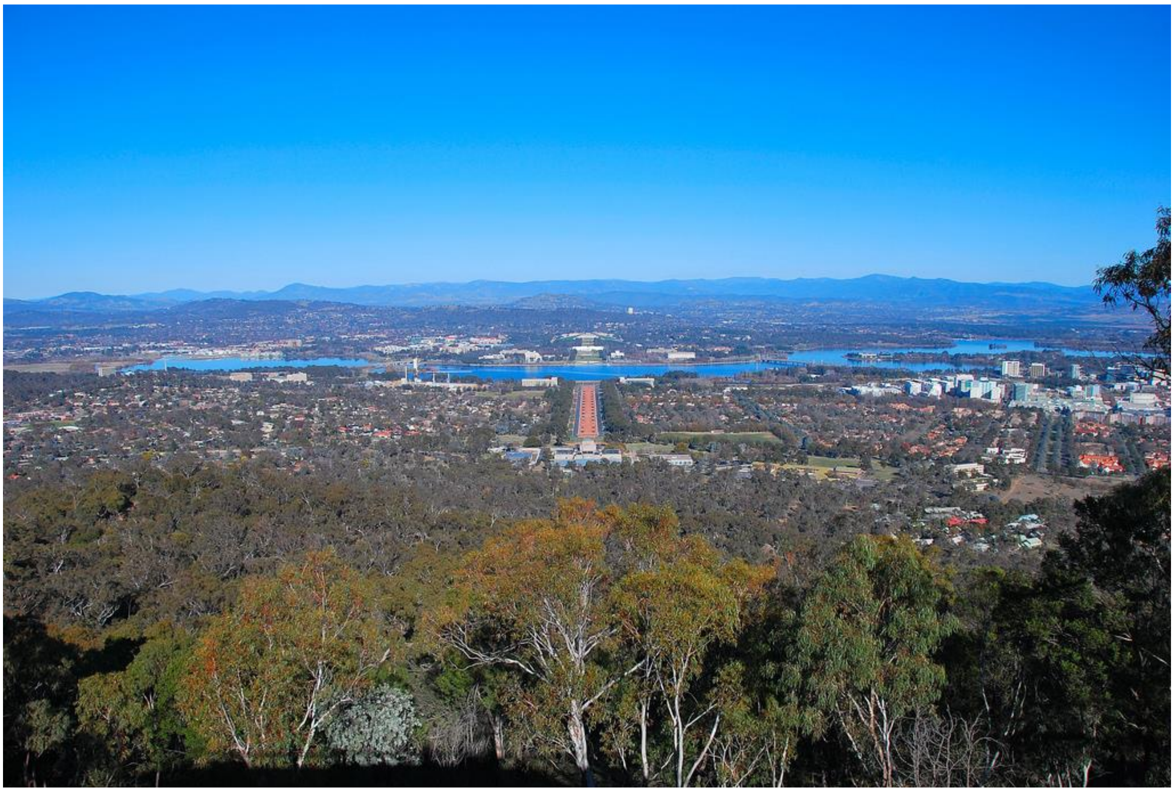
The 2011-12 Ecological Footprint of the population of the ACT



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The 2011-12 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 Australian Capital Territory (ACT). The Ecological Footprint is a concept for assessing the sustainability of resource use and pollution of households, cities, and entire nations. Applied to households as it is here, the Ecological Footprint represents the land area equivalence (in hectares) of all the resources required to support the lives of the people in the households, and to absorb their pollution. Although reduced to a single indicator, the Ecological Footprint is a powerful concept when various population results are 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 greenhouse gas emissions faster than they can be absorbed (WWF 2014).

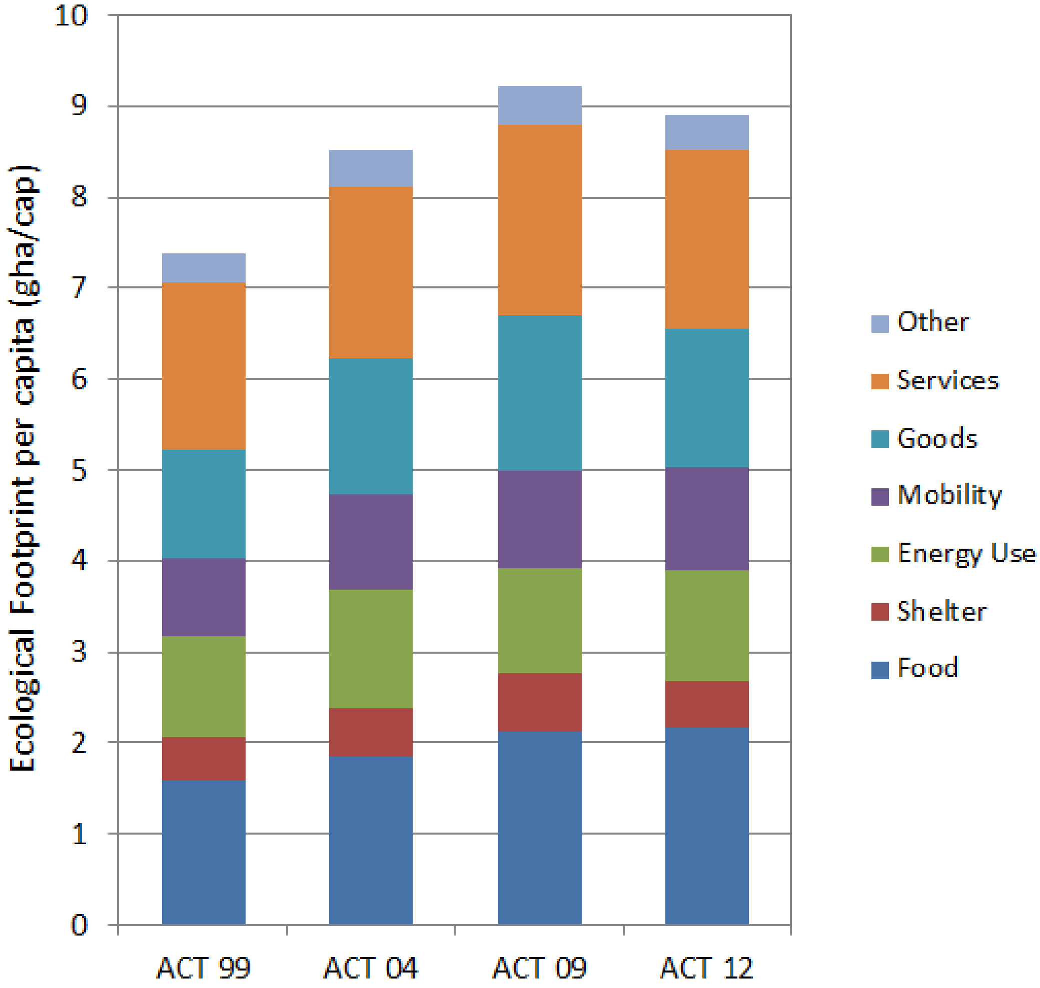
In the calculation of the Ecological Footprint of populations, consumption data are converted into a single index: the land area that represents the exclusive demand that a population places on Nature's services (often called 'bioproductivity') in order to sustain itself indefinitely. Since the method's conception, many research teams around the world have carried out significant modifications and improvements to the Ecological Footprint concept. Two of these improvements 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 viewpoints 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 finding in this report are that the average Ecological Footprint of a person living in the ACT in 2011-12 is 8.9 global hectares (gha). With the population at the time of around 375,000 people, this amounts to a total area of approximately 3,300,000 global hectares, roughly fourteen times the land area of the ACT. This figure includes all upstream impacts, capital requirements, government and import effects. That the Ecological Footprint of the ACT is many times larger than its administrative area reflects the fact that the full impacts of a given population's consumption go well beyond arbitrary borders, drawing on land areas all over Australia and around the World.

ISA has also previously calculated the Ecological Footprint of the ACT for 1998-99, 2003-04 and 2008-09. Although there have been changes in the Ecological Footprint calculation methodology over the last decade, this times series of results is broadly comparable. After a growth in the ACT per-capita Ecological Footprint between 1998-99 and 2008-09 of over 20%, the footprint for 2011-12 is 3% lower than for the previous period. For comparison, in 2011-12 the average Australian's Ecological Footprint was 8.2 gha, or about 9% lower than that for the average resident of the ACT.

The graph on the following page shows the Ecological Footprint results for the ACT for the four years as well as the main components of the footprints. The fall in the 20011-12 footprint is noteworthy: going against continual growth for many years. There are many reasons for this change in total footprint, and not all the drivers and reasons for the change will be apparent until further work is done and future footprints performed. Direct energy use (electricity, natural gas and to a lesser extent transport fuels) have been steady or falling in the ACT in the last 8-10 years, and are projected to fall significantly over the next 5 years.

However, the main determinant of most footprints is the level of household consumption. The aftermath of the global financial crisis and lower economic growth has led to slower rises in household incomes in the last five years. In addition, and probably because of this, household saving rates in Australia have increased, meaning that household expenditure levels have decreased. In turn this reduces the overall footprint resulting from the consumption of goods and services.



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

2. Project background

2.1. The Ecological Footprint

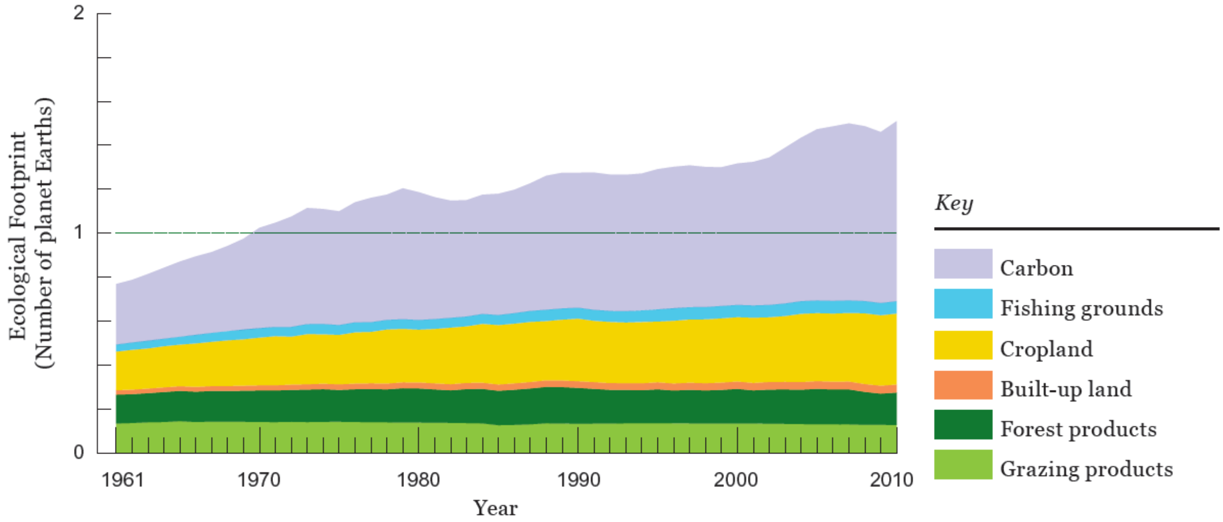
The Ecological Footprint is a method aimed at measuring the sustainability of resource use and pollution of populations. Consumption data are converted into a single index: the land area that represents the demand that a population places on the Earth's bioproductivity in order to sustain itself indefinitely. 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). In 2010, this had fallen to 1.7 gha per person (WWF 2014). 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 2010), with the latest figure being 2.6 gha for 2010 (WWF 2014). But as this exceeds the 1.7 gha per person available, it would take 1.5 years to regenerate what humanity consumes in a year. So, in other words, average resource consumption globally results in an 'ecological overshoot' of about 50%. The figure below clearly shows this growing *unsustainability* of the impact of humans on the planet (WWF 2014).



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 2011-12 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 2011-12.
- 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 2011-12 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 (gha = 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 years[8], and is the most robust approach of assessing environmental impacts of populations.

Final Ecological Footprints are based on a static, single-region, open, basic-price, industry-by-industry input-output model of the domestic Australian economy, coupled with an extensive database on environmental indicators.[1] The methodology has been successfully employed in a

[1] Foran, B., 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.

, ibid.

With a summary in Foran, B., 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.

range of Australian company and government applications, a pilot program on triple 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 meaningless[3], or the result for a single population being significantly underestimated. In addition, the aggregated form of the final Ecological Footprint makes it difficult to understand the specific reasons for the unsustainability of the consumption of a given population (Rapport 2000), and to formulate appropriate policy responses (Ayres 2000); (Moffatt 2000); (Opschoor 2000); (van Kooten and Bulte 2000). In response to the problems highlighted, the concept has undergone

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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 where land clearing may be an important source of emissions (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, Petroeschevsky et al. 2000), (Lenzen and Murray 2001).

The original Ecological Footprint is defined as the land area that would be needed to meet the consumption of a population and to absorb all their waste (Wackernagel and Rees 1996). 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, Petroeschevsky et al. 2000) all areas of land were included, irrespective of their productivity.

3.4. Input-output-based Ecological Footprinting

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

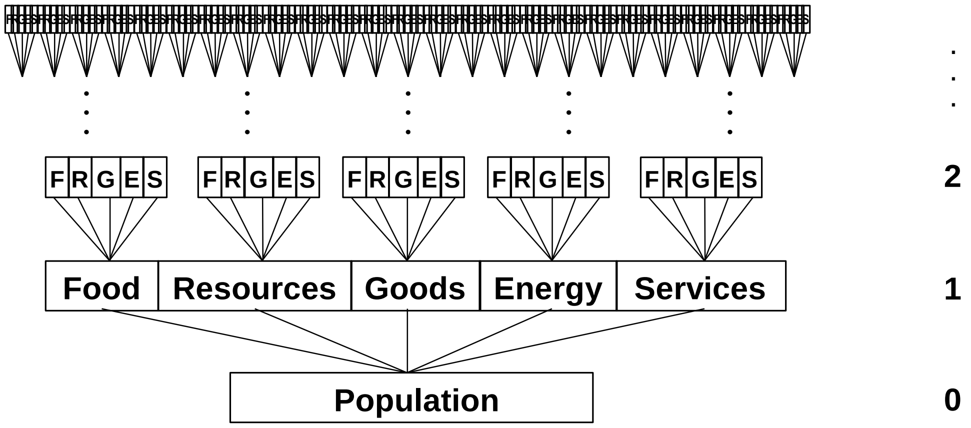

Figure 1: Industrial interdependence in a modern economy: a "tree" of upstream production layers.

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

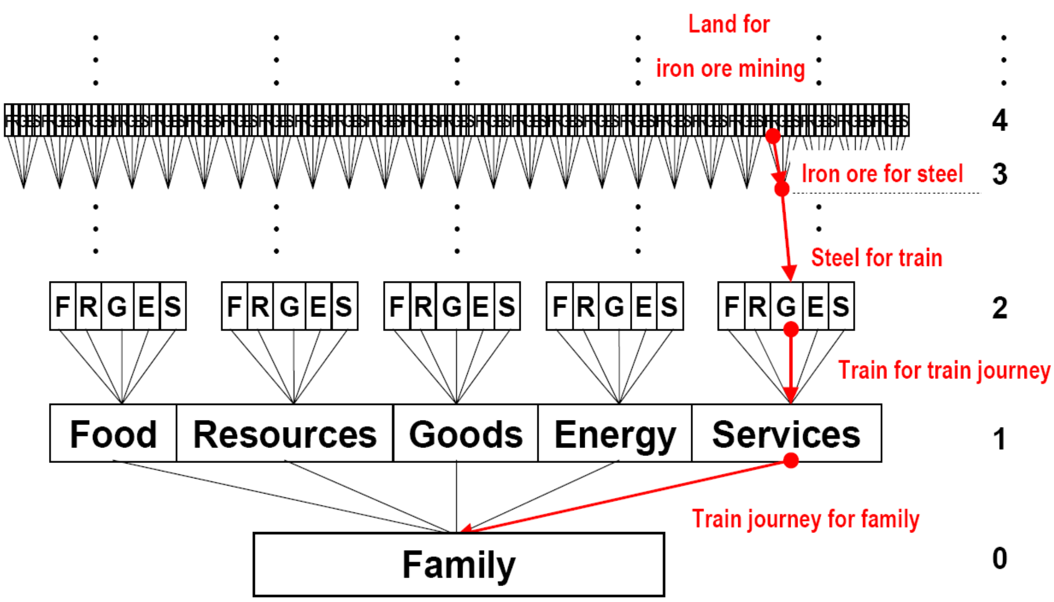

Figure 2: An example of production layers and input paths in Ecological Footprint calculations.

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

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

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

, Bagliani, M., et al. Ibid.Ecological footprint and input-output methodology: the analysis of the environmental sustainability of the economic sectors of Piedmont Region (Italy), Internet site http://www.io2002conference.uqam.ca/abstracts.pdf.

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

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

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

, 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.

, 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.

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). More recently, attempts have been made to standardised the Ecological Footprint methodology (http://www.footprintstandards.org/), with a strong focus on benefits of using 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 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

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

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

, Wiedmann, T., et al. Ibid.Multiregional input-output modelling opens new opportunities for the estimation of Ecological Footprints embedded in international trade, BRASS Research Centre, Cardiff University.

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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 CO_2-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, 2003-04 and 2008-09 to this current report, ISA datasets on consumption practices in the ACT have 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 2011-12, it is estimated that the average ACT resident had an Ecological Footprint of 8.9 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 2012 footprint is 9% higher than the Australian average (8.2 gha) in 2011-12, which is in turn well up from the average in 2004.

The 2012 total Ecological Footprint of 3.3 million global hectares is approximately 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 12				
		Ecological Footprint ('000 gha)				
Cropland	**Pasture**	**Forests**	**Energy land**	**Built land**	**Water**	**TOTAL**
427	374	542	1,902	85	1	3,330
		AUS 12				
		Ecological Footprint ('000 gha)				
Cropland	**Pasture**	**Forests**	**Energy land**	**Built land**	**Water**	**TOTAL**
24,969.56	21,277	30,437	106,259	4,374	42	187,359
		ACT 12				
		Ecological Footprint (gha / cap)				
Cropland	**Pasture**	**Forests**	**Energy land**	**Built land**	**Water**	**TOTAL**
1.14	1.00	1.45	5.08	0.23	0.00	8.9
		AUS 12				
		Ecological Footprint (gha / cap)				
Cropland	**Pasture**	**Forests**	**Energy land**	**Built land**	**Water**	**TOTAL**
1.09	0.93	1.33	4.63	0.19	0.00	8.2

Table 1: The Ecological Footprint of the ACT and the whole of Australia by land type for 2011-12. Results are shown at the top in absolute terms (thousands of global hectares, '000 gha) and then lower down as per-capita figures (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 (5% and 4% respectively each of the total, see further below). In terms of "Real Land", the forest Footprint has the largest contribution with about 14% of the total Ecological Footprint (down a few percent from the last report). This largely reflects the use of wood for construction and for heating.

5 Refer Section 3.5

The Ecological Footprint on farming lands (Cropland and Pasture) in the ACT (1.14 and 1.0 gha respectively) is slightly higher than for the average Australian (1.09 and 0.93 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 26% of the ACT Ecological Footprint, compared to 24% of the Australian Ecological Footprint. Built land contributes only 2.5% 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 ACT footprint in 2003-04 was 8.5 gha rising to 9.2 gha in 2008-09, before falling slightly to 8.9 gha for the most recent year. The average Australian had a per-capita Ecological Footprint of 7.3 gha in 2003-04 (not shown in graph), rising to 8.2 in 2011-12.

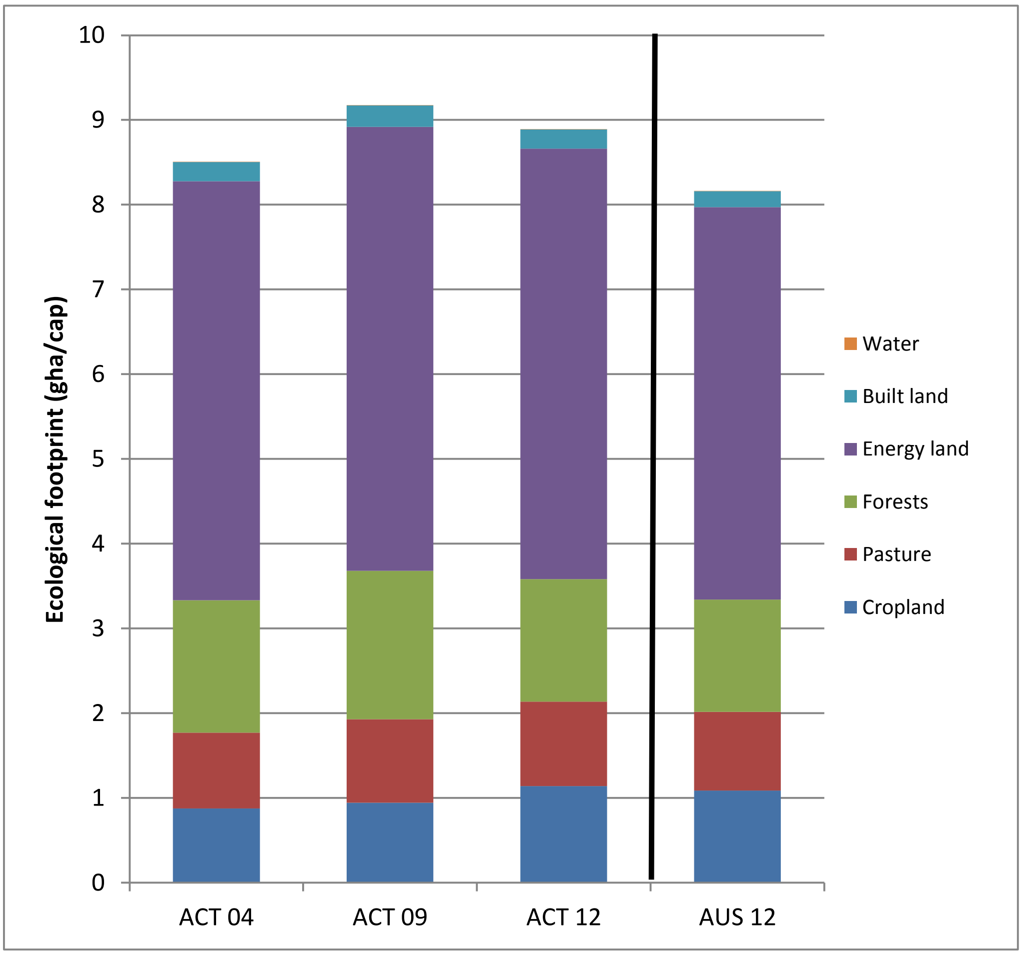

Figure 3: The time series of per-capita Ecological Footprints of the ACT compared to the average Australian's footprint for 2011-12.

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.

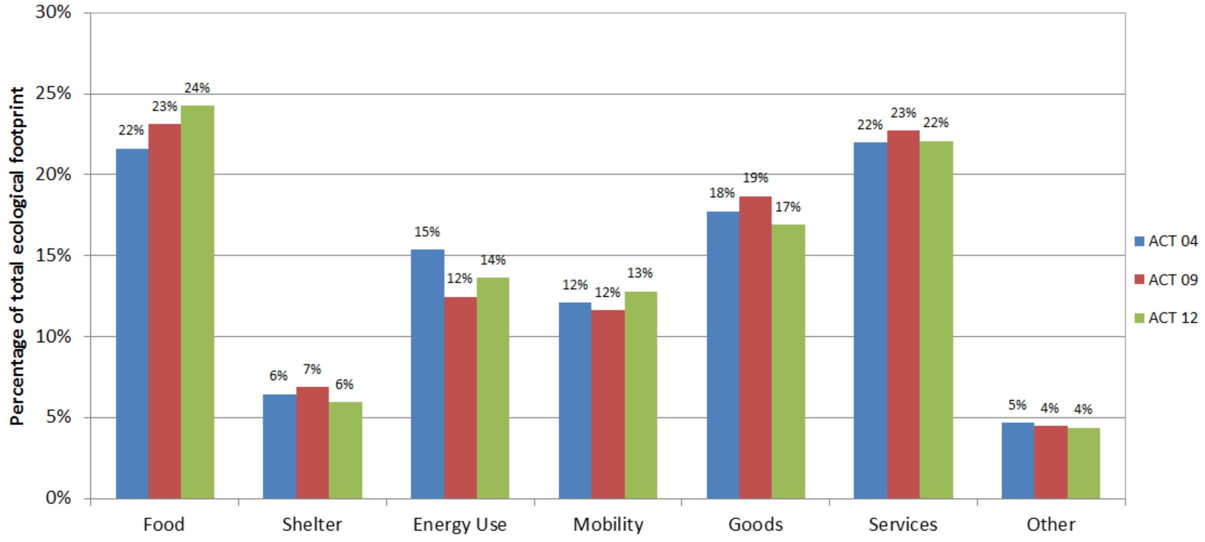

Figure 4: Comparison of Ecological Footprint consumption categories for the ACT for past three periods.

Using these categories, the consumption of food and the demand for services have the most significant Ecological Footprint. Fifty four percent of the food impact (1.2 gha) is due to plant based food products, whilst the remainder (1.0 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 of the economy (which mainly represent services). No clear pattern is evident in energy use impacts, although energy use per capita is not increasing substantially, even as per capita incomes continue to rise, emissions coefficients for electricity have increased. Overall, the changes in the percentages of impacts between the different consumption categories are not significant. The average lifestyle of an ACT resident has not changed substantially in the eight years between the breakdowns shown in Figure 4.

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).

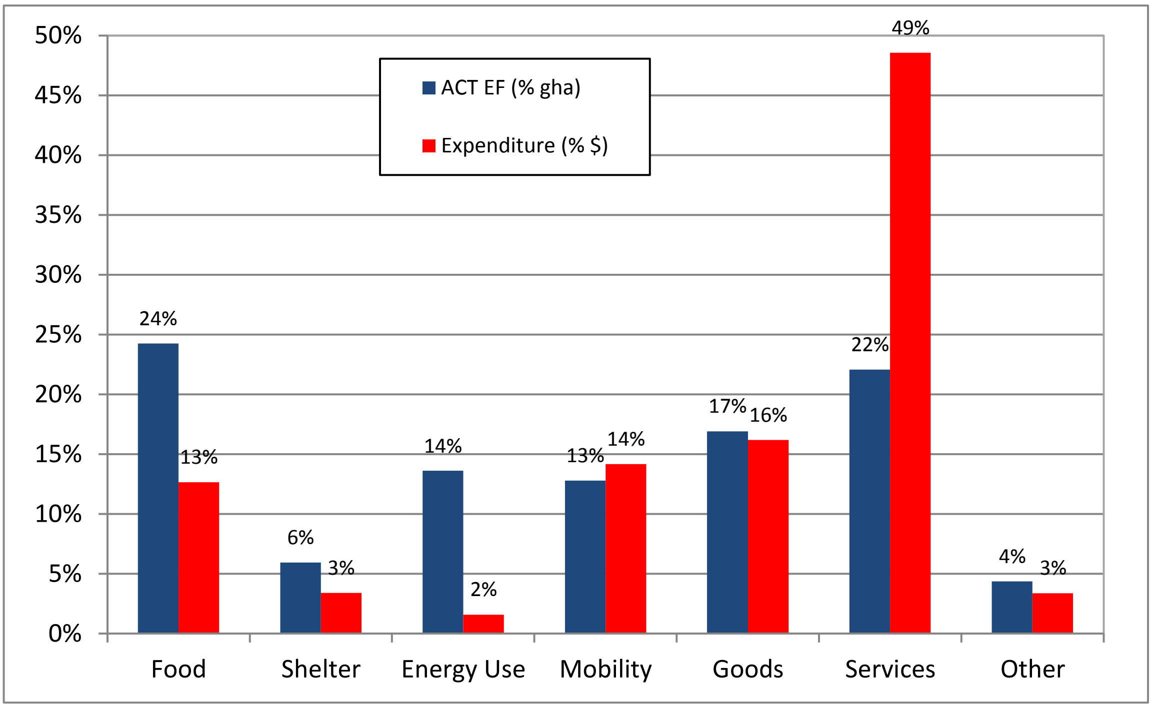

Figure 5: Comparison of consumption categories by EF and Expenditure for ACT 2011-12.

Hence, whilst food accounts for about 24% of the ACT Ecological Footprint, it is due to only roughly 13% of an ACT resident's expenditure ("Expenditure" on food includes meals out). In significant contrast, is the expenditure on services, making up almost 50% of total expenditure, but having an impact of 22% of the total.

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 an individual might take action to achieve an efficient reduction in their Ecological Footprint.

Rank	Commodity	Impact (gha/capita)	% of Total
1	Electricity supply	1.01	12%
2	Hotels, clubs, restaurants and cafes	0.46	6%
3	Petrol	0.41	5%
4	Gas supply	0.33	4%
5	Air and space transport	0.31	4%
6	Other food products	0.23	3%
7	Ownership of dwellings	0.22	3%
8	Beer and malt	0.19	2%
9	Clothing	0.19	2%
10	Wooden furniture	0.18	2%
11	Finished cars	0.18	2%
12	Beef cattle	0.17	2%
13	Education	0.16	2%
14	Non-building construction	0.14	2%
15	Non-residential building construction	0.14	2%
16	Electronic equipment	0.13	2%
17	Recorded media and publishing nec	0.12	2%
18	Wheat	0.12	1%
19	Joinery products	0.12	1%
20	Meat products	0.12	1%
21	Community services and religious organisations	0.12	1%
22	Accommodation	0.11	1%
23	Cakes	0.11	1%
24	Federal government	0.10	1%
25	Fresh meat	0.09	1%

Table 2: Top 25 commodities in terms of per-capita Ecological Footprint in the ACT in 2011-12.

These first twenty-five out of the 300 commodities account for two thirds (67%) 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% (1.01 gha) to each person's Ecological Footprint every year. The ACT is expanding its renewable electricity capacity, but for the year of this report, this new capacity is not yet on line. Hence the ACT is reliant on relatively highly emissions intensive power stations in adjacent states. On the consumption side of electricity, the trend with household electricity is for average residential consumption per customer continuing to decrease to 7.7 MWh in 2011-12, which was down from 8.8 MWh in 2003-04 (ACT Independent Competition and Regulatory Commission 2009) and (ICRC 2014)

The second biggest single component of the Ecological Footprint is created by meals out (hospitality) followed by petrol for transport. Although electricity use is falling (see later figures), car use in the ACT is static or slightly increasing. Building, construction and repairs in the ACT together add around 0.4 global hectares to each person's Ecological Footprint every year. In this case it is dominated by the land area needed to grow timber and produce minerals used for construction as well as the carbon footprint of generating energy used in construction that creates this Footprint impact.

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). However, the later few years have seen a steadying of this growth in income, and therefore also a slower rate of expenditure growth (Figure 6).

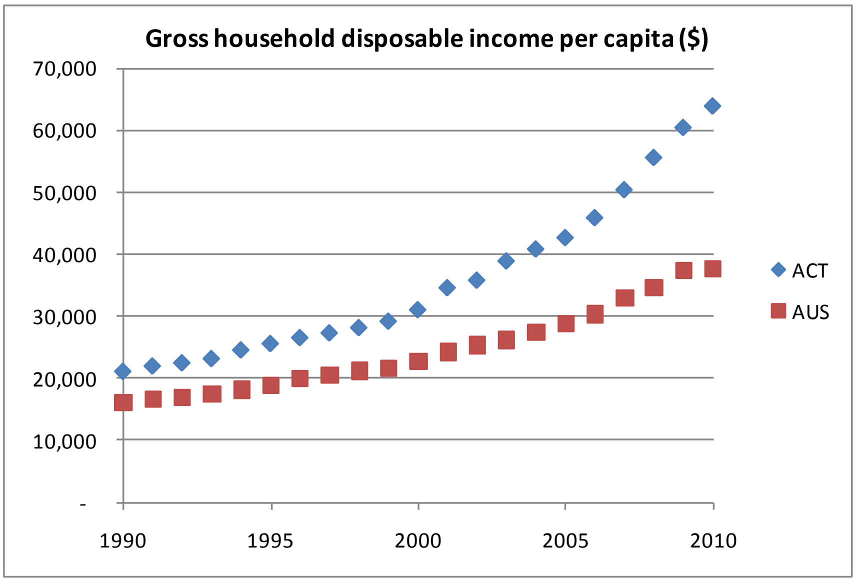

Figure 6: Average gross household disposable income per capita for Australian and the ACT.

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. Increasing saving rates, a generally less optimistic consumer outlook have both combined to lead to smaller increases in expenditures. In turn these changes result in the ecological footprints for the ACT (and Australia) being more stable over the last five years.

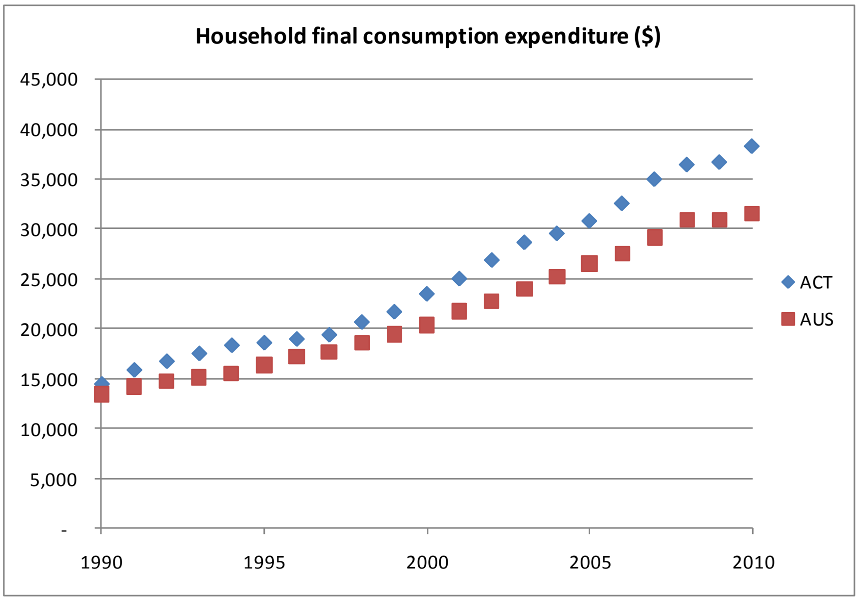

Figure 7: Comparison of average final consumption expenditure.

There has been a steady fall in electricity use per household each year from 2003-04 to 2011-12 (ICRC 2014), shown in Figure 8. The difference between these two periods amounts to a 20% reduction in emissions (Department of Climate Change 2010), although some of the agree emissions factors have changed over the periods. Residential natural gas usage per household from 2003-04 to 2011-12 does not follow a clear trend, more than likely reflecting the severity of the winters from year to year (Figure 9). Whilst the annual gas data appears to fluctuate more than the electricity usage, there is a general trend towards increasing use of natural gas overall, with the number of residential gas customers increasing by 20,000 in the last ten years or so.

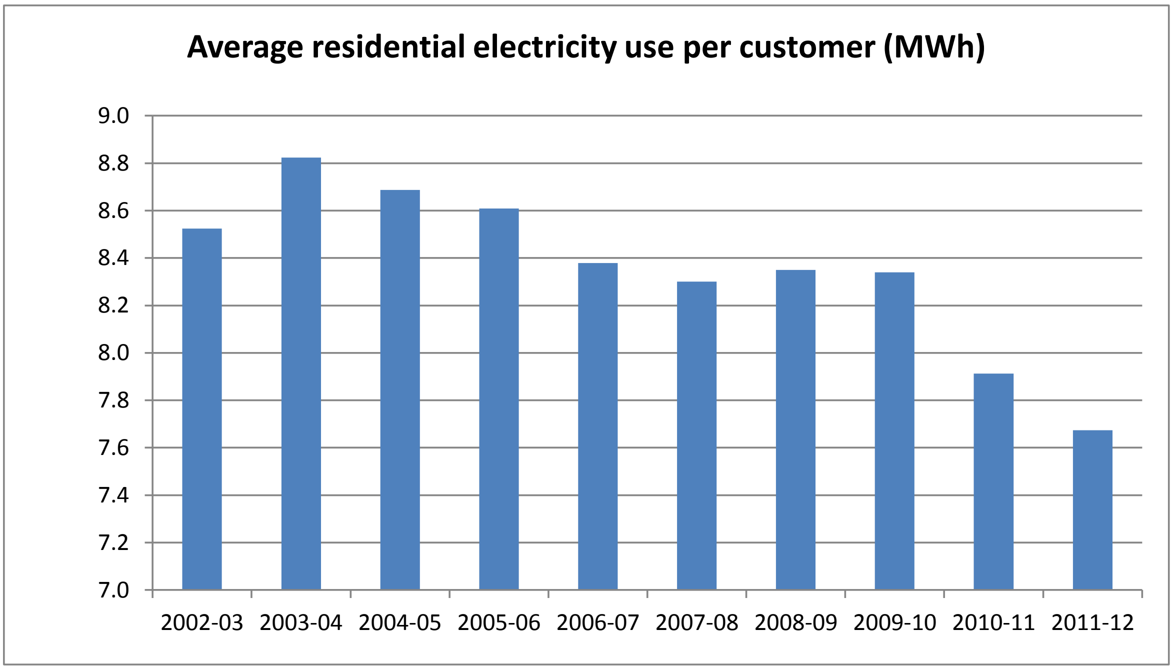

Figure 8: Average annual household electricity consumption. Emissions from electricity are flatter as the emissions coefficients have increased.

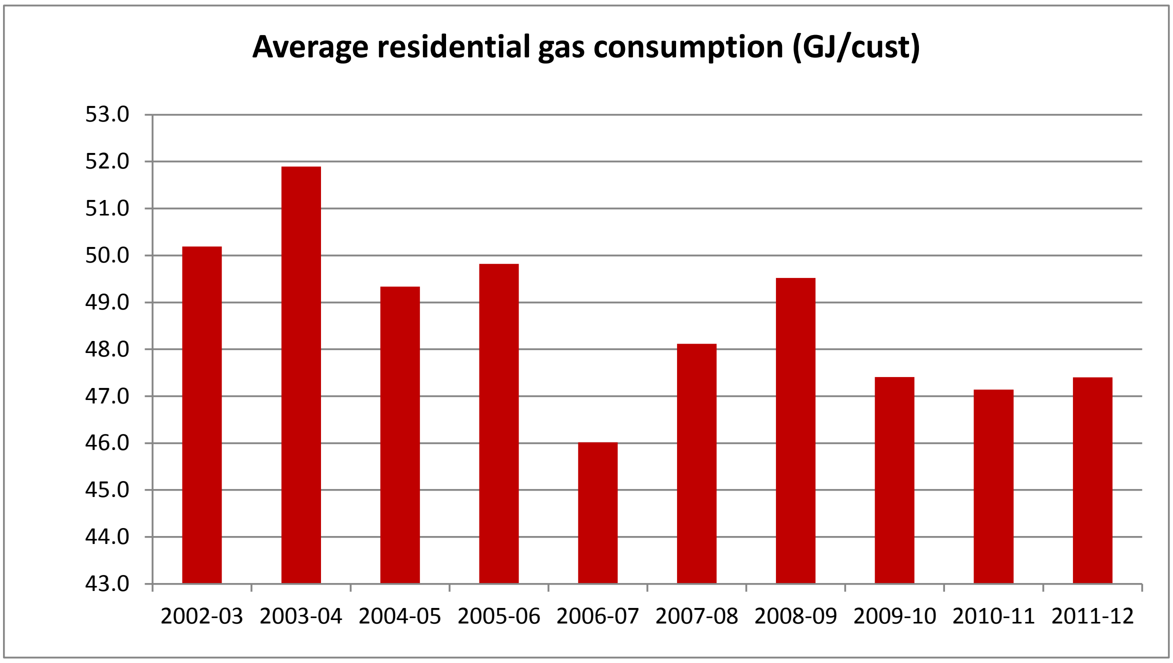

Figure 9: Average annual household (per gas customer) natural gas consumption.

Passenger car travels appears to be increasing over the last five years after having levelled off over the 5 years before that (Figure 10). , 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), (Bureau of Transport and Regional Economics 2015). 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, but the number of vehicles is increasing.

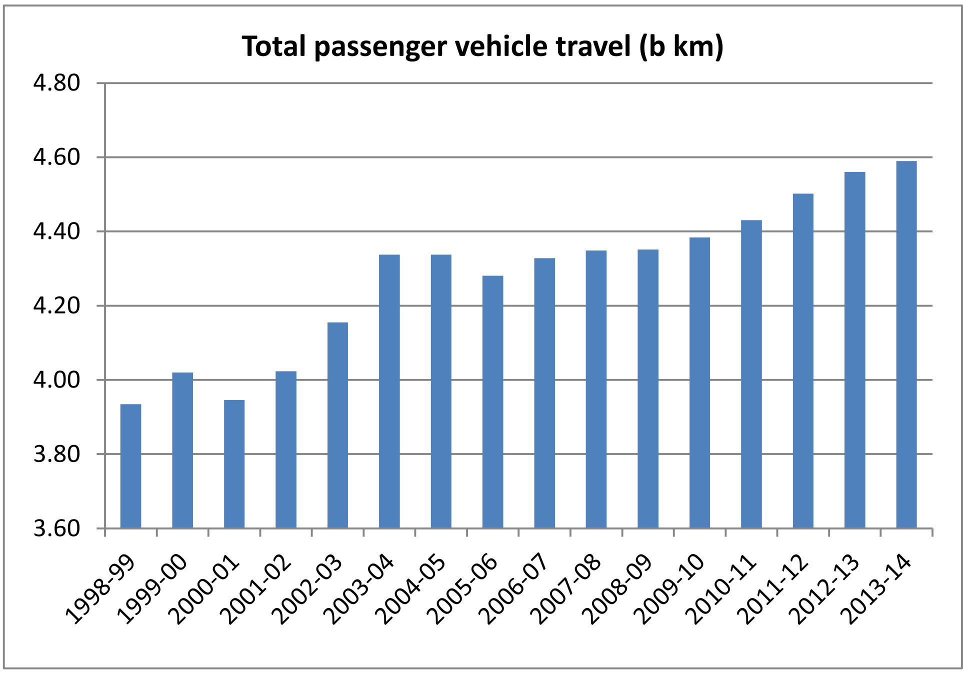

Figure 10: Total vehicle kilometres for ACT passenger vehicles (billions of km).

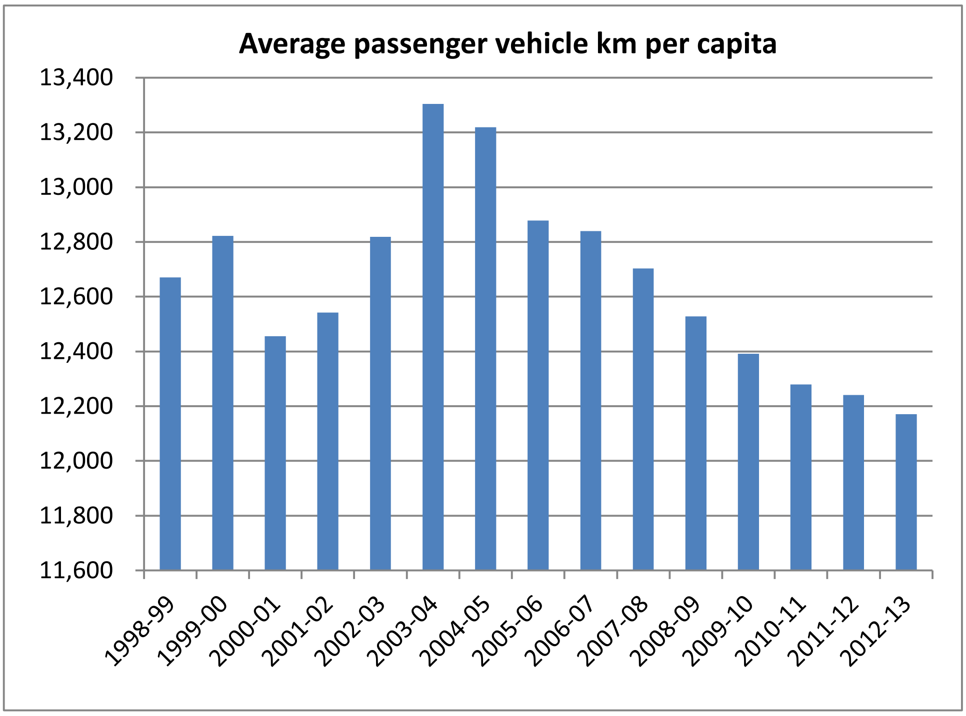

Figure 11: Average per capita vehicle kilometres for ACT passenger vehicles.

4.5. Conclusion

In 2011-12 the ACT Ecological Footprint was 8.9 global hectares (gha) per capita, a reduction of approximately 3% from the ACT Ecological Footprint of 2008-09. The ten years prior saw a very last increase in footprint, so the fall in the current numbers is noteworthy. In 2011-12, the average ACT resident has a Ecological Footprint some 9% larger than the Australian average. The total Ecological Footprint of all ACT residents is approximately 3,300,000 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. Sixteen percent of the Ecological Footprint is in Forests – primarily used within the residential construction industry. In comparison, less than 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, hospitality, petrol and natural gas use, aviation, housing and then a range of goods and services.

It is significant that the ACT per-capita Ecological Footprint has fallen slightly, after a period of 15-20 years over which it steadily increased (and particularly in the ten years from 1998-99). It will take some further research to determine the various driving factors (accelerators and retardants) which will adequately explain this behaviour fully. Furthermore, to firmly establish if this trend will continue requires new household expenditure data (due in a few years) to be analysed.

It is clear that if ACT residents want to move away from having one of the highest Ecological Footprints in Australia. The recent large investments in renewable energy could start to be seen as significant reductions in the energy land component (currently more than half the total footprint) in the near future.

5. Mathematical exposition of the methodology

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

5.1. Input-output analysis

Input-output analysis is a macroeconomic technique that uses data on inter-industrial monetary transactions to account for the complex interdependencies of industries in modern economies. Since its introduction by (Leontief 1936, Leontief 1941), it has been applied to numerous economic

[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., 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.

, Santiago de Chile Wackernagel, M. Ibid."The ecological footprint of Santiago de Chile." (1): 7-25.

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

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

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

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

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

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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 authors[8], with only one study (Moll and Norman 2002) applying this approach to cities.

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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." Ibid. **3**: 615-630.

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

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

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

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

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

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

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

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

The variables in Equation 1 are:

F Matrix of household factor requirements.

Its elements $\{F_{ij}\}_{i=1,\ldots,f\,;\,j=1,\ldots,g}$ describe the total amount of factor *i* required by household group *j*. The term *factor* represents resource and Ecological Footprint components (land disturbance; fuel consumption; greenhouse gas emissions). **F** comprises (1) factors $\mathbf{Q}^{\text{hh}}\times\mathbf{Y}$ 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.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$\mathbf{Y}$ Matrix of household expenditure.

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

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

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

The variables in equation 2 are:

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

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

$\mathbf{I}$ The unity matrix.

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

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[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.

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A Matrix of direct requirements.

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

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

5.2. Data sources

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

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

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[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.

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[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." Ibid. **17**: 1-23.

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flows (monetary and physical) are associated with large uncertainties, as indicated in some of the results sheets.

Household Expenditure Survey data

Due to changes in the timing of household expenditure surveys (HES), no more recent comprehensive HES was available at the time of this report than the 2009-10 survey. Hence various sources are used to estimate the 2011-12 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 2009-10 Household Expenditure Survey (Australian Bureau of Statistics 2011), while the direct requirements matrix A was constructed from the Australian input-output tables over many years eg. (Australian Bureau of Statistics 1999, Australian Bureau of Statistics 1999); see also (Lenzen 2001). 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 sources refer to various financial years. Since petrol and gas prices and tariffs may have experienced high variability, which has to be accounted for by continuously and manually adjusting intensities in order to keep them up-to-date. The most accurate way of doing this is to proceed as follows:

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

Ecological Footprint data

The industrial Ecological Footprint multipliers $\mathbf{Q}_{\mathrm{ef}}^{\mathrm{ind}}$ as well as household Ecological Footprint multipliers $\mathbf{Q}_{\mathrm{ef}}^{\mathrm{hh}}$ were obtained by consulting a range of sources such as fuel statistics (Australian Bureau of Agricultural and Resource Economics 1999), (Australian Bureau of Agricultural and Resource Economics 2000), the Australian National Greenhouse Gas Inventory (Australian Greenhouse Office 1999), (George Wilkenfeld & Associates Pty Ltd and Energy Strategies 2002), the ABS' Integrated Regional Database ((Australian Bureau of Statistics 2001), and a CSIRO report on landcover disturbance across the Australian continent (Graetz, 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 $\Delta Q_{ij}^{\mathrm{emb}}$ of elements in the embodied factor multiplier matrix $\mathbf{Q}^{\mathrm{emb}}$ due to the above sources defy analytical treatment, and can therefore only be determined using stochastic analysis. The $\Delta Q_{ij}^{\mathrm{emb}}$ can be calculated by Monte-Carlo simulations of the propagation of normally distributed perturbations from $\mathbf{Q}^{\mathrm{ind}}$ and $\mathbf{A}$ through to $\mathbf{Q}^{\mathrm{emb}}$ (see (Lenzen 2001). Given the standard errors $\Delta\left(Q^{\mathrm{emb}} + Q^{\mathrm{hh}}\right)_{ik}$ of $\mathbf{Q}^{\mathrm{emb}} + \mathbf{Q}^{\mathrm{hh}}$, and ΔY_{kj} of $\mathbf{Y}$, the total standard error ΔF_{ij} of an element F_{ij} in the household factor requirement $\mathbf{F}$ in Equation 1 is

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

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

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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.

Office of the Commissioner for Sustainability and the Environment

Ecological Footprint for the ACT: Our Challenge

Key findings of the ACT 2008-09 ecological footprint

- 9.2 global hectares was the size of the average ACT resident's ecological footprint in 2008-09. The footprint has increased by 8% in 5 years and nearly 25% in 10 years.
- Our recent ecological footprint was 13% above the Australian average and nearly 3.5 times the global average.
- We used 14 times the land area of the ACT to support our lifestyles.
- If everyone in the world lived in the same way as the average person in the ACT, we would need 5 Earths to give us enough land (and surface water) to provide our resources and absorb our wastes. Yet, we only have one earth!

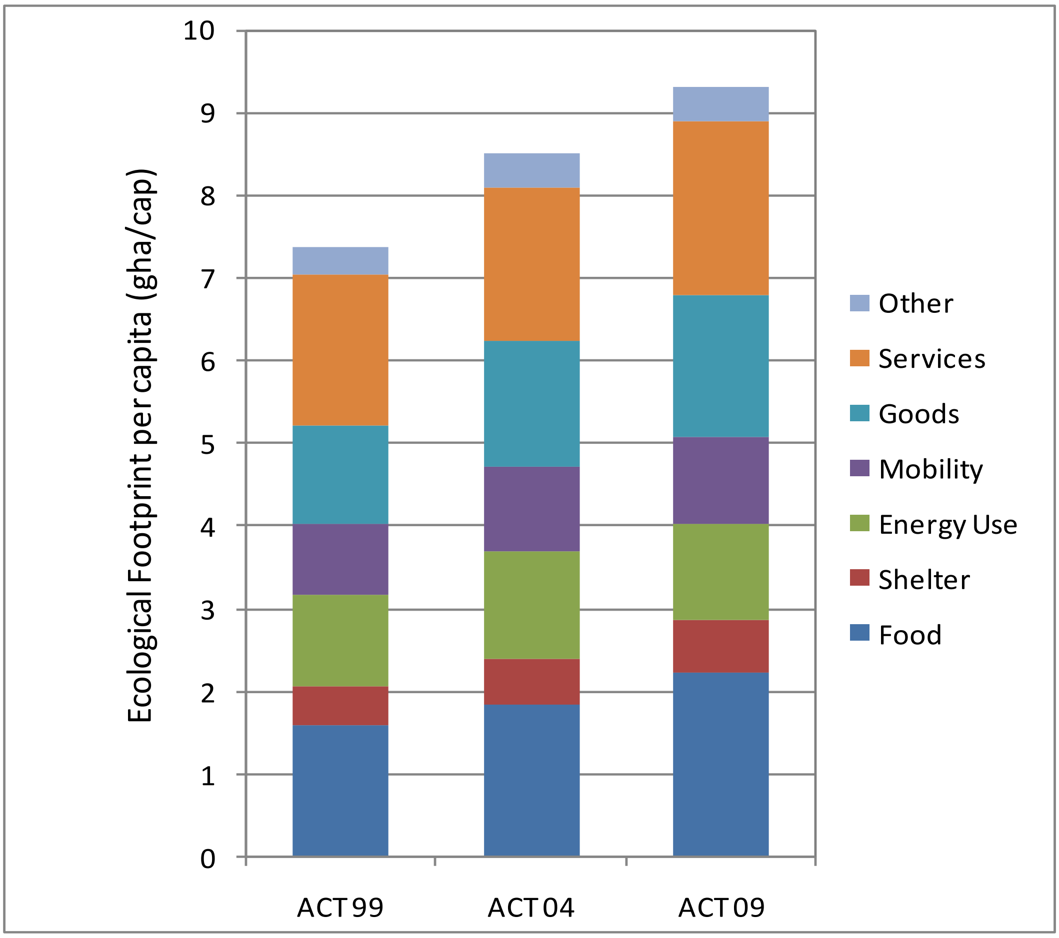

Fig 1. Per capita ACT footprint for 1998-99, 2003-04 and 2008-09

What is an ecological footprint?

An ecological footprint is a calculation of the amount of land and water required to support our use of resources and disposal of our wastes. It provides a calculated measure of the extent of human impact on the earth, helping us understand the link between our lifestyles and the environment. It provides us with a means by which to determine our relative consumption of global resources and thereby assist us in assessing the sustainability – or not - of our lifestyle.

The ecological footprint is expressed in 'global hectares'. The average world ecological footprint in 2007 was 2.7 global hectares per person, which is the equivalent of needing 1.5 Earths to support the global population's current consumption. Put another way, it took the Earth approximately a year and a half to regenerate the resources used by humanity in 2007[1]. This figure includes only the land needed to support the human population; it does not ensure sufficient natural resource to support other species.

Why is our ecological footprint so high?

The ACT's ecological footprint means that 9.2 global hectares per person of land (and surface ocean) is needed to support each person in the ACT; this includes the raw material for food, building, energy, etc. as well as the area needed to absorb our waste including the carbon dioxide emitted due to ACT residents' consumption. This includes land inside the ACT such as offices and homes, as well as land outside such as that used to grow food consumed in the ACT.

In our case, the calculation draws attention to the unsustainability of the current quantity and nature of our consumption.

The nature of and increase in our consumption per person is driving the increase in our footprint. Our consumption of food and demand for services (including financial, telecommunications, medical, entertainment and government services) has a significant effect on our footprint (see Fig 2). The contribution from our consumption of goods (other than food) is growing, while the contribution from services (albeit high overall) has also declined slightly (less than 5%).

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[1] http://www.footprintnetwork.org/images/uploads/Ecological%20Footprint%20Atlas%202010.pdf p18

Fig 2. Comparison of ecological footprint consumption categories for the ACT for the three years.

We have seen a very small decrease (less than 5%) in the direct energy (primarily electricity and gas use) used per person between 2003-04 and 2007-08. Some of this may be explained by an increase in the volume of GreenPower sold in the ACT, (rising from 28.7 GWh in 2003–04 to 103.6 GWh in 2007–08[2]) and a small decrease in residential annual electricity consumption per customer (from 8.8 MWh in 2003–04 to 8.3 MWh in 2007–08[3]). Despite this, electricity remains the largest single factor affecting our footprint making up 12% (1.07 global hectares) of each person's footprint. It is significant that energy use has a considerable impact on our footprint yet we spend a relatively small proportion of our income on energy use (see Fig 5).

The second biggest contributor is new (and renovated) houses, flats and other residential buildings; making up 6% (0.56 global hectares) or each person's footprint.

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[2] Independent Competition and Regulatory Commission, *ACT Licensed utilities compliance and performance report 2007–08* http://www.icrc.act.gov.au/__data/assets/pdf_file/0019/156016/Compliance_and_Performance_Report_2007-08_Web.pdf

[3] Independent Competition and Regulatory Commission, *ACT Licensed utilities compliance and performance report 2007–08* http://www.icrc.act.gov.au/__data/assets/pdf_file/0019/156016/Compliance_and_Performance_Report_2007-08_Web.pdf

Rank	Commodity	Group	Impact (gha/capita)	% of total
1	Electricity supply	Energy	1.07	12
2	Residential building construction	Shelter	0.56	6
3	Retail trade	Services	0.51	6
4	Hotels, clubs, restaurants and cafes	Services	0.44	5
5	Air and space transport.	Energy	0.35	4
6	Petrol	Energy	0.32	4
7	Other food products	Food	0.29	3
8	Wooden furniture	Goods	0.25	3
9	Ownership of dwellings	Shelter	0.24	3
10	Clothing	Goods	0.21	2

Fig 3. Top10 commodities in terms of per-capital ecological footprint in the ACT in 2008-09

The rises in consumption are driven by our rising income. The ACT has the highest mean household disposable income in the country ($1,026/week), significantly higher than the national average ($811/ week) (see Fig 4)[4]. Higher incomes generally result in higher spending, resulting in a larger footprint. However, this link can be changed. Countries such as Switzerland and France have managed to continue or improve their development while reducing their ecological footprint.

[4] ABS (2009) Household Income and Income Distribution, Australia 2008-07 (ABS 6523.0) http://www.ausstats.abs.gov.au/ausstats/subscriber.nsf/0/32F9145C3C78ABD3CA257617001939E1/$File/65230_2007-08.pdf

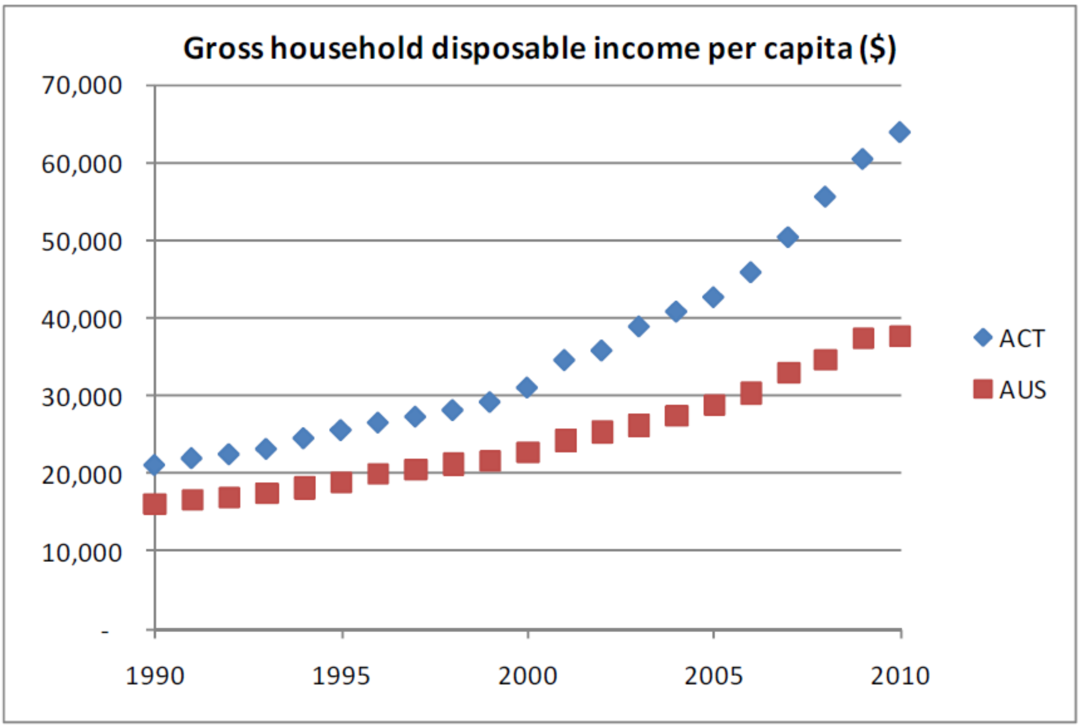

Fig 4. ACT and Australian gross household disposable income per capita

What are the consequences of an increasing footprint?

The ACT is not self-contained, the resources that we use come from across the world.

We only have one Earth. Using our natural capital faster than it can be replenished is like maintaining spending that continually exceeds income. This results in shrinking forests, loss of biodiversity, freshwater stress and climate change.

There are also social and economic costs. In a world with limited resources, excess consumption by some, requires that others live without sufficient resources to sustain life and health. If we in the rich countries maintain our current consumption patterns, we put pressure on others to live in poverty without sufficient resources to sustain life and health. Our ecological footprint is a social and economic issue as much as an environmental one.

The upcoming ACT 2011 State of the Environment Report will consider the consequences of our increasing footprint in the ACT, including what we have done that is making a difference and where we need to focus our efforts in the future.

What can Canberrans do to reduce our footprint?

1. Be smarter in our consumption and

2. Protect and enhance our natural environment so our land and water is biologically more resilient and productive.

1. Being smarter in our consumption

There are some things which have a greater impact on our ecological footprint than others. This is not necessarily linked to how much they cost. For example we can see from Fig 5 that energy is quite a small source of expenditure in regard to our income (red bar) but has much larger effect on our footprint (blue bar). There is great potential for services to play a significant role in the ACT economy, while helping us to reduce our footprint. As Fig. 5 highlights spending on services will have less of an effect on our footprint then spending on energy or food.

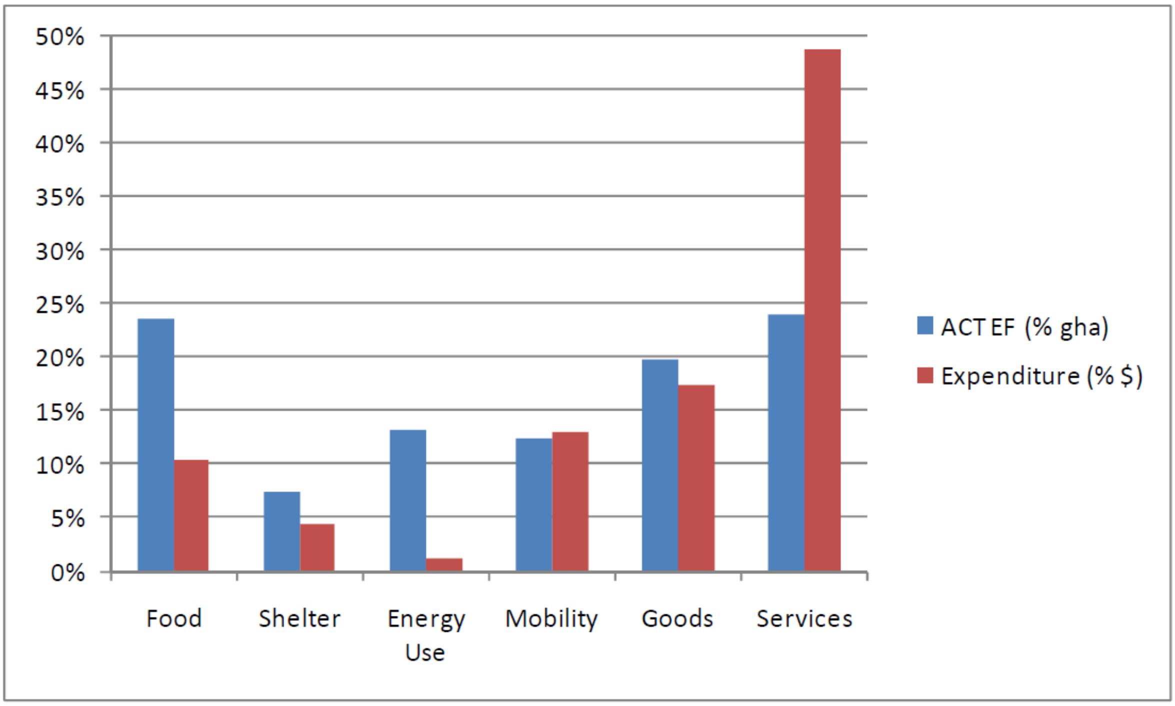

Fig 5. Comparison of consumption categories by Ecological Footprint and Expenditure, ACT 2008-09

Key decisions that Canberrans can make on a daily basis to reduce our footprint include:

- Repair, reuse or borrow where possible instead of buying new things.
- Before tossing something in the bin see if there is another use for it;
- Buy quality goods that are efficient and will last a long time;
- Invest in doing an activity as an alternative to purchasing goods. eg. Concerts, movies, picnics etc.;
- Use renewable energy; and
- Make your home and appliances energy efficient.

Larger changes need to be made with the help of community, business and government. These include:

- Transforming our economies to lower our overall resource use
- Improving the efficiency and source of our energy
- Pursing regional opportunities to promote renewable energy production and develop a green economy

2. Protecting and enhancing our natural environment

We need to invest in the health of our natural environment to improve its resilience. This needs to happen not just in the ACT but across the country and the world where the resources we use come from. In the ACT we have a significant amount of natural resources in our national parks and our nature parks and the supporting corridors.

The Office of the Commissioner for Sustainability and the Environment, will consider the consequences of our increasing footprint in the ACT in the upcoming *ACT 2011 State of the Environment Report*. We welcome suggestions from the community on ways to reduce our footprint. Suggestions can be provided to the Office by email envcomm@act.gov.au