipliers \mathbf{Q}^{ind} into embodied factor multipliers \mathbf{Q}^{emb} .

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

5.2. Data sources

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

Surveys of industries, households and farms are not conducted in identical intervals. Hence, the input-output, household expenditure, resource use and pollution data refer to different years between 1998 and 2003. In order to minimise discrepancies, input-output and factor data was assembled for years closely around 1998-99, where data availability was best. Data were reconciled using RAS matrix balancing¹¹, and optimisation techniques¹². As a consequence, small

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

¹¹ Gretton, P. and P. Cotterell (1979). The RAS method for compiling input-output tables - Australian Bureau of Statistics experience. Eighth Conference of Economists, La Trobe University.

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

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 for the 1998-99 and 2003-04 years 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.

Due to changes in the timing of household expenditure surveys, no more recent comprehensive HES was available at the time of this report. Hence various sources are used to estimate the 2008-09 expenditures for Australia and the ACT. These include Housing Income Surveys, regional profiles of the ACT, and a time series of detailed State Accounts, which are consistent with the national accounts.

The household expenditure matrix Y was derived from the 1998-99 Household Expenditure Survey (Australian Bureau of Statistics 2000), while the direct requirements matrix A was constructed from the Australian input-output tables (Australian Bureau of Statistics 1999; Australian Bureau of Statistics 1999); see also (Lenzen 2001). The baseline year for the Ecological Footprint model is 1998-99, hence all prices were deflated to 1999 levels. To do this, the ABS published Consumer Price Index (Australian Bureau of Statistics 2006) was supplemented with Produce Price Indices (Australian Bureau of Statistics 2006) where necessary, and subsequently correlated with the HES data. Price indices were created at a state level, with the assumption that the published price indices in capital cities were similar across each respective state. The importance of state based price indices is particularly evident for such consumer items as automotive fuel, which not only forms a significant component of the population's Ecological Footprint, is also quite volatile over time and across locations.

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

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

¹² Tarancon, M. and P. Del Rio (2005). "Projection of input-output tables by means of mathematical programming based on the hypothesis of stable structural evolution." *Economic Systems Research* 17(1): 1-23.

Ecological Footprint data

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

Other data

State specific figures were taken from (Australian Greenhouse Office 2004). The full fuel-cycle emission factor for electricity in the ACT is 1.06 kg CO₂-e/kWh (Department of Climate Change 2010).

5.3. Uncertainties

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

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

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

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7. Glossary

Biocapacity:	the actual amount of land (and water) area available on Earth to support the resources required by human populations.
Ecological footprint:	the amount of biologically productive land required to support a population and absorb its waste (including and most importantly CO ₂ emissions).
Ecological Overshoot:	the current situation where the total Ecological Footprint of the Earth exceeds the available biocapacity.
Energy land:	the land equivalence required to absorb the CO ₂ emissions produced from combustion of fossil fuels.
GFN:	Global Footprint Network: an organisation with the aim of improving the science behind ecological footprint measurements and promoting more sustainable policy development around the world.
Global hectares (gha):	the unit of measurement of the ecological footprint, related to the average yield of which represent the average yield of all biologically productive areas on Earth.
HES:	Household Expenditure Survey from the Australian Bureau of Statistics (ABS), representing the most detailed information available on what Australian households buy.
Input-output analysis:	IOA is a well-developed macro-economic technique for understanding linkages in economies. The ISA group are world leaders in the application of IOA to sustainability issues.
ISA:	Integrated Sustainability Analysis (research group).