Ecological Footprint Analysis of Aurora Residential Development

Prepared for EPA Victoria, VicUrban and Building Commission
by the Centre for Design at RMIT and Global Footprint Network

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Contents

Executive Summary

As expanding economies place ever greater demands on the natural systems that support us, the need for sustainable development is increasingly apparent. How can we all live well, yet live within the limits of our finite planet? While there are many ways we can begin to meet this challenge, the design of residential housing – because it affects not only so much of our infrastructure, but also our lifestyles – plays a particularly important role.

Residential developments like Aurora in Epping North, Victoria, are pioneering efforts to bring principles of sustainable design into the construction of new housing projects. Built under the auspices of VicUrban and the terms of a 'Sustainability Covenant' with EPA Victoria, the development will consist of a mix of terraced, semi-detached and detached homes with an anticipated population of 25,000. A small number of model homes have already been constructed.

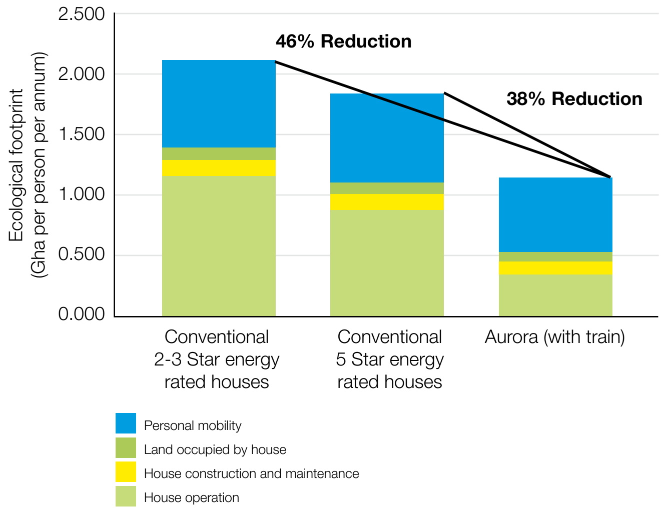
To determine the extent to which incorporation of sustainable design principles in Aurora will bring about tangible reductions in environmental impacts as compared with more conventional developments, VicUrban proposed that a formal assessment be conducted. The Ecological Footprint, a measure of human demand on ecosystems, was selected as the assessment tool because of its scientific credibility and established international use as a sustainability metric. It was also selected because a detailed study was recently conducted to determine the average Footprint of a typical Victorian person, providing a useful basis for comparison. While no sustainability measure includes all aspects of human impact on nature – the Footprint doesn't track pollutants other than carbon dioxide, for example – the Ecological Footprint is perhaps the most comprehensive measure currently available. In addition, the Footprint provides a detailed accounting of how much demand human activity at any scale – global, national, local and even individua – places on cropland, pasture, forests and fisheries.

The study analysed the existing structures in Aurora and extrapolated findings to the remainder of the still-to-be completed development. It also explored various scenarios to estimate how design options would influence residents' lifestyles and the corresponding demands they will place on ecosystems. Results of the study revealed which Aurora design features will yield significant Footprint savings in construction and operation of the homes and by influencing choices residents make when offered various transportation options. Key findings include recommendations on low-Footprint building materials and design strategies. Specifically, we found that:

- Total Aurora residents' Footprint is approximately 9% less than for residents of a 5 Star greenfields development and less than that of the average Victorian. If this saving could be replicated globally, humanity would be able to eliminate a substantial amount of its current ecological deficit.
- Aurora's 6 Star energy efficient house design and its effect on heating and cooling loads, combined with the mandating of solar hot water and higher housing density represent the most significant savings in the Footprint of Aurora residents.
- The housing Footprint of Aurora achieves a 53% reduction.
- The combined housing and mobility Footprint is 38% less compared to 5 Star developments now being built in Victoria; and 46% less than developments constructed before the 5 Star standard was mandated. (See Figure 1)
- Aurora homes have 60% less household energy use as a result of the 6 Star energy efficient house design including evaporative cooling with gas heating and compulsory solar hot water compared to a conventional 5 Star development.
- Water consumption is reduced by 45% at Aurora due to a third pipe providing recycled water to all homes for toilet flushing, garden watering and car washing plus the inclusion of AAA efficient water fixtures.
- The mobility Footprint at Aurora is reduced by 11% due to the pedestrian and bike friendly design combined with greater housing densities. If a train service to Aurora is provided now (with double current patronage pattern usage) the total transport Footprint for Aurora would be reduced by 21%.
- The selection of green materials, use of dual reticulation and improvements to local transport options (better pedestrian and bicycle provisions) all provide significant benefits compared with conventional alternatives. Their effect on the overall Footprint is small only because of the relatively low contribution of these factors to the total Ecological Footprint in the first instance.

Figure 1 summarises the housing and mobility Footprint reductions are dominated by house operation, with a small shift in the personal mobility Footprint.

Figure 1: Combined housing and transport Footprint for conventional development and Aurora



As anticipated, the study found that the design features incorporated into Aurora will significantly reduce the Footprint of the development as compared with conventional housing projects. Once Aurora is completed and populated, follow-up studies would make it possible to confirm that the predicted savings, especially for operating the homes, are actually being realised. Additional studies would also allow more detailed assessments of how Aurora's design features are affecting residents' lifestyles. Together, results gathered from these initial and subsequent studies would show how developments like Aurora can contribute to a reduction in the overall demand residents are placing on nature, and bring us one step closer to successfully meeting the challenge of sustainable development.

How to Use this Report

The report presents a progressive analysis from very specific elements such as house construction, cooling options and so on, moving through to a complete 'household construction and use' Footprint, and finally with the Footprint of residents' total consumption. It is important to look not just at the final aggregate results because many of the benefits of Aurora are diluted in percentage terms by residents' other consumption areas.

This report provides a baseline and guidance for strategically examining the effectiveness of strategies implemented at Aurora. This needs to be done with consideration of other environmental impacts and economic and social costs and impacts of strategies. The examination could be undertaken through a workshop with key planners to examine the Footprint results and contextualise them within the planning framework in place for future stages of Aurora and other VicUrban developments.

This may lead to the development of a sustainability evaluation framework which is semi-quantitative. This should be incorporated into the 're-imagining the suburb' research being undertaken at RMIT for VicUrban and associated partners.

It also highlights areas where there are still substantial challenges to reducing the Footprint. Transport stands out as a key area for improvement, particularly in commuter trips to work, where above-average Victorian patronage is required for the train, when it is provided, to make a significant dint in the transport Footprint.

The other areas which require investigation are the goods and services and the food Footprints which dominate the Ecological Footprint. In this analysis, they are assumed to be relatively static in the context of Aurora. As these lifestyle factors are in fact likely to be influenced by design features of Aurora, future VicUrban strategies could be developed to more accurately capture the impact of design features on these Footprint components.

Introduction

1

1.1 Housing and Sustainability

Sustainability promises rewarding lives for all, now and in the future. Natural capital – nature's goods and services – is not the only ingredient in this vision. But without this type of capital – without adequate food, energy for mobility and heat, fibre for paper, clothing and shelter, fresh air and clean water – sustainability is impossible. This is why careful management of natural capital is central to current and future human well-being. Sustainability thus depends on protecting natural capital from systematic overuse; otherwise nature will no longer be able to provide society with these basic services.

Residential development plays a critical role in any effort to manage our use of natural capital. The way we design our homes and communities is perhaps the single largest determinant of the demands we place on nature. Design not only impacts the choice of construction materials and the energy required to produce, transport and assemble them, but also the (typically) far greater amounts of resources used to operate our homes – to heat, cool, light them, to run electrical appliances, to cook and clean, to provide clean water and remove wastewater, and to do necessary maintenance. In addition, residential design directly influences many aspects of our lifestyles and the resource use they entail – whether we walk, bike or drive to work, school and shops, how often we use public transport, what we recycle or compost, even the extent to which we buy locally grown food.

Beyond good intentions, how can architects and urban designers know if the choices they are making will result in housing infrastructure and communities that are in fact moving us in a sustainable direction? *They need to be able to measure the extent to which design options will increase or decrease demand on nature.* To begin to address this need, EPA Victoria, VicUrban and the Building Commission sponsored this study to evaluate the usefulness of the Ecological Footprint, a widely used measure of human demand on nature, in assessing the ecological benefits of the Aurora residential development over more traditional housing developments.

1.2 Ecological Footprint Accounts: Capturing Human Demand on Nature

How well are we using natural capital? Without measurements, we are blind and cannot effectively manage these essential resources. To take care of our natural capital, we must know how much we have and how much we use. This is no different from any financially responsible household, business, or government using accounts to keep track of its income and spending. To protect our natural assets, we need accounts that keep track of both humanity's demands on nature and nature's supply of ecological resources.

Ecological Footprint accounts are such balance sheets. They document for any given population the area of biologically productive land and sea required to produce the renewable resources this population consumes, and to assimilate the waste it generates, using prevailing technology. In other words, Ecological Footprints document the extent to which human economies stay within the regenerative capacity of the biosphere, and who uses each portion of this capacity.[1]

Such biophysical resource accounting is possible because resources and waste flows can be tracked, and because most of these flows can be associated with the biologically productive area required to maintain them. Thus, the Ecological Footprint of a population is the area of biologically productive land and sea required to produce the resources this population consumes, and to assimilate the wastes it generates, given prevailing technology. This area is expressed in global hectares – adjusted hectares that represent the average yield of all bioproductive areas on Earth. In 2002, the planet's total biocapacity was 11.2 billion global hectares. With a population of 6.2 billion, this means 1.8 global hectares was available for each person on the planet – less if some of this is left for the use of wild species.

Since people use resources from all over the world and pollute far away places with their wastes, the Ecological Footprint accounts for these areas wherever they happen to be located on the planet. In 2002, the global Ecological Footprint was 13.7 billion global hectares, or 2.2 global hectares per person.[2] This exceeded the available biocapacity of 1.8 global hectares per person by 22%, meaning that it took the Earth more than a year and two months to regenerate the resources used in 2002. In other words, the human economy is in 'ecological overshoot' – the planet's natural resource capital stock is being depleted, eroding the future supply of these resources. A minimum condition for a sustainable economy, therefore, is that it avoids overshoot, and operates within the ecological budget of our one planet.

1.3 Limitations of Ecological Footprint Analysis

No single measure can capture all aspects of sustainability. The Ecological Footprint addresses a key question, how much of nature's regenerative capacity is necessary to keep up with human demand for ecological resources and services. It is a conservative measure, providing an historical accounting without attempting to predict future demand or biocapacity. The Footprint can show who is using what, but does not prescribe how resources should be allocated, this being a policy decision rather than a scientific question.

Using less than the earth's regenerative capacity is a necessary condition for sustainability, but it is not sufficient. The Footprint does not include other biophysical impacts of human activities, such degradation of soils through erosion or salination. If degradation results in loss of bioproductivity, however, this will be captured in future Footprint accounts. The impact on human or ecosystem health of pollutants such as heavy metals, PCBs, dioxins, DDTs or radioactive materials is not captured by the Footprint, nor are the essential social or economic aspects of sustainability.

1.4 Goals of the Aurora Residential Development Footprint Analysis

In 2001, the Ecological Footprint of the average Australian was 7.7 global hectares, and that of the average Victorian 8.1 gha. If everyone in the world consumed resources and produced wastes the way Victorians do, we would need more than four Earths to be sustainable (Living Planet Report 2004; Global Footprint Network and University of Sydney 2005; Lenzen et al 2004; *www.myFootprint.org*).

Recent studies indicate that housing in Australia constitutes 18% of the average person's total Footprint, with the balance originating from food (36%), transport (11%), and goods and services (35%) (Global Footprint Network and University of Sydney 2005). But housing choices affect far more than this 18%, as housing and urban design strongly influence many areas of individuals' lifestyles. For instance, building housing developments near workplaces and schools can significantly reduce residents' transport Footprints, and providing space for farmers' markets increases access to local foods, reducing the energy required to get products from farm to consumer. Good housing and urban design, both directly and through its influence on many aspects of modern lives, can help generate large Footprint savings and play a major role in eliminating humanity's ecological overshoot.

Toward this end, the Aurora residential development project in Epping North seeks to achieve a pioneering level of sustainable outcomes by embracing the 'Guiding Principles and Objectives' already established and now enshrined within the 'Sustainability Covenant' for Aurora. The Aurora development is an area sited for the construction of approximately 8,000 houses. Currently only a handful of model homes have been constructed, the purpose of which is to preview the development for the public, increase interest in the project as a whole and identify prospective buyers for the properties once completed. These model homes have also served as the subjects of detailed life-cycle assessments, as described in this report. The overarching intent of this study is to assess the ecological performance of the as-built model homes, in addition to a wide range of specific scenarios involving public transit and resident lifestyles, for the purpose of identifying challenges and opportunities in achieving a truly sustainable residential development for the completed Aurora community. To complete this assessment, Aurora life-cycle results and lifestyle scenarios were compared with those of a conventional urban development. Findings were expressed in terms of Footprint in order to allow direct comparison of the ecological demands for the two different types of development.

In order to create low-Footprint design strategies, reliable ecological performance measurements are needed to assess their effectiveness. Aurora will benefit from measurements that are well established, scientifically credible and documented, as they will help to demonstrate the value of Aurora's sustainability strategies and provide an evidence base to support incorporating similar strategies into future VicUrban developments.

1. Mathis Wackernagel, and William E. Rees, Our Ecological Footprint: Reducing Human Impact on the Earth. New Society Publishers, Gabriola Island. 1996.
2. Global Footprint Network, 2005. National Footprint and Biocapacity Accounts, 2005 Edition (2002 data). Available at *http://www.footprintnetwork.org*
3. It is possible to compare the results of local Footprint analyses with local rather than global biocapacity. Each approach has its advantages, although accurate data on local biocapacity is often more difficult to obtain. Using global per capita biocapacity as the basis for comparison increases comparability of Footprint analyses, and makes it easier to understand and communicate results. Because people uses resources from all over the world, and this is reflected in their Footprint, using global biocapacity as the basis for comparison helps reveals the relationship between this demand on global ecological resources, and the available supply. Comparing local per capita Footprint results with global per capita biocapacity also allows one to answer the question, 'If everyone lived like I do, would we all fit on the planet, and if not, how many planets would it take?'

Overview of the Project

2

VicUrban proposes to monitor the extent to which design features of the Aurora development promote changes in material and energy use and how these changes contribute to reducing the Ecological Footprint. The project both measured and modelled the materials and energy use of different housing types in Aurora and calculated the Ecological Footprint of these decisions. Included in this assessment are demands on the environment from construction and operation of Aurora's homes. In addition, in order to put the Footprint results in context, the project estimated possible reductions in the Footprint from urban design in other sectors, namely food as well as goods and services, resulting from architectural as well as possible behavioural modifications.

Throughout Aurora's early development, design concepts were continually evaluated and compared with a conventional development. For this Ecological Footprint assessment, a baseline model of a 'typical' conventional suburban development was developed to provide a basis of comparison for evaluating the initiatives introduced at Aurora. The results can be used to determine the extent to which the design features incorporated into Aurora show the anticipated sustainability benefits. Once validated, these benefits can be used to promote the adoption of these sustainable design practices in planning other developments.

Aims

3

The project aimed to:

Compare how much of the Earth's bioproductive capacity is occupied through the development and operation of an urban residential housing development, Aurora, which incorporates sustainable design principles, as compared with a conventional greenfields development in Victoria.

Throughout the development of Aurora, the assumption has been made that the incorporation of environmentally preferable features in its design and construction will produce a more sustainable project when compared with a conventional residential estate. To test this assumption, the Ecological Footprint was used to identify which of Aurora's specific elements contribute most to lowering demands on ecological resources and services required to support both the physical infrastructure of Aurora and the lifestyles of residents. Results were further disaggregated by Footprint component – energy land, cropland, pasture, forest, built area, and fishing ground. Appendix 8 provides additional detail on how each of these area types are defined.

Beyond the basic comparison of conventional development with Aurora, different design and policy scenarios have been modelled to investigate the potential impacts of the Footprint of Aurora and future developments. These scenarios are described to the right.

3.1 Housing Types

Evaluate the Ecological Footprint housing types and designs and the mix of these within the development. Three generic structures have been identified – terraces, semi-detached and detached houses.

3.2 Transportation

Transport scenarios were assessed based on a possible policy option available to Aurora. Rail transport is currently planned, but the actual data on implementation is uncertain. The options modelled are:

- Conventional development
- Aurora – local bike/pedestrian friendly design incorporated with:
  - No development of train line extension
  - Access to train services immediately
  - Access to train service immediately with double average patronage
  - Access to train services in 10 years

3.3 Cooling Technologies

Air conditioning appears to be an area of significant impact even in new energy efficient developments, so a range of cooling options have been tested for Aurora:

- Electric fans, combined with gas central heating
- Evaporative cooling, combined with gas central heating
- Reverse-cycle air conditioning (also used for heating)
- Conventional air conditioning combined with gas central heating

Methodology

4

4.1 Calculation of Baseline Conventional and Aurora Model

The base model for the Aurora development represents, as close as is practicable, the expected implementation of the development and associated consumption patterns over the initial 50-year life of the development. The conventional residential estate development was modelled on Aurora, but with conventional planning and implementation.

The conventional development and the Aurora development were modelled with a range of different tools including:

- A Life-Cycle Assessment (LCA) model of three basic housing construction types: terrace, semi-detached and detached houses;
- Energy modelling of the three housing types;
- Assessment of lot sizes and housing mix;
- Lighting layout and anticipated energy use;
- Water and wastewater supply (infrastructure and operation); and
- Transport behaviour assumptions and modelling.

The urban form and mix of housing was taken from comparisons of the housing market survey information provided by VicUrban.

Three typical house designs were provided by VicUrban. These were used to develop a Life-Cycle Assessment (LCA) model of house construction. The house designs provided basic layouts and much of the material construction information. Missing data was interpreted from typical construction practice or from the Material Selector developed for VicUrban. Material quantities in construction were taken from Bill Lawson's book on building material construction (Lawson and Royal Australian Institute of Architects. 1996) with some modification where it was appropriate. The details of the LCA models for house design are shown in Appendix 1.

Energy modelling of the houses was undertaken in First Rate and Accurate – two types of energy modelling software, the latter being a more detailed model which was used in case the First Rate model missed subtleties of the energy efficient design. Nearly all of the data for this energy modelling was found in the house designs with some minor inputs being inferred. Detailed results from the energy modelling are shown in Appendix 2. The heating and cooling supplies were modelled using gas central heating and split-system air conditioning as the base case.

Lighting energy usage for households was taken from housing designs, some of which came with lighting specifications. For others, lighting specifications had to be inferred from the design. Operational usage of lighting was estimated to match typical measured lighting energy usage as found in the literature. Lighting specifications and usage assumptions are shown in Appendix 3.

Water supply and water supply infrastructure were interpreted from work commissioned by Yarra Valley Water looking at dual reticulation design and its operation in the northern suburbs of Melbourne. (Grant et al. 2005)

Transport behaviour was taken from average statistics for Melbourne, modified depending on the assumption regarding rail infrastructure to Aurora. In this area, the effects of meeting specified targets are shown rather than a detailed transport behaviour prediction model, which was beyond the scope of this study. Details of the transport modelling are shown in Appendix 5.

The remaining consumption elements are taken from the Victoria Ecological Footprint commissioned by EPA Victoria (Global Footprint Network and University of Sydney 2005). Modifications to these are modelled under the consumption scenarios section.

Water usage, hot water usage and water heating requirements were taken from data developed by the Sustainable Energy Authority.

CO_2 emission factors for energy production in Victoria were taken from the National Greenhouse Gas emission factors workbook. These were used to develop the energy land calculation, based on sequestration of 3704kg/CO_2 per global hectare per year.

One of the key features of Aurora is increased housing density, particularly in the context of urban fringe development. Data on planned urban densities and house sizes has been taken from market survey data undertaken for VicUrban. Table 1 shows the assumption used for housing development mix in Aurora and more conventional development.

Table 1: Data and assumption on house design mix

		Conventional	Aurora	Typical house gross floor area
Terrace	% of total	7%	32%	200
Semi-detached	% of total	4%	23%	240
Detached	% of total	89%	45%	262

Scenarios and Model Component Results

5

Various scenarios were modelled in order to quantify the Ecological Footprint associated with different decisions regarding housing design, proximity to transit and so forth. The scenarios allow comparison of the ecological performance of design decisions and are also useful in the decision-making process because, when coupled with cost information on various alternatives, they allow more accurately weighing of environmental benefits with price.

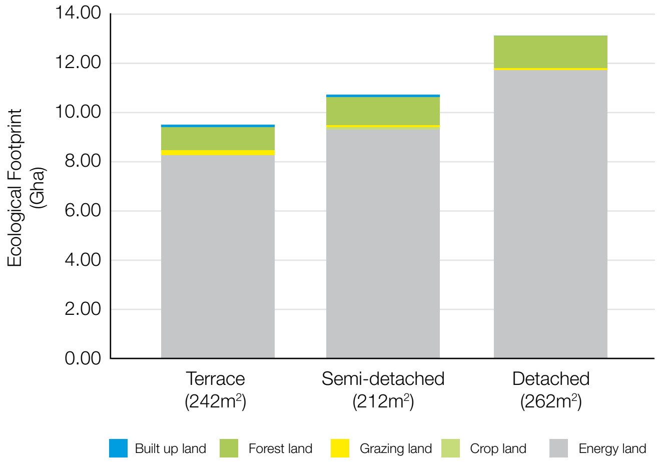
Two types of models were generated in this study. The first model, whose key results are described below, involved detailed calculations and analysis, taking into account various assumptions about housing designs, materials choices, house energy use, water use, personal mobility options and so on, in order to calculate the Ecological Footprint associated with each decision. The calculation worksheets for these models are included as an attachment to this report.

The second model that was generated is in the form of a user-friendly software tool, based in Microsoft Excel, which allows the user to interact directly with the model and quickly see the outcomes based on his or her inputs. Although much more simplified than the materials and energy models demonstrated below, the scenario calculator provides an interactive tool for designers of Aurora to experiment with a wide range of variables and immediately view the Ecological Footprint implications of these decisions. More advanced users can change the underlying assumptions in the calculator. This will be useful for those wanting to model specific scenarios not included as part of the default settings, and for purposes of updating the calculator with more detailed conversion factors should they become available in the future. This scenario calculator is also included as an attachment to this report.

5.1 Housing Development Scenarios

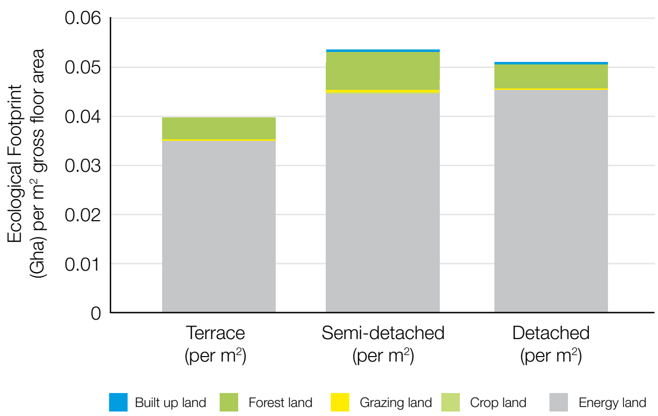
Three specific house designs were modelled in detail to determine typical impacts of different housing types which were terraces, semi-detached houses and detached houses. It would be expected that there would be a decreasing efficiency in material use from terraces to semi-detached houses to detached houses due to a decreasing number of shared components (i.e. party walls), however larger buildings will have a greater material efficiency on a per square metre basis due to economies of scale. Figure 2 shows the terrace having lower construction Footprint than the detached house both in total and on a per m^2 basis as shown in Figure 3. There is little difference between the semi-detached and detached house on a per m^2 basis.

Figure 2: Three typical Aurora housing types – initial construction impact per house in global average hectares



	Terrace (242m²)	Semi-detached (212m²)	Detached (262m²)
Energy land	8.42	9.46	11.87
Crop land	0.01	0.01	0.01
Grazing land	0.12	0.13	0.08
Forest land	1.00	1.17	1.28
Built up land	0.03	0.03	0.06

Figure 3: Three typical housing types – initial construction impact per square metre of gross floor area



	Terrace (per m²)	Semi-detached (per m²)	Detached (per m²)
Energy land	0.03479	0.04463	0.04530
Crop land	0.00002	0.00002	0.00004
Grazing land	0.00050	0.00062	0.00029
Forest land	0.00413	0.00552	0.00489
Built up land	0.00014	0.00016	0.00025

5.2 Housing Material Selection

The difference between Aurora and conventional developments in terms of materials data is largely due to the development and use of the Eco-selector. Three key elements were taken from the Eco-selector which are thought to be commonly integrated and likely to have significant impact on the Ecological Footprint of house construction and maintenance. These are high extender concrete, low energy bricks and recycled timber. Comparative Ecological Footprints for each of these substitutions are shown in Figure 4, Figure 5 and Figure 6.

The combined effect of smaller houses and using 40% slag concrete, low embodied energy bricks and 1500kg of recycled timber flooring (out of a total timber input of 9.5 tonnes) is shown in Figure 7.

Figure 4: Comparison of conventional concrete, 40% slag content concrete and 80% extender concrete

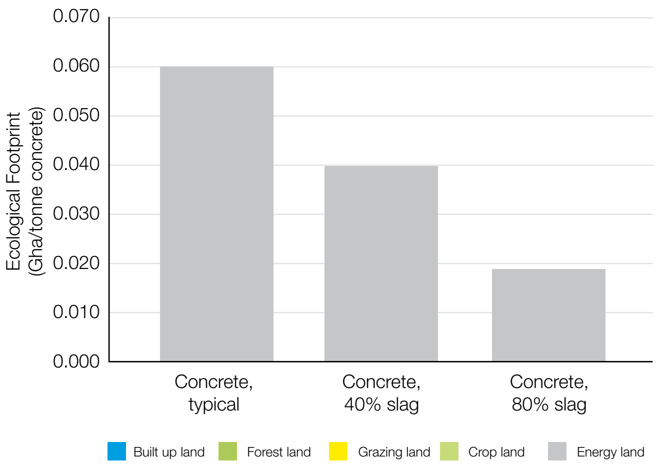


Figure 5: Comparison of conventional bricks with low energy eco-bricks

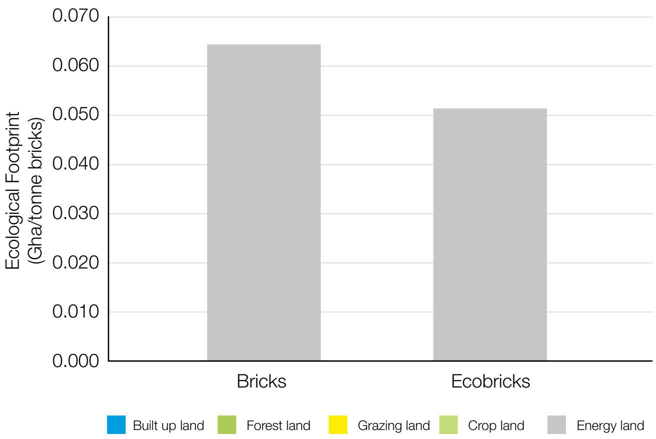


Figure 6: Comparison of softwood, hardwood and recycled timber

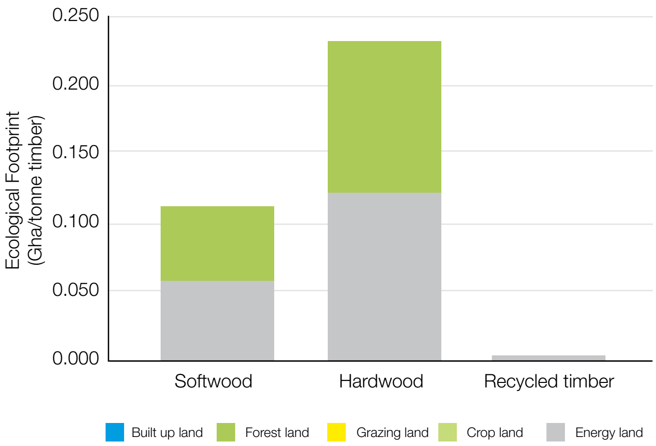
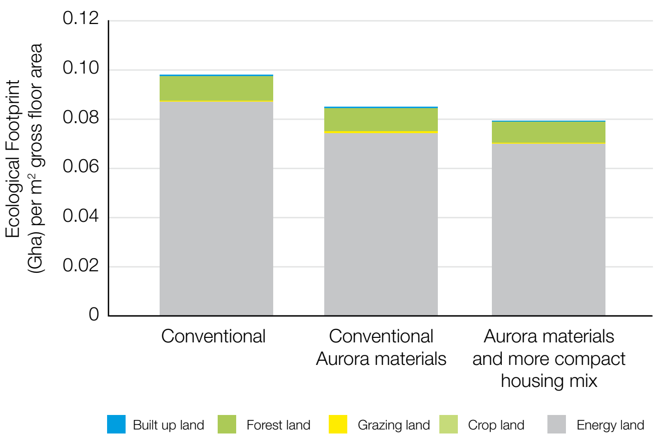


Figure 7: Comparison of Aurora house construction with conventional house construction and effects of different housing mix

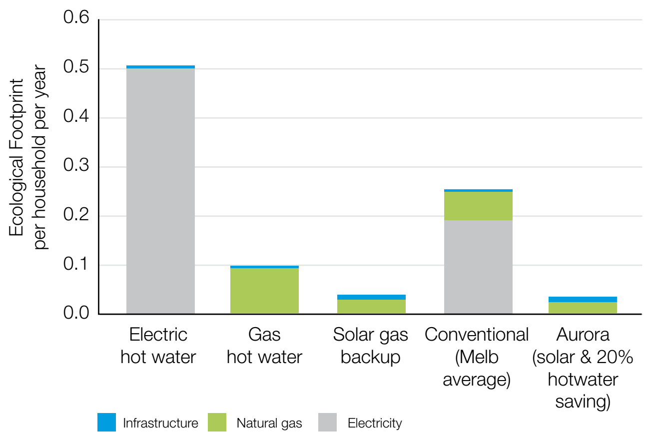


5.3 Energy Modelling

5.3.1 Hot Water

Aurora has compulsory solar hot water which leads to significant energy savings. The conventional development was assumed to be a mix of electric and gas hot water systems as detailed in Appendix 6. Figure 8 shows the Footprint results of average gas and electrically heated hot water against the Aurora solar hot water with natural gas backup at two different water usage rates- the first being conventional usage and the second being a 20% lower usage at Aurora. The average hot water usage for Melbourne was taken to be 45% of 532 litres (the total household water usage per household per day) to give 240 litres per household per day (pers. comm. Ross Young, Water Services Association of Australia), which is expected to drop by 20% at Aurora with efficient water fixtures to 200 litres per household per day. The electric hot water produced much higher greenhouse emissions due to the high Footprint factor for electricity. Hot water from natural gas has a Footprint more than double that of solar hot water.

Figure 8: Hot water system comparisons

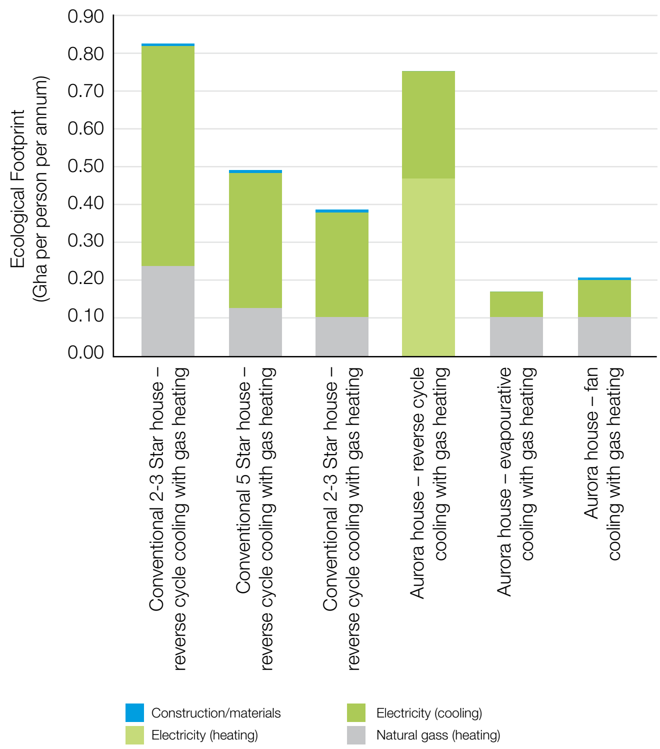


5.3.2 Cooling Options

The basic system modelled as the baseline for Aurora and the conventional development was a split-system air conditioner for the living areas of the house and ducted gas heating for the living and sleeping areas of the house. Figure 9 shows that the Aurora 6 Star house improves on conventional housing (2-3 Stars) by about 60%. The Aurora house has a significant advantage over 5 Star energy-rated conventional houses which are shortly to become compulsory in new construction in Victoria.

The different heating and cooling options show that evaporative coolers provide the most efficient cooling. If gas heating is replaced by heating with a reverse cycle air conditioner, the heating load Footprint is doubled. This is because, despite reverse cycle being more thermally efficient, energy input per unit of heat output, the energy source – electricity – has a Footprint about 6 times greater than that of natural gas energy on an equivalent delivered energy basis. This is unique to Victoria, where the electricity supply is dominated by brown coal power generation. If renewable energy from wind or run-of-river hydro power is used, the Footprint impacts of the electrical heating and cooling would be drastically reduced. Evaporative coolers and fans both provide much lower Footprint results for the cooling system, due to the lower energy requirements for cooling.

Figure 9: Heating and cooling options compared to conventional house options

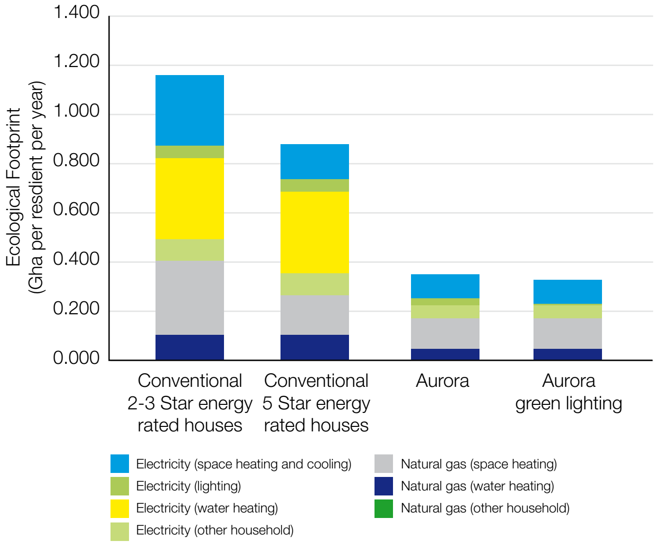


5.3.3 Household Energy Use

It is known that the operation of houses dominates their ecological impact, so specific attention was given to the operation of the houses, focusing on heating, cooling, hot water use and lighting. Figure 10 shows the results for household energy use including heating and cooling, hot water supply, lighting and general household gas and electricity use. Hot water contributes a significant impact in conventional houses.

Lighting is also a significant contributor to energy use, so a green lighting option was included here as a sensitivity test. The details of lighting specification are provided in Appendix 3. Other electricity includes household appliance usage. Other household natural gas usage is principally cooking.

Figure 10: Comparison of Footprint for household energy use in a conventional house, conventional 5 Star house, Aurora house and Aurora house with green lighting in global hectares per resident per annum



5.4 Combined Building Footprint

Figure 11 and Table 2 show a Footprint that is a combination of the operational and production housing Footprint. It represents the annual housing Footprint per person in Aurora and the conventional development. The highest single saving is the use of solar hot water in Aurora compared with a mix of gas and electrical hot water systems in conventional developments. Also, reductions in household heating and cooling loads due to the improvement in thermal performance of the houses make a significant difference. The site occupation Footprint is the land occupied by the housing development. This is lower for Aurora due to the higher density of housing development (12 compared with 8 lots per hectare in conventional fringe development.)

Figure 11: Building Footprint including construction, maintenance, occupation and use phases of the building

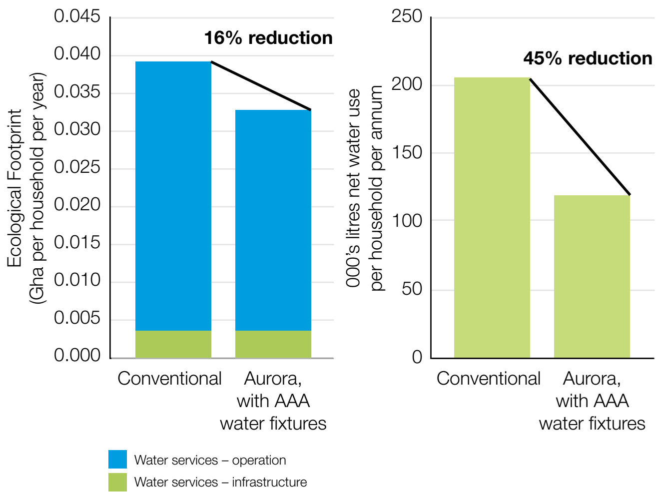
Table 2: Ecological Footprint for combined data for household energy and construction in global average hectares

	Conventional 2-3 Star energy rated houses	Conventional 5 Star energy rated houses	Aurora	Aurora reduction from conventional	
				2-3 Star	**5 Star**
House construction	0.097	0.097	0.079	19%	19%
House maintenance	0.029	0.029	0.029	0%	0%
Land occupied by house	0.104	0.104	0.069	33%	33%
Electricity (heating and cooling)	0.288	0.143	0.095	67%	34%
Electricity (lighting)	0.052	0.052	0.031	41%	41%
Electricity (water heating)	0.332	0.332	0.000	100%	100%
Electricity (other household)	0.090	0.090	0.053	41%	41%
Natural gas (space heating)	0.300	0.162	0.125	58%	23%
Natural gas (water heating)	0.105	0.105	0.044	58%	58%
Natural gas (other household)	0.001	0.001	0.001	0%	0%
Total household	1.398	1.115	0.526	62%	53%

5.5 Water Services Footprint

The water service Footprint has been inferred from detailed LCA work undertaken for Yarra Valley Water on dual reticulation (a third pipe that provides recycled water to homes for garden and toilet usage) and conventional water servicing. The water service model for the conventional development is based on centralised water and sewage services with sewage being pumped to the Western treatment plant in Werribee. It also assumes current water usage patterns as reported by Yarra Valley Water. The Aurora options include recycling water for provision to households and water demand management consistent with the Victorian Government's White Paper recommendations. These strategies results in a 45% reduction in water required from Melbourne's catchments. Figure 12 shows that the dual reticulation option at Aurora combined with demand management significantly reduces Aurora's Footprint for water services, which includes water and sewerage pumping and treatment, compared with the water services Footprint for the conventional development.

Figure 12: Annual per capita water services Footprint and total water extraction from the environment for conventional development and Aurora



5.6 Transport Scenario Results

The transport Footprint is difficult to determine for an as yet un-established development. However the transport Footprint for Aurora has been estimated from average statistics for Victorian households under different public transport scenarios.

For the conventional development and Aurora with no rail service, the principal differences are the number of local trips undertaken by car. The higher density of Aurora, combined with bike and pedestrian access, are assumed to reduce the number of local trips less than five kilometres by 25%. These trips account for about half the total transport Footprint, giving a transport Footprint improvement of about 11% for Aurora as compared with the conventional development, as shown in Figure 13. A train service provided to Aurora in its initial development, assuming patronage based on a Melbourne-wide average, would reduce Aurora's transport Footprint by a further 6%.

Given that the Melbourne-wide average train usage is low (around 9% of total passenger kilometres), a scenario was developed to show how improvements in patronage could effect the transport Footprint. With no specific data or target being available, an arbitrary doubling of the average train patronage was modelled and leads to an improvement on the 'no train' scenario of 12%. Combined with local transport improvement in Aurora, this gives a 21% reduction in the overall transport Footprint.

If a train is provided in 10 years time, the transport Footprint over the first 40 years of the development will be higher, as it takes time for residents' established behaviour patterns (and infrastructures such as second and third vehicle ownership) to change in response to the supply of rail services. Details of the assumptions made for the transport modelling are provided in Appendix 5.

Figure 13: Annual per capita transport Footprint for conventional fringe developments and Aurora with different train servicing scenarios

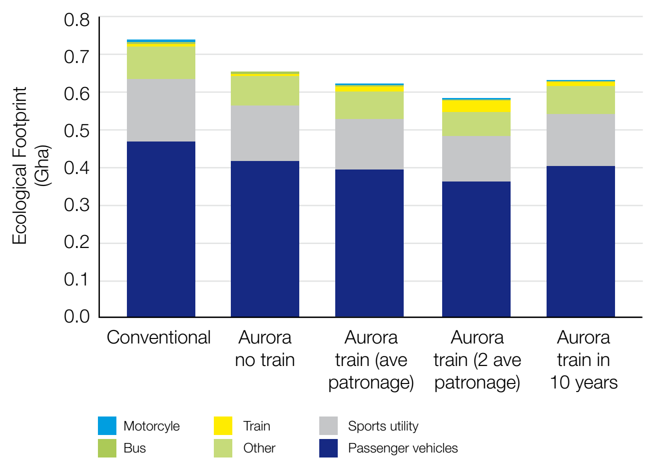


Table 3: Annual per capita transport Footprint for a conventional development and Aurora with different train servicing scenarios and showing percentage improvements

	Conventional	Aurora no train	Aurora train now (av patronage)	Aurora train no (2*av patronage)	Aurora train in 10 years
Passenger Vehicles	0.466	0.414	0.393	0.358	0.401
Sports Utility	0.165	0.147	0.133	0.121	0.138
Other	0.088	0.078	0.071	0.065	0.074
Train	–	–	0.015	0.029	0.009
Bus	0.005	0.005	0.002	0.002	0.003
Motorcycle	0.007	0.007	0.003	0.003	0.004
	0.731	0.652	0.617	0.579	0.629
Percentage reduction from Aurora with no train with the percentage reduction from conventional development shown in brackets					
Passenger Vehicles		11% (11%)	5% (15%)	13% (23%)	3% (14%)
Sports Utility		11% (11%)	9% (19%)	17% (26%)	6% (16%)
Other		11% (11%)	9% (19%)	17% (26%)	5% (16%)
Train					
Bus		0% (0%)	52% (52%)	52% (52%)	33% (33%)
Motorcycle		0% (0%)	60% (60%)	60% (60%)	39% (39%)
Total		10% (10%)	5% (15%)	11% (20%)	3% (13%)

5.7 Combined Housing And Transport Footprint

Aurora's main influence on the size of residents' Footprints relates to housing and transport Footprints. This is because the remaining areas of the Ecological Footprint, the consumption of goods and service and food, are difficult to affect by good housing design. Figure 14 and Table 4 shows that the percentage reduction in the housing and transport Footprints achieved through the implementation of sustainability at Aurora is 46%, assuming the train is available early in the development and 45% if no train in provided. Once conventional development is being built to 5 Star energy efficiency the relative improvement of Aurora will be 38%.

Figure 14: Combined housing and transport Footprint for conventional development and Aurora

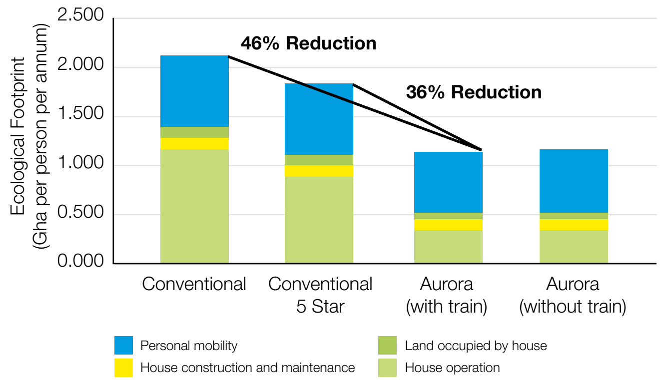


Table 4: Combined housing and transport Footprint for conventional development and Aurora

Global hectares per person per annum	Conventional 2-3 Star energy rated houses	Conventional 5 Star energy rated houses	Aurora (with train)	Aurora (without train)
House operation	1.168	0.885	0.349	0.349
House construction and maintenance	0.126	0.126	0.108	0.108
Land occupied by house	0.104	0.104	0.069	0.069
Personal mobility	0.731	0.731	0.617	0.652
Total	2.129	1.846	1.144	1.178
Reduction from conventional			46%	45%

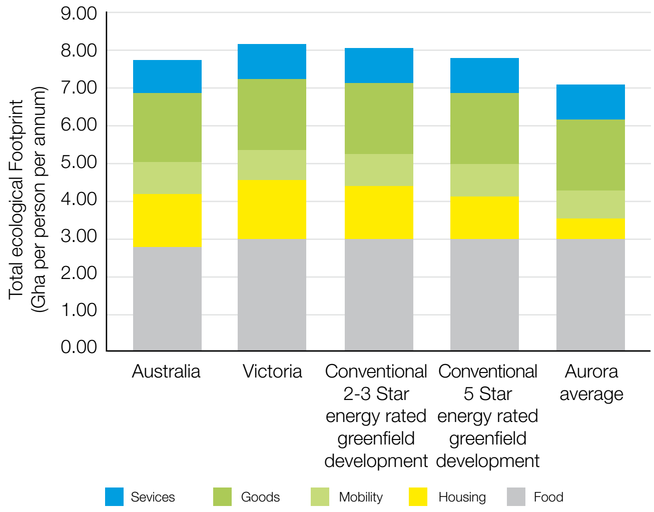
5.8 Total Consumption Footprint

Results of this study show that the major savings in the Aurora Footprint are in the housing component. In addition, there are also small savings in transport due to better local facilities for cycling and walking for short trips. As a result, the overall Footprint of an average Aurora resident is 12% smaller than that of the average resident of a older 2-3 Star energy rated greenfield development, and 9% from the conventional 5 Star energy rated development, showing that the sustainable design features of Aurora are yielding their intended benefits. The full significance of a Footprint savings of this magnitude becomes apparent when considering that if just these savings could be replicated globally, humanity would be able to eliminate half of its current ecological deficit, which in 2005 was at 23%.

Housing and transportation together comprise only 28% of the average Victorian Footprint, and because of the savings, an even smaller percentage (18%) of the average Aurora resident's Footprint. This suggests that ample opportunities exist for savings in these other Footprint components, and that these savings might be encouraged through design features incorporated into developments like Aurora.

Consider the Footprint of food, for example. Figure 15 shows that in Australia, at 36% of the total, food is easily the largest single component of an individual's Footprint. While food consumption may normally be considered the purview of grocers and chefs rather that architects and urban planners, design choices made by the latter can indeed influence how and where people obtain their food. Providing garden areas in developments where families can grow some of their own fruits and vegetables, or communal spaces to host farmers markets, can help shrink the food Footprints of Aurora residents. Both encourage residents to eat locally grown food, which entails far fewer 'food-kilometres' to get from farm to table and therefore considerably less energy for transport.

Figure 15: Total population-based consumption Footprint on an annual per capita basis



	Australia	Victoria	Conventional 2-3 Star energy rated greenfield development	Conventional 5 Star energy rated greenfield development	Aurora – average	Reduction at Aurora as compared with conventional greenfield development 2-3 Star	5 Star
Food	2.73	2.97	2.97	2.97	2.97	0%	0%
Housing	1.41	1.54	1.40	1.11	0.53	62%	53%
Mobility	0.82	0.80	0.82	0.82	0.75	9%	9%
Goods	1.86	1.88	1.88	1.88	1.88	0%	0%
Services	0.86	0.91	0.91	0.91	0.91	0%	0%
Total	7.67	8.10	7.98	7.70	7.03	12%	9%

Conclusions and Recommendations

6

6.1 What The Study Tells Us

The Ecological Footprint for an average resident of Aurora will be substantially less (approximately 12% less) than for residents of a conventional greenfields development, and less than that of an average Victorian. This is a conservative result as no reductions have been assumed in the food and goods Footprint despite smaller housing stock which could encourage lower consumption of furniture and household equipment. The food Footprint is a large component which is also assumed not to be affected by the development.

The household energy use Footprint is over 70% less for Aurora than for a conventional development and 60% less than that of a new conventional development including 5 Star energy ratings. A reduction of about 15% is achieved in the construction Footprint for Aurora through use of greener materials and smaller house construction. A reduction of 11% is achieved in the transport Footprint from local traffic in Aurora. Additional reductions in the transport Footprint due to a rail connection should be between 5% and 10%.

The combined reduction in the transport and personal mobility Footprint is between 38% and 46% depending on which baseline is taken for conventional housing (the lower amount taking 5 Star rated housing developments as a baseline). This is significantly less than the average Victorian's Footprint, which is now more than four times the amount of biologically productive land available per person worldwide.

Housing design and its effect on heating and cooling loads, combined with the mandating of solar hot water, represent the most significant savings in the Footprint of Aurora residents.

The selection of green materials, use of dual reticulation and improvements to local transport options (better pedestrian and bicycle provisions) all provide significant benefits compared with conventional alternatives. Their effect on the overall Footprint is small only because of the relatively low contribution of these factors to the total Ecological Footprint in the first instance.

Many other features of architectural and urban design can influence Footprint savings. Planting trees can provide shade and change the albedo of an area, reducing the 'urban heat island' effect so that less energy is necessary for cooling. Roof gardens can provide a similar summer benefit, can insulate in the winter as well, and allow residents to grow some of their own food, displacing a portion of their food Footprints. Incorporation of photovoltaic panels can eliminate need for some of the fossil fuel used for electricity production. Providing easily accessible communal facilities that encourage reuse and recycling of products, and composting of food and yard wastes, can yield reductions in the goods, services and food components of the Footprint. No account has been taken for any of these activities as they are outside the scope of the development.

Mixed use developments, placing residences in close proximity to schools, retail shops, places of worship, offices and health care facilities can greatly reduce the number and distances of trips made by personal car, significantly decreasing the average resident's transport Footprint. Note that a 20% reduction in local traffic kilometres was assumed for Aurora.

Once one begins looking, the opportunities for approaching sustainability through creative design appear to be endless.

6.2 What The Study Doesn't Tell Us

There are many aspects of sustainability. The design of Aurora addresses many social and community aspects of sustainability that are not measurable in terms of the Ecological Footprint. However, urban form and urban design can significantly influence lifestyle and other factors which do significantly impact Footprint components other than those directly related to housing. Once Aurora is occupied and data can be gathered on these other factors, their impacts on residents' Footprints will be measurable.

There are many environmental impacts of materials and energy use in the housing and transport area which are not addressed by the Ecological Footprint, either because they involve resources for which nature has no regenerative capacity, the use of which is therefore inherently unsustainable, or because insufficient data is available allowing translation of their use into the bioproductive area occupied by this use. (Note that the energy used to extract, process and transport these resources is included in the Footprint.) Examples include the use of toxic substances, mineral resources (other than fossil fuels) and water, and the emission of environmental pollutants such as acid gases and nutrient-rich effluents. Many of these impacts have been reduced through the materials selector, the dual reticulation of recycled water, and the energy efficiency of housing. These should be reported and quantified separately from the Ecological Footprint.

While every endeavour has been made to ensure results are as accurate as possible, the authors have taken the underlying data provided to be accurate and acknowledge this creates a potential for some error. The national Ecological Footprint accounts, which provide the conversion factors used to translate material and energy quantities into global hectares, are constructed so as not to exaggerate human demand on nature; they may therefore lead to conservative under-reporting.

Appendix 1 Housing Models

Terrace house is 242m², features include: concrete slab, timber frame, clay brick veneer wall, timber windows with timber frames, concrete roof tiles, elevated timber floor (upper level), particle board internal doors, floor tiling in family room, meals, kitchen, laundry, entry and bathrooms, carpet in lounge and all bedrooms, ceiling insulation R4.0, wall insulation R4.0, all windows double glazed.

Semi-detached is 212m², features include: a concrete slab, timber frame, clay brick veneer wall with a timber frame, timber weatherboard wall, timber windows, concrete roof tiles, aluminium entrance door, particle board internal doors, linoleum flooring throughout the building, insulation R2.0 for walls and R3.5 for ceiling, windows with clear single glazing.

Detached house is 262m², features include: concrete slab, timber frame, clay brick veneer wall, PVC windows with timber frames, terracotta roof tiles, aluminium entrance door, particle board internal doors, linoleum flooring throughout the building, windows with single clear glazing, ceiling insulation R3.5 and wall insulation R2.0.

Table 1: Details of Aurora houses modelled

	Walls m²		Floors m²		Ceiling m²			Windows (1300 x 1650)	Roof m²
Aurora Houses	**External**	**Internal**	**Ground**	**First**	**Lower**	**Upper**	**Insulated**		
Terrace	299.31	234.29	140	83	142	83	103	12	137
Semi-detached	232.04	202.55	139	74	100.6	66.9	93.9	13	100.6
Detached	287.24	295.41	166	96	184	60	150	22	160

Appendix 2 House Energy Models

In order to gain a lower Star rating for conventional houses of a similar construction, the original Aurora Accurate files were adapted by: reducing wall insulation and removing ceiling insulation, making all windows single-glazed with no awnings, removing eves and slightly altering the azimuth.

All three Aurora houses had been designed to meet the first rate 6 Star rating. First rate is the basis for house energy rating in Victoria, but for more closer prediction of heating and cooling loads, more detailed energy simulation tool was used called accurate. The first rate rating and heating and cooling loads from the accurate modelling.

Table 4: Accurate energy ratings and requirement modelling compared

	Terrace (242m²)		Semi-detached (212m²)		Detached (262m²)	
	Aurora	**Conventional**	**Aurora**	**Conventional**	**Aurora**	**Conventional**
First rate Star rating	6 Star	2.5 Star	6 Star	2 Star	6 Star	3 Star
Accurate energy modeling results						
Heating MJ/m² PA	58.9	84.5	102.8	202	71	167
Cooling MJ/m² PA	85.6	137.9	20.4	52.9	25.4	69.7

The results of energy requirements showed considerable differences between the Aurora and conventional houses, the greatest difference being that a 212m² semi-detached house at Aurora would require almost half the energy of an equivalent conventional dwelling.

Appendix 3 Lighting Models

Lighting type and usage was assumed based on typical house electrical plans with estimates of daily usage of each light. This was used to develop lighting energy use per metre squared of household space. The study did not assume energy efficient lighting in Aurora, but did include one model in which energy efficient lighting is used in the Aurora houses. The estimation of lighting use and specification for baseline and efficient lighting are shown in Table 5.

Table 5 The estimate for conventional and energy efficient lighting options

		Normal house				**Energy efficient house**			
Room	**Hours usage per day**	**Light type**	**Wattage**	**Number in bay**	**wH**	**Light type engery efficient scenario**	**Wattge**	**Number in bay**	**wH**
Lounge	**0.2**	**Halogen downlights**	**50**	**4**	**40**	**Halogen downlights**	**50**	**4**	**40**
Garage	0.75	Halogen downlights	50	1	37.5	Halogen downlights	50	1	37.5
Entry	0.125	Halogen downlights	50	4	25	Halogen downlights	50	3	18.75
Porch	0.125	Incandescent bulb	75	1	9.375	CFL ceiling light	20	1	2.5
Stairs	0.125	Halogen downlights	50	2	12.5	Halogen downlights	50	2	12.5
Laundry	0.125	Incandescent bulb	60	1	7.5	CFL ceiling light	20	1	2.5
Kitchen	0.75	Halogen downlights	50	8	300	Halogen downlights	50	1	37.5
Family	0.4	Halogen downlights	50	8	160	Halogen downlights	50	2	40
Meals	0.25	Halogen downlights	50	6	75	Halogen downlights	50	1	12.5
Bathroom	0.125	Halogen downlights	50	1	6.25	Tastic smart switch lights/ fan/heater	50	1	6.25
Bedroom 1	0.5	Incandescent bulb	75	2	75	CFL ceiling light	20	2	20
WIR	0.06	Halogen downlights	50	2	6	Halogen downlights	50	1	3
En-suite	0.12	Halogen downlights	50	2	12	Halogen downlights	50	1	6
Bedroom 2	0.5	Incandescent bulb	75	1	37.5	CFL ceiling light	20	1	10
Bedroom 3	0.5	Incandescent bulb	75	1	37.5	CFL ceiling light	20	1	10
Toilet	0.125	Halogen downlights	50	1	6.25	Halogen downlights	50	1	6.25
Bathroom	0.125	Halogen	50	2	12.5	Halogen	50	1	6.25
Stairs	0.125	Halogen	50	2	12.5	None			0
Balcony	0.125	Incandescent	75	1	9.375	Halogen	50	1	6.25
Energy use Wh per day					881				277.
Energy use in Wh per m^2 of floor area per day					3.92				.1.234

Appendix 4 Air Conditioning Scenarios

The life cycle effects of different cooling options for the Aurora houses were modelled using the semi-detached (lot 52) house which has a floor area of 175m^2. The house was modelled in Accurate and provided to establish annual cooling and heating loads.

Systems to model:

Following discussion with system suppliers, and a review of the report 'Status of Air Conditioners in Australia', the following scenarios were modelled to meet the cooling and heating requirements of the house:

- Reverse cycle ducted system providing cooling and heating (an average system and the market leader were assessed)
- Ducted evaporative cooling and gas ducted heating
- Fans in each room with ducted gas heating
- Ducted evaporative cooling to living areas, ceiling fans in other areas and ducted gas heating.
- Split-system cooling to living areas, ceiling fans in other areas and ducted gas heating (an average system and the market leader were assessed).

The scenarios chosen were all designed to provide heating and cooling to the majority of the house. However, it should be noted that the different systems do not give the same nature and quality of service. Fans do not remove heat energy from a room in a comparable way to air conditioners and therefore do not provide the same level of service. Evaporative coolers increase the relative humidity of the cooled air and reverse cycle air conditioners provide both heating and cooling options.

The 'whole of house' cooling systems were selected based on their ability to provide approximately 15kW cooling capacity. This figure is based on cooling and heating 80% of indoor space. Cooling capacity was based on 0.125 kW/m2 for living areas, and 0.08kW/m2 for bedrooms (SEAV 2005). A few suppliers have since commented that this estimate would be too low and that cooling capacity should be calculated on at least 0.15kW/m2 and even higher for second floors.

There is a significant difference in the efficiency of the two evaporative cooling systems. The 'whole of house' system is less efficient because the motor powering the system has to work harder to provide the cooling capacity required.

The data was entered into SimaPro to construct the LCA of the three different scenarios used in the body of the report.

- The 'whole of house' systems were modelled to remove 100% of the annual heating and cooling load calculated using Accurate.
- The 'part air conditioner' systems were modelled to remove 50% of the annual cooling load calculated, with fans catering for the rest. The heating systems were modelled to remove 100% of the heat load.

Selected Systems:

The following table presents the three scenarios modelled:

System type	System configuration	Market example	System capacity (kW)	Efficiency	Weight (kg)	Water use (L/year)	References
Reverse cycle ducted system (single phase inverter)	Average system (2.5 Star cooling, 2.5 Star heating)	Pioneer international MG-6-A/EH-6 (MAOC-6-A/EAOC-6)	14.24	2.56 Cooling 2.77 Heating	215	n/a	Details from *www.energy rating.gov.au*
	Leading system (4 Star cooling, 5 Star heating)	Actron Air SRA17C/SRA17E	16.8	2.95 Cooling 3.68 Heating	215	n/a	Highest performing system on *www.energyrating.gov.au*; details on *www.artronair.com.au*
Reverse cycle split system (single phase inverter)	Average system (2 Star cooling, 2.5 Star heating)	Daikin FTY35C	3.5	2.36 Cooling 2.8 Heating	39.5	n/a	Details from *www.daikin.com.au/home/pages/common/show-story.cfm?product_id=153*
	Leading system (6 Star cooling, 6 Star heating)	Fujitsu AWT14LSAZ/ AOT14LSAWC	4	3.8 Cooling 4.32 Heating	51.5	n/a	Highest performing system on *www.energyrating.gov.au*; details on *www.fujitsugeneral.com.au/awt14lsaz.php*
Evaporative cooling	Whole hose	Breezair (EXH210)	15.5	10.33	78	13400	Details from *http://www.breezair.com.au/brochures/SEEL0005_breezair_FINA:22_9.pdf*; water consumption from *http://www.savewater.com.au/default.asp?SectionId=603&CategoryId=31&ProductId=60*
	Living areas only	Breezair (EXH150)	9.8	17.8	77	13400	
Fans cooling	Single fan				6.5	n/a	
Fans heating	Leading system (5 Star)	LENNOX (G34M4-80)	19	0.87	60	n/a	*http://www.lennoxaus.com.au/pdf/LEN_019_DuctedHeatingInt.pdf*

Limitations/Assumptions:

- Heating and cooling is required to 80% of floor area.
- Ducting, piping and other materials were not included in the LCA.
- All systems were assumed to have an equal life span of 20 years.
- As evaporative cooling systems are not subject to appliance rating, it was difficult to get independently verified data on efficiency and water consumption.
- There is significant potential for efficiency losses in the duct work for ducted systems. Poorly installed ducted cooling systems also have potential to cause significant heat loss through the duct work in winter. This modelling exercise has assumed a high quality of installation.

Appendix 5 Transport Assumptions

Footprint results for four different transport scenarios were modelled for the Aurora Estate. The four scenarios included:

Scenario 1: Access to Train Services Immediately (average Melbourne Patronage)
Scenario 2: No Development of Train Line Extension
Scenario 3: Access to Train Services in 10 Years
Scenario 4: Access to Train Services immediately (double average Melbourne patronage).

An additional scenario was modelled for conventional greenfields development which had no access to the train.

The vehicles modelled were dependent on the scenarios. However, the modes of travel considered for the analysis included car, train, bus and motorcycle. Scenario 1 was established as a baseline scenario with the assumption that the residents of Aurora would follow typical Melbourne resident travel behaviour with a constant population and net travel distance. Estimates for tram use were excluded from all calculations on the basis that residents from the new estate would be more likely to be dependent on train and bus travel.

Total transport kilometres were used to estimate the CO_2 emissions which feed into the Footprint calculations. The following information details the assumptions and calculations used throughout the calculation of transport kilometres for the 3 scenarios.

The modelling of these scenarios is evidently a simplification of complex transport modelling scenarios. Aspects excluded from this analysis include, but are not limited to:

- Impact of car ownership
- Population density and household size
- Incomes
- Distance from local shops, city, places of work
- Impacts of fuel and vehicle prices

Local and Non Local Trips

Data from the ABS and other sources where used to estimate local trips as opposed to longer, commuter based trips. Table 6 shows that over half of the vehicle kilometres of typical Victorian are local trips. For the purpose of this study Aurora is assumed to have a 25% shift of local trips to bicycling and walking mode.

Table 6: Local and non local trip data

Purpose of journey	% kms	% Trips	Average minutes per trip	Distance (inferred)	% time spent in total	Total kms per capita per year	Proportion assumed to be local	Local km per capita per year	Not local per capita per year
Shopping	46.2	25.7	13	6	17.6%	1,454.76	75%	1,091.07	363.69
Work(a)	41.7	22	31	14	35.2%	2,905.76	10%	290.58	2,615.18
Social activities	36.3	18.7	20	9	19.2%	1,587.79	50%	793.89	793.89
Voluntary & community activities	17.8	9.3	18	8	8.5%	701.91	50%	350.95	350.95
Active leisure	16.7	7.4	32	10	8.4%	698.14	50%	349.07	349.07
Child care	12.9	9	13	5	5.1%	424.54	90%	382.09	42.45
Domestic activities	9.9	5.4	16	6	3.7%	305.67	90%	275.10	30.57
Education	4.7	2	22	8	1.8%	150.95	75%	113.21	37.74
Personal care	1.5	0.5	16	6	0.3%	28.30	50%	14.15	14.15
Passive leisure	* *	0.1	22	8	0.1%	7.55	50%	3.77	3.77
Total journeys	100	100						44%	56%

% km and trip breakdown is from ABS data, distance was inferred from trip type

Scenario 1: Access to Train Services Immediately

Total transport kilometres via transport modes were calculated by dividing the total number of Victorian passenger kilometres by the Victorian population (Australian Bureau of Statistics 2005). This was undertaken for each of the transport modes and illustrated in Tables A1, A3 and A4.

Car use, however, was disaggregated to account for the varying CO_2 emissions associated with vehicle operation. Disaggregation of vehicle kilometres was via Victorian vehicle sales documented by the ABS (2005). Allocation of the total passenger kilometres was then allocated along sale lines. Sales as a percentage of vehicle type reported by the ABS (2005) include:

- 65% passenger vehicle
- 17% sports utility
- 17% other

Table A1: Average car kms per person in Victoria

	Totals	Per capita car kms
Victorian population	4,872,500	8265.36
Total car kms	40,273,000,000	

Table A2: Total estimated vehicle kms for Aurora

Vehicle types	Totals	Total per capita vehicle Passenger kms	Local trips	Non local trips	Local trips reduction
Average Victorian car kilometres		8,265.37	44%	56%	25% of 44%
Passenger vehicles	65%	5,407.27	2,396.95	3,010.32	599.24
Sports utility*	17%	1,421.41	630.09	791.32	157.52
Other*	17%	1,436.69	636.86	799.83	159.22

* Numbers do not add due to rounding of figures in report

A similar methodology was followed in order to obtain the total number of passenger kilometres travelled by bus and motorcycle. Tables A3 and A4 illustrate these estimated average travel distances.

Table A3: Total estimated number bus kms for Aurora

	Totals	Per capita bus kms
Total Victorian bus kms	329,000,000	67.52
Total Victorian population	4,872,500	

Table A4: Total estimated number motorcycle kms for Aurora

	Totals	Per capita motorcycle kms
Total Victorian motorcycle kms	232,000,000	47.61
Total Victorian population	4,872,500	

Data for total passenger kilometres of train travel in Victoria could not be found. Subsequently, the total kilometres travelled via bus were subtracted from Moriarty's (Moriarty 1996) estimated passenger kilometres. The result was an estimated 732.48 per capita passenger kilometres. Light rail kilometres (tram) were allocated to train kilometres rather than subtracted from the equation.

Table A5: Total estimated number of public transport kms for Aurora

Train	Per capita train kms
Public train kms	732.48

Table A6: Summary of transport kms for scenario 1 Aurora

Vehicles mode	Total estimated kms travelled
Passenger Vehicles	4,808.03
Sports utility	1,263.89
Other	1,277.48
Train	732.48
Bus	67.52
Motorcycle	47.61

Scenario Baseline Conventional and 2: No Development of Train Line Extension

From the base scenario, the total number of train kilometres was reallocated to the other transport categories. The allocation of train kilometres and the total kilometres by transport mode is illustrated in Table A6.

Table A7: Total estimated kms travelled for scenario baseline conventional

Vehicle type	Train km allocation	Total kms
Passenger vehicles	40%	4,808.03
Sports utility	20%	1,263.89
Other	20%	1,277.48
Bus	10%	140.77
Motorcycle	10%	120.86

For Aurora local transport improvements are included in the results which reduce the road transport kilometres.

Table A8: Total estimated kms for scenario 2 – no train line extension

Redistributed PT kms to car kilometres	Total kms travelled via transport mode
Passenger vehicles	4,275.20
Sports utility	1,123.82
Other	1,135.91
Bus	140.77
Motorcycle allocation	120.86

Scenario 3: Access to Train Services in 10 Years

The method used to estimate the total number of kilometres travelled by vehicle type for Scenario 3 required the accumulation of vehicle kilometres over a 10 year period added to the total vehicle kilometres once a hypothetical train line to the estate is introduced. The modelling period in total was 40 years. This scenario included modelling an increasing level of train use over the time period up to average train kilometres identified in Scenario 1. The total uptake of train use was assumed to be 50% with a 25% uptake over the first 3 years and a subsequent 1% increase each year thereafter. Total kilometres travelled for each of the transport modes is illustrated in Table A7.

Assumptions associated with the subsequent reduction in total kilometres travelled via other modes were:

- 47% passenger vehicles
- 35% sports utility vehicles
- 10% other vehicles
- 6% bus
- 2% motorcycle

Table A9: Total estimated kms travelled over a 40 year period

	Total estimated passenger kms (Yr 1 – Yr 10)	Total estimated passenger kms (2015 – 2044)	Total estimated passenger kms for Scenario 3 (2005 – 2044)
Vehicles			
Passenger vehicles	57,002.57	163,448.52	220,451.09
Sports utility vehicles	15,679.05	43,257.58	58,936.63
Other	15,831.87	43,716.03	59,547.90
Motorcycle kms	1,208.62	1,736.07	2,944.69
Train kms	–	18,897.94	18,897.94
Bus kms	1,407.70	2,333.30	3,740.99
Total	91,129.81	273,389.43	364,519.24

Scenario 4: Train Now – Double Average Patronage

In this scenario, average rail patronage is assumed to be double the Victorian average, with these trips being subtracted from the vehicle Footprint.

Table A10: Total estimated kms travelled per year

Vehicles Mode	Total estimated kms travelled
Passenger Vehicles	4,381.94
Sports Utility	1,151.88
Other	1,164.27
Train	1,464.96
Bus	67.52
Motorcycle	47.61

The Footprint of energy land was calculated using the following formula:
(Total kms X CO_2 emission conversion) X land sequestration conversion (m^2) X equivalence factor (1.8) / 10000

The Footprint of built up land was calculated using the following formula:
Total kms X land conversion (m^2) X equivalence factor (2.9) / 10000

Table A11: Conversion of factors used

	Energy Land kg CO_2 / pkm	Built up land (m^2a)
Ride / Walk	0	
Tram	0.044	
Rail / City	0.058	0.0223
Rail Country	0.051	
Bus / City	0.11	0.0223
Bus / Country	0.07	
Air travel	0.200	0.0363
For 1 passenger		
Hybrid car	0.11	0.04
Small car	0.18	0.04
Family car	0.28	0.04
Large car (4WD)	0.37	0.04
Motorcycle	0.192	0.0455

Table A12: Equivalence factors used

Australia	Equivalence Factor [gha/ha]
Primary cropland	2.19
Marginal cropland	1.80
Forest	1.38
Permanent pasture	0.48
Marine	0.36
Inland water	0.36
Built	2.19

Appendix 6 Hot Water System Assumptions

Hot water system usage data for Victoria was taken from a Greenhouse Office Report (Redding Consulting Services 1999) (Redding Energy Management Pty Ltd (REM) 1999). The energy usage for different appliance types was taken from reports from Sustainable Energy Victoria report. (Sustainable Energy Authority Victoria 2002)

Figure 16: Market share percentages for domestic hot water systems:

	Electric	**Gas**	**LPG**	**Solar**
Victoria hot water service market share	38%	59%	3%	2%

Source: *http://www.greenhouse.gov.au/markets/mret/pubs/13_solar.pdf*

Figure 17: Hot water energy calculations

Hot water type	**Low energy cost**[1]	**High energy cost**[1]	**Average energy cost**[1]	**Tariff**	**Annual energy use**	**Assumed volume per year**	**Energy use per litre**
Unit			$ per annum per household	$/kWh or $/MJ	kWh or MJ	litres	kWh/l or MJ/l
Electric hot water (off peak power)	225	350	275	0.05	5500 kWh	80300	0.0685 kWh
Gas (range from storage and instantaneous)	175	300	225	0.0087	25862 MJ	80300	0.322 MJ
Solar gas storage backup	55	80	70	0.0087	8045 MJ	80300	0.100 MJ

Source: *http://www.sustainable-energy.vic.gov.au/ftp/advice/domestic/hotwater/Choosingahotwatersystem0_a.pdf*

[1] Energy cost per four person household per year

The infrastructure component (the hot water system) was taken from EcoInvent database and is therefore only indicative. A ten year life was assumed for the hot water system.

	Electric hot water	**Gas hot water**	**Solar gas backup**	**Conventional (Melbourne average)**	**Aurora (solar & 20% hot water saving)**
Electricity	0.4955			0.18829	
Natural gas	0	0.0915	0.0285	0.0573	0.0228
Infrastructure	0.0055	0.0055	0.0105	0.00571	0.0105

Appendix 7 Consumption Categories

Activity	Sub categories
Food	Plant-based Animal-based
Housing	New construction Maintenance Residential energy use
Mobility	Passenger cars and trucks Motorcycles Buses Passenger rail Passenger air Passenger boat
Goods	Appliances Furnishings Computers and electrical equipment Clothing and shoes Cleaning products Paper products Tobacco Other miscellaneous goods
Services	Water and sewage Telephone and cable Solid waste Financial and legal Medical Real estate and rental lodging Entertainment Government Other miscellaneous services

Source: Global Footprint Network and University of Sydney 2005

Appendix 8 Area types of the Ecological Footprint and Biocapacity Accounts

The accounts include six main bioproductive area types. Once the human impacts are expressed in global hectares, these components are added together.

Cropland

Growing crops for food, animal feed, fibre, and oil occupies cropland, the most productive land type. Food and Agriculture Organisation (FAO) estimates that there are about 1.5 billion hectares of cropland worldwide (FAO 2004b). Using FAO harvest and yield data for 74 major crops, the use of cropland for crop production was traced (FAO 2004b). These accounts may underestimate long-term productivity, since other impacts from current agricultural practices, such as long-term damage from topsoil erosion, salination, and contamination of aquifers with agro-chemicals, are not yet accounted for. Still, such damage will affect future bioproductivity as measured by these accounts.

Grazing Land

Grazing animals for meat, hides, wool, and milk requires grassland and pasture area. Worldwide, there are 3.5 billion hectares of natural and seminatural grassland and pasture. It is assumed that 100 per cent of pasture is utilized, unless pasture produces more than twice the feed requirement necessary for the grass-fed livestock. In this latter case, pasture demand is counted at twice the minimum area requirement. This means that the pasture Footprint per unit of animal product is capped at twice the lowest possible pasture Footprint per unit of animal product. This may lead to underestimating pasture demand since, even in low productivity grasslands, people usually allow grazing animals full range and thus create human demand on the entire available grassland. Diet profiles are created to determine the mix of cultivated food, cultivated grasses, fish products, and grazed grasses consumed by animals in each country. Each source of animal food is charged to the respective account (crop feed to the cropland Footprint, fish-based feed to the fishing ground Footprint, etc.). The embodied cropland and pasture is used with FAO trade data (FAO 2004b) to charge animal product Footprints to the consuming country.

The dividing line between forest areas and grasslands is not sharp. For instance, FAO has included areas with 10 per cent of tree cover in the forest categories, while in reality they may be primarily grazed. While the relative distribution between forest and grassland areas may not be accurate, the accounts are constructed to ensure no area is counted as more than one type of land.

Forest Area

Harvesting trees for timber and paper-making and gathering fuel wood require natural or plantation forests. Worldwide there are 3.9 billion hectares of forests according to FAO's most recent survey (FAO 2003). Forest productivities were estimated using a variety of sources (FAO 1997b, FAO 2000, FAO/UNECE 2000). Consumption figures for timber and fuel wood also come from FAO (2004b). The Footprint of fuel wood consumption is calculated using timber growth rates that are adjusted upward to reflect the fact that more forest biomass than merely round wood is used for fuel, and that less mature forests can be used for fuel wood production.

Fishing Ground

Fishing requires productive fishing ground. Most of the ocean's productivity is located on continental shelves. Excluding inaccessible or unproductive waters, these comprise 1.9 billion hectares. Although a mere fraction of the ocean's 36.3 billion hectares, they provide more than 95 per cent of the marine fish catch (Postma and Zijlstra 1988). Inland waters consist of an additional 0.4 billion hectares, making 2.3 billion hectares of potential fishing grounds out of the 36.6 billion hectares of ocean and inland water that exist on the planet. FAO fish catch figures (FAO 2004b, FAO 2002) were used, and compared with FAO's 'sustainable yield' figure of 93 million tonnes per year (FAO 1997a). The accounts include both fish catch for fishmeal and fish for direct human consumption. Also, bycatch was added to each country's reported fish catch to account for discarded fish.

Built-Up Land

Infrastructure for housing, transportation, industrial production, and capturing hydroelectric power occupies built-up land. This space is the least documented, since low-resolution satellite images are not able to capture dispersed infrastructure and roads. Data from CORINE (EEA 1999), GAEZ (FAO/IIASA 2000), and GLC (JRC/GVM 2000) were used to reach a global total of 0.2 billion hectares of built-up land. Built-up land is assumed to have replaced cropland, as human settlements are predominantly located in the most fertile areas of a country. For this reason the 0.2 billion hectares of built-up land appear in the Ecological Footprint accounts as 0.44 billion global hectares.

'Energy Land'

Burning **fossil fuel** adds CO_2 to the atmosphere. The Footprint of fossil fuel is calculated by estimating the biologically productive area needed to sequester enough CO_2 to avoid an increase in atmospheric CO_2 concentration. Since the world's oceans absorb about 1.8 Giga tonnes of carbon every year (IPCC 2001), only the remaining carbon emission is accounted for in the Ecological Footprint. The current capacity of world average forests to sequester carbon is based on FAO's Global Fibre Supply Model (FAO 2000) and corrected where better data are available from other FAO sources such as FAO/UNECE 2000, FAO 1997b, and FAO 2004b. Sequestration capacity changes with both the maturity and composition of forests, and with shifts in bioproductivity due to higher atmospheric CO_2 levels and associated changes in temperature and water availability. Other possible methods to account for fossil fuel use would result in even larger Footprints (Wackernagel and Monfreda 2004; Dukes 2003).

Each thermal unit of **nuclear energy** is counted as equal to a unit from fossil energy. This parity was chosen to reflect the possibility of a negative long-term impact from nuclear waste.

The **hydropower** Footprint is the area occupied by hydroelectric dams and reservoirs, and is calculated for each country using the average ratio of power output to inundated reservoir area for the world's 28 largest dams.

The net **embodied energy in trade** (which by definition balances for the globe as a whole) is calculated using trade statistics broken down into 109 product categories. The energy intensities used for each category stem from a variety of sources (IVEM 1999, Hofstetter 1992). This calculation is based on averages for the 1990s. This segment of the Ecological Footprint accounts will be improved in the future by using more detailed national trade data and more accurate embodied energy figures. **Embodied energy** is the energy used during a product's entire life cycle for manufacturing, transportation, product use, and disposal.

(Taken from Living Planet Report 2004.
See *http://assets.panda.org/downloads/lpr2004.pdf*)

Global Footprint Network and its partner organisations are in the process of developing Ecological Footprint standards – technical and communication. This report endeavours to comply with early drafts of these Ecological Footprint Standards and Certification protocols. Further information on the standards is available at www.footprintstandards.org

Appendix 9 Ecological Footprint Factors

The Ecological Footprints in this report are quoted in global average hectares (Gha) which represent hectares of land with average global productivity. Much of the analysis of house construction and use was undertaken using Life-Cycle Assessment (LCA) software which provided results in terms of actual land areas used by processes such as timber growing, cropping and land covered by buildings. Additionally the LCA provides greenhouse emissions in kilograms of carbon dioxide equivalents. To calculate ecological Footprint from these results, conversion factors are applied taken from the national accounts for Australia developed by the Global Footprint Network. The factors are shown in Table 6 and consist of two parts. The equivalence factor shows the average productivity between different land uses. For example cropping land is more productive than grazing land, and is therefore weighted more highly in calculation of the ecological Footprint. The second factor, the yield factor, adjusts Australian land relative to global average land so that Footprints can be compared between different countries. All the yield factors for Australian land are less than one, indicating it is less productive than world average land, which has the effect of reducing the final Footprint results when converting to global hectares.

The energy land calculation is based on the land required to absorb carbon dioxide from energy production, after accounting for the fraction of carbon dioxide which is absorbed by the oceans. Each 3,703 kg of carbon dioxide represents 1 global hectare of energy land.

Table 7: Equivalence and yield factors for converting Australian land use into global average hectares

Land Type	**Equivalence factor**	**Yield factor**	**Combined factor for converting actual Australian land use to Global average hectares**
	[Gha/ha]	Australian land productivity as a fraction of global land productivity	
Primary Cropland	2.19	0.90	2.179
Forest	1.38	0.31	0.32
Grazing land	0.48	0.77	0.29
Built	2.19	0.90	0.537
Energy land	kgCO_2/Gha		3703

Source: Global Footprint Network

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