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Waikato Region Ecological Footprint 2004

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Waikato Region

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EXECUTIVE SUMMARY

This report estimates the Ecological Footprint of the Waikato Region for the year ending March 2004. The Ecological Footprint measures the total amount of productive land (in hectares) required to support a given population. It is increasingly being used as an indicator of sustainability performance after being developed by Mathias Wackernagel and William Rees in the early 1990s.

An input-output framework based on Bicknell *et al*. (1998) and extended by McDonald (2000, 2001, 2001a), McDonald and Patterson (2003, 2004), and Patterson and McDonald (2002) is used in this report to calculate Waikato Region's Ecological Footprint.

WAIKATO REGION'S ECOLOGICAL FOOTPRINT

The Waikato Region's Ecological Footprint was calculated to be 1,405,612 ha (848,225 excluding fishing grounds). This represents the total amount of land required to sustain the Region's population. It consists of inputs of Grazing Land (371,313 ha), Crop Land (3,042 ha), Forest Land (92,075 ha), Degraded/Built-up Land (199,679 ha), Energy Land (181,516 ha) and Fishing Grounds (557,387 ha).

The amount of usable land available in the Waikato Region is calculated to be 1,689,100 ha. Usable land is defined as the total land area of the Region excluding parks, reserves and non-productive land. On this basis, residents of the Waikato Region 'undershoot' their 'carrying capacity' by 840,875 ha, or by 50 percent. It is not surprising however that Waikato residents do not exceed their carrying capacity – as the Waikato's rural hinterland is more than capable of supporting its population base.

The per capita footprint for the Waikato Region is calculated to be 3.68 ha (2.2 ha excluding fishing grounds). This was compared with the per capita footprint of other countries after making adjustments for land productivity, as recommended by Wackernagel and Rees (1996) and Hails (2006). On an adjusted basis, Waikato's Ecological Footprint increases to 5.80 gha (global ha per person[1]) (including fishing grounds), due to New Zealand land being more productive than the global average. The United States (9.6 gha per capita), Canada (7.6 gha per capita), Finland (7.6 gha per capita), Australia (6.6 ha per capita) and Sweden (6.1 gha per capita) all had higher adjusted per capita Ecological Footprints than the Waikato Region. These differences can be explained by higher incomes, higher levels of material affluence and consumption in these countries. There are however a number of countries that have higher per capita GDP than the Waikato Region, but somewhat surprisingly have lower Ecological Footprints per capita: United Kingdom (5.6 gha per capita), France (5.6 gha per capita), Switzerland (5.1 gha per capita), Ireland (5.0 gha per capita) and Japan (4.4 gha per capita). There appears to be a greater "decoupling" between economic growth (GDP per capita) and the Ecological Footprint (embodied land per capita) in these countries, seemingly due to higher population densities. This is usually, but not always, associated with urbanisation, diet, lifestyle, and technological efficiencies, all of which reduce land and resource use.

[1] A global hectare (gha) is hectare with world-average ability to produce resources and absorb wastes (Hails, 2006).

The Waikato Region has a positive Ecological Balance of Trade of 1,253,126 ha. This indicates that the region is able to satisfy much of its demand for goods and services, particularly food related products.

ASSESSING THE SUSTAINABILITY PERFORMANCE OF THE WAIKATO REGION

The sustainability performance of the Waikato Region is assessed against two criteria:

- *Ecological Footprint Per Capita*. This measures the amount of land appropriated by a person in supporting their consumption. The smaller this amount of land the more sustainable this pattern of consumption is deemed to be.
- *Degree of Overshoot.* It is argued that to be sustainable, a population must consume less embodied land than the amount of useful land that is available. That is, the population must live within its "carrying capacity" or "bio-capacity". If the population "overshoots" its carrying capacity by using too much land, then it is argued that this amount of land cannot sustain the population.

In terms of total land appropriated, the Waikato Region 'undershoots' its 'carrying capacity'. On a per capita basis, Waikato's Ecological Footprint of 2.2 ha (excluding fishing grounds) is also significantly lower than the New Zealand average of 3.40 ha. There thus appears to be a greater level of "decoupling" between economic growth (GDP per capita) and the Ecological Footprint in the Waikato Region compared with other areas in New Zealand. The Waikato Region's comparatively low Ecological Footprint per capita is also a result of the region having land productivities above the national average, meaning less land is required to produce the same amount of product which deflates the per capita footprint measure, i.e. the land from which products are derived is more productive and therefore less of it is required.

OUTSTANDING RESEARCH ISSUES

This analysis represents the second comprehensive and systematic quantification of the Waikato Region Ecological Footprint. It is a significant update of the 2000 Ecological Footprint Report prepared for Environment Waikato. Specific improvements include: (1) greater resolution of the within economy transactions. In particular, the footprinting analysis has been extended from 23 to 48 industries. This has led to more accurate results particularly regarding the appropriation of agricultural land (as it relates to diet) and to degraded and energy land – via accounting for different transport modes; and (2) the development of 'extended footprint' reporting including not only 'embodied land' requirements, but also important other resources such as delivered energy by type (aviation fuel, diesel, fuel oil, geothermal, LPG, natural gas, petrol, wood and black liquor), energy related air emissions associated with combustion of each delivered energy type (CO_2, N_2O and CH_4), and solid waste. Nevertheless, the Waikato Ecological Footprint could be further improved by (1) developing productivity indices for each New Zealand region. This would substantially improve the goods-based components of the Ecological Footprint i.e. agricultural land; and (2) adding to the number of resources, pollutants and emissions analysed in the 'extended footprint'. In these respects, the appropriation of water and its associated discharge (including pollutants) are critical strategic issues within the Region. In relation to the appropriation of ecosystem services, crude estimates of the value derived from the Waikato's biodiversity have previously been made by Patterson and Cole (1999), but further work is required to take these from region-wide to industry based estimates.

1 INTRODUCTION

1.1 SCOPE OF THE REPORT

This report represents an update of the 2000 Ecological Footprint (EF) Report undertaken for Environment Waikato by McDermott – Fairgray Group Ltd (McDonald, 2000). The EF is increasingly being used as an indicator of sustainability, after originally being developed at the University of British Columbia's School of Community and Regional Planning in the early 1990s by Mathias Wackernagel and William Rees.

Specific research objectives for this report are:

- To develop a scientifically defensible and replicable framework upon which the Waikato Region's natural resources (land, water, air, energy etc) and emissions (pollutants, wastes etc) may be footprinted.
- To calculate a land-based EF for the Waikato Region for the base year ending March 2004 using the above framework. These calculations will pay particular attention to disaggregating the EF into its component land types (Crop, Grazing, Forest, Degraded, Energy and Fishing) and according to categories of commodities that are consumed.
- To compare the Waikato Region's EF with the last EF undertaken for Environment Waikato in 2000, New Zealand and other nations to understand the key reasons behind any significant differences.
- To identify and briefly discuss any theoretical and methodological limitations of the EF not identified in the earlier report, particularly as it relates to the foregoing analysis and calculations.

1.2 THE ECOLOGICAL FOOTPRINT CONCEPT AND ITS MEASUREMENT

1.2.1 What is the Ecological Footprint?

The EF is defined by Rees (2000, p 371) as the "area of productive land and water that ecosystems require to produce the resources that a population consumes, and assimilate the wastes that a population produces, wherever on Earth that land and water may be located". It can be seen as a 'sustainability indicator' in two senses. First, it measures the total ecological cost (in land area) of supplying goods and services to a human population. This recognises that people not only *directly* require land for agricultural production, roads, buildings and so forth, but also *indirectly* via manufactured goods and services. In this sense, the EF can be used to make visible the 'hidden' ecological cost of an activity or population.

A second and more controversial interpretation of the EF as a sustainability indicator invokes the idea of 'carrying capacity'. In ecology, carrying capacity is the maximum population a given land area can support indefinitely. The idea is relatively straightforward when applied to well-defined biological populations, e.g., a certain number of hectares are required to support a herd of deer. If the number of deer exceeds the carrying capacity then the population is said to be in "overshoot". Resources (mainly food) will therefore become scarce and population dieback will occur. This idea is more controversial when applied to human populations, as in the

"Limits to Growth" study, which predicted a decline in global human population as it overshot its carrying capacity (Meadows *et al*., 1972; Meadows *et al*., 1992). Based on this second interpretation Wackernagel and Rees (1997) argue that the EFs of most developed nations are unsustainable as they exceed their available bio capacity. For example, Hails (2006) estimates the EF of France is 339 million gha, compared with its bio capacity of 180 million gha, resulting in a considerable population overshoot. At the global level the EF for humanity exceeds global bio capacity by 0.4 gha per person or 25 percent (Hails, 2006).

1.2.2 How is the Ecological Footprint Calculated?

Several methods have been advanced for calculation of the EF. Refer, for example, to Wackernagel and Rees (1996), Folke *et al*. (1997), Bicknell *et al*. (1998), Wackernagel *et al*. (1999), Loh (2000), van Vuuren and Smeets (2000) and so on. Although each of these methods has its own peculiarities and insights, many have their roots in the work of Wackernagel and Rees (1996).

1.2.3 Input-Output and Ecological Footprinting

In this report, input-output analysis is used to calculate the Waikato Region EF[2]. This makes explicit the direct plus indirect (embodied) land required to support local consumption. This framework of analysis was first developed in the early 1970's by analysts such as Herendeen (1972), Hite and Laurent (1971) and Wright (1975). These input-output methods were not only applied to resource inputs (into the economy) but also to pollutant outputs (from the economy).

Carter, Peet and Baines (1981) pioneered the use of input-output analysis in New Zealand for calculating the embodied energy content of output from various sectors in the economy. Initially, Peet and his colleagues calculated embodied energy requirements based on the 1971-72 input-output table of the New Zealand economy, but subsequently updated this analysis to cover the 1976-77 and 1981-82 input-output tables (Peet, 1985). In addition, they extended their analysis to cover dynamic input-output scenario models, employment issues, New Zealand's energy balance of trade, and more recently, CO_2 policy issues.

McDonald (1994, 1995, 1995a, 1997) and Patterson and McDonald (1996) undertook an input-output analysis of the Manawatu Wanganui and Wellington Regions to quantify the indirect land, water and air emissions and water pollutants embodied in the Regions' economic products. This analysis used data primarily from Regional Council consents and monitoring databases, and used regionalised versions of the national input-output table. This work was extended in the *Eco*Link project (McDonald and Patterson (1999, 1999a) and McDonald and LeHeron (1999, 1999a)) sponsored both by councils (including Environment Waikato) and the Ministry for the Environment's Sustainable Management Fund. This project quantified ecological multipliers[3] (direct and indirect effects) for land energy, greenhouse gases, water

[2] An input-output table is an economic statement of the industrial structure of an economy for a given year. It records how much each industry purchases from, and sells to, other industries and also measures the indirect relationships between industries.

[3] An ecological multiplier measures the total amount of 'embodied' resources/emissions per unit of industry output ($).

takes/discharges and water pollutants for all territorial local authorities in the Northland, Auckland and Waikato Regional Council areas.

Bicknell *et al*. (1998) specifically developed a new methodology, using New Zealand as an example, for calculating national EFs based on input-output analysis. This methodology was the first published application of input-output analysis for calculating EFs, which has since been extended by analysts such as Ferng (2001) and Lenzen and Murray (2001). More recently McDonald (2000, 2001, 2001a) and McDonald and Patterson (2003, 2004) have used an input-output framework to trace land embodied in interregional trade. Additionally, Patterson and McDonald (2002) have used an input-output framework to calculate various ecological multipliers for the New Zealand tourism industry. These multipliers show that the indirect environmental effects of tourism in New Zealand are very significant, and challenge the idea that tourism in New Zealand is "clean and green".

1.3 KEY DEFINITIONS

1.3.1 Location Quotient

Location quotients are discussed in the results section of this report. They are used to gain insights into the economic strengths and weaknesses of the Waikato Region.

A location quotient is a measure of the extent to which a particular economic industry is under or over-represented in an economy. If the location quotient is less than one (LQ<1) then the economic industry is under-represented in the region compared with the nation. In other words, the industry is unable to satisfy local demand for its products and therefore imports from elsewhere will probably be required. By corollary, if the location quotient is greater than one (LQ>1), then that economic industry is over-represented in the region.

It is preferable to measure the location quotient in terms of monetary value-added. However, such data is not available at a regional level in New Zealand. Instead, we have relied on employment as a surrogate measure for value-added. This surrogate measurement assumes that the labour productivity for a given industry in a region is the same as for that given industry nationally.

1.3.2 Ecological Footprint Components

Rees (2000) defines the EF as the "area of productive land and water that ecosystems require to produce the resources that a population consumes, and assimilate the wastes that a population produces, wherever on Earth that land and water may be located". This definition is used in this report, with the exception that water ecosystems are not included[4].

This update of the Waikato EF consists of six different types of land:[5]

- *Grazing land*. This is land used for food and fibre production consisting primarily of dairy, sheep, beef and other livestock farming.

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[4] Water ecosystems have been excluded from this analysis due to technical difficulties and data paucity.

[5] In the 2000 report a combined 'crop and grazing land' known as 'agricultural land' was used. Separation into crop and grazing land, however enables more accurate estimates of the EF, in particular comparison with EFs calculated elsewhere. Furthermore, an additional category has been used to account for fishing grounds.

- *Crop land*. This is land used for food and fibre production, encompassing horticulture, cropping, vegetable and fruit growing.
- *Forest land*. This land is used for the production of commercial forests. It does not include non-commercial forests, such as those in National Parks or those in the conservation estate. Furthermore, it does not include the hypothetical planted forest land required to sequester CO_2 emissions.
- *Degraded land*. This represents built-up areas that host human settlement. This includes land used for housing, commercial and governmental purposes, as well as land covered by the transport network.
- *Energy land*. This represents the hypothetical amount of land planted in forest that is required to sequester CO_2 emissions resulting from the burning of fossil fuels.
- *Fishing grounds.* This is the coastal marine area covered under the jurisdiction of Environment Waikato i.e. the 12 nautical mile limit.

Different industries in international, national and regional economic systems utilize these six categories of land. There is a complex pattern of 'flow' of these land types through and between these economic systems.

1.4 REPORT STRUCTURE

This report begins by exploring the EF concept and, in turn, outlines a framework for comprehensively footprinting the Waikato Region's resources (land, and energy) and emissions (pollutants, waste etc). The framework is then applied to calculate a land-based EF for the Waikato Region (Section 3). This builds on recent EF work undertaken by McDonald (1997, 2000, 2001, 2001a), McDonald and LeHeron (1999, 1999a), McDonald and Patterson (1999, 1999a, 2003, 2004), Patterson and McDonald (1996, 2002) and McDonald, Forgie and MacGregor (2006). Section 4 of the report provides an extended footprint by reporting on appropriation of energy be delivered type, energy related emissions (CO_2, N_2O and NH_4) and solid waste. The final section of this report (Section 5) provides conclusions and recommendations.

2 METHODOLOGY

2.1 RATIONALE FOR THE INPUT-OUTPUT FRAMEWORK

Much of the EF work undertaken to date is based on methodologies that lack formal structure. Some approaches may even be considered to be *ad hoc*. (McDonald and Patterson, 2003, 2004). A major limitation of such methods is that they may lead to results that are not easily reproduced, either through time or across space. In turn, this restricts comparability and may lead to inconsistencies that are more an artefact of the method than actual occurrence.

Very recently, the calculations for global and national Ecological Footprints have been standardised within the National Footprint Accounts (Hails, 2006). Nevertheless, a variety of approaches exist for calculating the EF of cities and regions. Broadly speaking, these approaches may be divided into two categories: (1) 'process based' – using production recipes and statistical data to allocate national per capita footprints to consumption categories and, in turn, scaling the national per capita footprints up or down to reflect local consumption patterns and (2) 'input-output based' – allocating overall demand via industry relationships to consumption categories. In this report the latter of the two approaches is adopted.

Input-output analysis, developed by Wassily Leontief during the 1930s, provides a comprehensive snapshot of the structure of inter-industry linkages in an economy. Most developed nations prepare input-output tables at regular intervals. Generally speaking, an input-output table of a nation is conceptually reconcilable with its System of National Accounts (SNA). In addition, input-output tables adopt internationally recognised systems of commodity/industry classification, e.g., the International Standard Industrial Classification (ISIC). This facilitates comparison over time, between nations and with standard economic aggregates such as GDP and balance of trade.

Although input-output tables are usually presented in monetary terms, authors such as Daly (1968), Isard (1968), Leontief (1970) and Victor (1972) have demonstrated that biophysical information on resource use and pollution generation may also be placed in the input-output framework. A major strength of input-output analysis is that it may be used to calculate the *indirect* effects of economic change, including indirect effects relating to resource use and pollution generation, if this information is included in the input-output table. For example, the indirect (or embodied) land required to produce a kilogram of butter includes not only the land used directly in manufacturing, but all land embodied in the inputs that went into producing the butter – dairy farm land, land required to produce the packaging and so on.

The major advantages of using an input-output framework to calculate the EF are:

- It is a more comprehensive method covering a wider range of inputs than the *ad hoc* methods. Typically, for example, *ad hoc* methods tend to ignore service sector inputs (banking, insurance, government etc) all of which have significant embodied land inputs. This neglect of several categories of inputs typically reduces the magnitude of the calculated EF. The mathematics of input-output analysis also means that the first, second, third … n^{th} round effects (infinite regress[6]) can be more accurately and comprehensively calculated.

- It is a systematic method. The input-output tables provide a convenient checklist to ensure that all flows in an economy are taken into account. The 'conservation' principle (inputs = outputs) of input-output accounting further ensures that there are no unintentional 'blind spots', as all inputs and outputs must be accounted for.
- Input-output analysis avoids a number of methodological problems – viz: (a) double-counting is a problem in *ad hoc* methods particularly when dealing with complicated networks of indirect flows that have significant feedbacks; (b) joint production causes problems when using *ad hoc* methods due to the need to 'allocate' land inputs across multiple commodities from a sector.
- It is a mathematically rigorous method. The use of matrix algebra is not only efficient in dealing with large datasets, but also enables analysis to be undertaken in an internally consistent mathematical framework.

The major disadvantages in using the input-output method for calculating EFs are:

- The input-output sector categories are often too broad which can lead to inaccurate results. For example, the type of food consumed by a person is a well-known determinant of the size of that person's EF. The input-output tables usually do not provide enough disaggregation into different food types to take account of these dietary differences – typically there might be only one input-output sector category representing 'food' that does not even distinguish between meat and vegetable consumption.
- Accurate and up-to-date input-output tables often do not exist. For example, in New Zealand, national-level input-output tables are only produced on a 5 yearly basis, and there is often a delay of up to 5 years before they are published. This could be problematical, particularly if there has been rapid technological or structural change in the economy over the intervening years. Furthermore, survey-based regional input-output tables do not exist in New Zealand, requiring estimation using semi-survey methods (e.g., the GRIT method).

Bicknell *et al.* (1998) was the first to attempt to generate Ecological Footprints using Input-Output Analysis. Authors such as Barrett (2001), Ferng (2001), Lenzen and Murray (2001, 2003), McDonald and Patterson (2003, 2004), Wiedmann *et al.* (2006) and McDonald *et al.* (2006). have improved and extended the input-output based approach to Ecological Footprinting.

2.2 DATA SOURCES

The presented methodology is applied to the Waikato Region for the financial year ending March 2004. Data sources are categorised into two groups below: 'bottom up' and 'top down'. Bottom up refers to datasets that are built-up from local data sources, whereas top down refers to datasets that are derived (using various methods) from spatial units larger than the region (e.g., from the nation). Generally speaking, top down datasets are employed when bottom up datasets are (a) too costly or too time consuming to develop, and/or (b) only partial in coverage.

[6] In an 'infinite regress' situation the individual indirect contributions become progressively smaller and smaller with each subsequent round.

Bottom up datasets employed in calculating the Waikato Region's EF include:

- *Land use data*. This data is based on data gathered from Quotable Value New Zealand (2004), Agriquality New Zealand's Agribase (2004), Ministry of Agriculture and Forestry (2004), and Works Consultancy Services Ltd (1996).
- *Employment data*. Employment figures are used in producing the Waikato Region input-output table (refer to the GRIT regionalisation in Section 2.3.1). These figures are extracted from Statistics New Zealand's Business Directory (2005).
- *Population estimates*. This data has been derived from usually resident census figures (Statistics New Zealand, 2001) and from sub-national population estimates produced by Statistics New Zealand (2004).

Top down datasets employed in calculating the Waikato Region's EF include:

- *Regional input-output tables*. The Waikato Region's input-output table is based on the national level Inter-industry Study of the New Zealand Economy 1995-96 produced by Statistics New Zealand (2001). The national table has been updated for volume and price changes to March 2004.
- *Energy related CO_2 emissions*. These estimates are derived from the Energy Efficiency Conservation Authority's (2002) Energy Database which provides estimates for Waikato Region. The estimates have been updated to 2004 using (1) FTE scalars at an industry level and (2) population estimates for household consumption.
- *Sequestration rate*. The conversion of CO_2 emissions into Energy Land is based on sequestration work undertaken by Hollinger *et al*. (1993). They estimate that on average a hectare of *Pinus radiata* in New Zealand absorbs 3.6 t of C per ha, which equates to 0.0758 ha per t of CO_2.

2.3 METHODOLOGY FOR MEASURING ECOLOGICAL FOOTPRINTS USING AN INPUT-OUTPUT FRAMEWORK

In this report a framework based on input-output analysis is developed that (a) provides a formal structure for EF calculations, (b) permits calculation of the EF at a regional (sub-national) level, and (c) makes explicit interregional appropriation of biologically productive land. The method presented assumes the reader is familiar with the technical and mathematical aspects of input-output analysis. If not, the reader is directed to McDonald and Patterson (2003) where a step-by-step example is available.

Essentially, the method requires the calculation of EF components as defined by the following accounting identity:

$$\text{EF} \equiv \alpha + (\beta_1 + \beta_2 + ... + \beta_n) + \chi, \qquad (1)$$

Where:

$\alpha =$ land appropriated from within the region

$\beta_1, \beta_2, ..., \beta_n =$ land appropriated from other regions (1…*n*)

$\chi =$ land appropriated internationally.

2.3.1 Generation of the Waikato Region Input-Output Table

The method begins with calculation of input-output tables for Environment Waikato and for all its trading partners. These tables are derived using the GRIT (Generation of Regional Input-Output Tables) methodological sequence (see Jensen *et al.*, 1979; West *et al.*, 1980)[7]. This method consists of a series of mechanical steps that reduce national input-output coefficients to sub-national (regional) equivalents, while providing opportunities for the insertion of 'superior data'. It is most frequently utilised, as in this report, when time, cost and data constraints preclude generation of input-output tables based on survey data. For a fuller description of the GRIT methodological sequence and how it is applied the reader is directed to Jensen *et al.* (1979).

2.3.2 Estimation of Land Appropriated from within the Waikato Region

Determining the land appropriated from within the Waikato Region to support its residents requires three steps. In brief:

1. *Calculate economic interdependencies[8] in the Waikato Region economy*. This is important because the contribution of an industry to the Waikato Region economy is not solely limited to the value it creates directly – an increase in demand for the goods/services it provides may have repercussionary effects throughout the economy. Such repercussionary effects are easily captured using the Leontief Inverse Matrix in input-output analysis. Mathematically, the Leontief Inverse Matrix is calculated as $(\mathbf{I} - \mathbf{A})^{-1}$ where $\mathbf{A}$ is a matrix of Waikato Region technical coefficients and $\mathbf{I}$ an identity matrix of the same dimensions.
2. *Calculate the land embodied in the Waikato Region economic interdependencies*. This requires a vector of land-to-output ratios (land coefficients) i.e. the total land used in each sector divided by its corresponding economic output. Premultiplying the Leontief Inverse Matrix, $(\mathbf{I} - \mathbf{A})^{-1}$, by the land coefficients (in diagonal matrix form), $\hat{\mathbf{B}}$, produces a matrix, $\mathbf{C}$, representing the direct plus indirect land supporting economic production within the City. Mathematically, this may be expressed as $\mathbf{C} = \hat{\mathbf{B}}\,(\mathbf{I} - \mathbf{A})^{-1}$.
3. *Calculate the share of land embodied in the economic interdependencies that supports solely Waikato residents*. This requires apportioning the embodied land supporting economic production within the City (as calculated in Step 2) between that which supports domestic consumption (i.e. as consumed by Waikato residents) and that which passes out of the Region as exports. Domestic consumption is determined directly from the household consumption column in the Waikato Region input-output table. Multiplying the matrix of direct plus indirect requirements, $\mathbf{C}$, by a matrix representing household consumption (in diagonal matrix form), $\hat{\mathbf{D}}$, produces a matrix of the embodied land supporting household consumption within the Region. Mathematically, $\mathbf{E} = \mathbf{C}\,\hat{\mathbf{D}}$. Summing

[7] Studies that have applied the GRIT method in New Zealand include Hubbard and Brown (1981), Butcher (1988), Kerr, Sharp and Gough (1986), Ministry of Agriculture (1997), McDonald (1994, 1995, 1995a, 1997, 1999), McDonald and Patterson (2003, 2004) and Patterson and McDonald (2004).
[8] Interdependencies in this context refer to inter-linkages between economic industries in the Environment Waikato economy.

the elements of this matrix provides an estimate of the land appropriated from within Waikato Region to supports its residents, i.e. 'α' in the EF accounting identity

2.3.3 Estimation of Land Appropriated from Other Regions

Land embodied in interregional trade may have a considerable influence on the size of the EF. It is argued here that not only must the size of such a contribution be known, but also the locations from where it originated. Adjustments can then be made for differences in biological productivity resulting from land management practices utilised and environmental factors such as soil type, climatic conditions and so on. In this way, significantly improved interpretations of the EF are possible. This requires three steps:

1. *Calculate interregional trade flows*. One possible method for determining the origin of interregional land appropriated is to solve an optimisation problem. Essentially, a problem is solved such that the level of interregional trade (by sector) between any permutations of regions can be defined. A full description of this optimisation problem is given in Appendix A of McDonald and Patterson (2003). The optimisation assumes that the major considerations when trading are (a) availability of goods/services and (b) road freight travel time. These are common considerations in logistics operations. Minimisation of road freight travel is set as the objective function, while known levels of imports/exports for each industry (by region) are used to formulate binding constraints.
2. *Determine the direct and indirect land appropriated from other regions*. The land embodied in interregional imports is derived by premultiplying the matrix of interregional imports by the direct plus indirect land requirements needed to make them. This is analogous to performing steps 1 to 3 of Section 2.3.2 for each region trading with the region of interest. One important assumption is however that imported goods and services are essentially final or finished goods. This implies that only backward linkages through the economy in the region of origin require measurement. If, however, the imported goods require further processing in the Waikato Region then forward linkages may also need to be estimated. The measurement of backward linkages alone may lead to underestimation of the EF.
3. *Apportion the direct and indirect land requirements between domestic consumption and exports*. Not all of the interregional land appropriated supports domestic (household) consumption. A portion passes out of the Waikato as land embodied in exports. The fraction supporting domestic consumption is obtained directly from the household consumption column in the Region's input-output table (as per Section 2.3.2). Multiplying the embodied interregional land appropriated from each region by the fraction of final demand representing household consumption produces an estimate of the embodied interregional land supporting Waikato residents. Summing the results for each region provides estimates of $\beta_1, \beta_2, ..., \beta_n$ in the EF accounting identity.

2.3.4 Estimation of Land Appropriated from Abroad

Land embodied in international goods/services imported into the region, like land embodied in interregional imports, may represent a considerable portion of the region's EF. Determining this component is however fraught with difficulties. Ideally this would involve the acquisition of detailed trade information by economic activity for each international trading partner. While detailed trade information is available from the internationally recognised Harmonised System, this data is only in monetary terms - little, if any, data is available to convert it into land terms. Furthermore, where information does exist it is usually partial in coverage, poorly documented, and eclectic in source. Much work is required to avoid such problems, but this is beyond the immediate scope of this study. Instead this report follows Bicknell *et al*. (1998), McDonald (2003, 2004) and McDonald *et al*. (2006) in assuming that international land management practices are similar to those employed within New Zealand as a whole. In this way, crude estimates of the land embodied in international imports can be made.

The calculation procedure is similar to that employed in estimating the land embodied in interregional trade. First, international imports are pre-multiplied by the direct plus indirect land requirements (based on the surrogate New Zealand figures) needed to make them. This derives the amount of land embodied in international imports. Second, the land embodied in goods/services consumed domestically must be separated from that which is exported. This is undertaken by multiplying the international land appropriated by the fraction of final demand (i.e. the household consumption column in the Waikato Region input-output table) consumed locally. Summing the results provides an estimate of χ in the EF accounting identity.

2.3.5 Energy land

The above calculation takes no account of the hypothetical land required to absorb the CO_2 emissions produce by Waikato residents. The calculation procedure is analogous to that described in Sections 2.3.2 to 2.3.4 above. There are however two major differences. Firstly, the land-to-output ratios (for Waikato Region, its trading partners, and the New Zealand surrogate) are replaced with CO_2-to-output ratios. Secondly, the final CO_2 estimates produced are converted into land equivalents using a sequestration rate of 3.6 t of C per ha (Hollinger *et al*., 1993). This is the sequestration rate for *Pinus radiata* in New Zealand.

3 THE WAIKATO REGION'S ECOLOGICAL FOOTPRINT

3.1 PROFILE OF THE REGION

The Waikato Region is the fourth largest region in New Zealand, with an area of approximately 2.5 million hectares. It is a geographically diverse region encompassing the rugged Coromandel Peninsula in the north, the fertile and gently rolling pasturelands around the Waikato River, the hilly King Country areas in the south west, and the volcanic plateau in the south.

The Waikato Region is also the fourth largest in terms of population (an estimated 381, 900 for June 2004), with approximately 75 percent of this population living within urban areas. With respect to population density, the Region ranks sixth out of the sixteen regions in the country at 15.3 people per km^2. The major employers in the Region are Retail Trade (17,104) Dairy Farming (13,355), Business Services (12,166), Health and Community Services (12,166), Construction (11,982) and Education (10,326).

Farming, in particular, is of critical importance to the Region's economy, with over three-quarters of the Region's productive land area devoted to this activity (Statistics New Zealand, 1998). Dairy Farming is clearly the dominant farming industry and, notably, is the largest industry contributor to GRP ($1,365 million; 10.9 percent of total 2004 GRP). Gentle topography, high quality pasture and ample rainfall make many areas within the Region particularly suited to dairy farming, as is illustrated by the industry's location quotient (LQ) of 3.83. Dairy Product Manufacturing (LQ 2.80) and Other Farming (LQ 2.05) are also important industries within the Region.

In addition to farming, the Region is notable for containing large tracts of plantation forests (310, 000 ha), located predominantly around the Taupo and South Waikato areas. The three forestry related industries, Forestry and Logging, Wood and Wood Product Manufacturing, and Pulp and Paper Manufacturing all have relatively high location quotients (LQs 2.00, 1.84 and 1.46 respectively). The Region also contributes significantly to the electricity generation within New Zealand as it is home to twelve hydropower, one thermal and five geothermal power stations. In 1998 these accounted for nearly three-quarters of the North Island's generation capacity.

Many manufacturing and service industries are relatively weak within the Region's economy e.g. Other Food Manufacturing (LQ 0.4), Furniture and Other Manufacturing (LQ 0.57), Insurance (LQ 0.41) and Finance (LQ 0.56). The Region does however exhibit a relative strength in education, mainly through the presence of Waikato University, WINTEC (Waikato Institute of Technology), Te Wananga O Aotearoa and, to a lesser degree, English language schools.

3.2 OVERALL ECOLOGICAL FOOTPRINT

The Waikato Region has an EF of 848,225 ha (excluding fishing grounds) for the year ending March 2004.[9] This represents 6.1 percent of New Zealand's EF and

[9] These figures (and those presented below) represent actual biological productive land areas needed to satisfy current levels of domestic final demand. These results are based on local rather than global

equates to approximately 50 percent of the Region's bio capacity. This also compares with an estimated productive land area for the region 1,689,100 ha meaning that the region has an 'ecological surplus' of 840,875 ha. The Waikato Region is therefore self-sufficient and is not ecologically dependent on land appropriated from other regions or overseas. In fact, the Waikato Region is an 'ecological exporter' of embodied land – both regionally within New Zealand and to other nations.

On a per capita basis the Waikato Region has a slightly lower EF at 2.2 ha (excluding fishing grounds) than the New Zealand average of 3.40 ha per capita.

3.3 Comparison with Other Countries

The Waikato Region's EF per capita of 3.68 ha per person (including fishing grounds) can be compared with the per capita footprint for different countries. However, according to the internationally recognised standards put forward by the Global Footprint Network (see Hails (2006)), this requires the Waikato footprint to be adjusted for:

- *Global yields*. Hails (2006) estimates New Zealand's average grazing land yield factor to be 2.5, with the average yield factors for crop land and forest land estimated to be 2.2 and 2.5 respectively. In the case of built-up land the crop land yield factor is applied. Fishing grounds are assumed to have a yield factor (explained below) of 0.2. New Zealand average yields are applied, as the Waikato Region yields were not available.
- *Biological equivalence factors*. The following equivalence factors based on Hails (2006) were applied: for crop land 2.21, for forest Land 1.34 and for grazing land 0.47. The equivalence factor (explained below) for crop land was used as a proxy for built-up areas. Fishing grounds were assigned an equivalence factor of 0.36.
- *Global average CO_2 sequestration rate*. Loh (2000) estimates the world average carbon absorption (including roots) to be 0.956 t of C per ha. In accordance with Hails (2006) oceans are also assumed to take up 35 percent of CO_2 emissions.

Essentially, the first two points adjust the international data to allow for land productivity differences between different types of land across the globe. The basic premise in these adjustments is that land is of different quality, and therefore land productivity factors need to be applied, to reflect the relative 'usefulness' of different types of land. In this sense, a hectare of New Zealand grazing land is 2.5 times more 'useful' (productive) than the global average, and a quality factor needs to be applied to the data to account for this difference.

Once these adjustments have been made, Wackernagel and Rees (1996), Loh (2000), Hails (2006) and others argue that the EF of different countries can be validly compared. For example, following these adjustments, the Waikato Region's EF is

average yields. No adjustments are made for differences in biological productivity between land types when aggregating. This facilitates comparison with the earlier Environment Waikato studies by Bicknell *et al.* (1998) and McDonald and Patterson (2003, 2004).

5.80 gha per person, and it can then be compared with adjusted EFs for other countries (Figure 3.1).

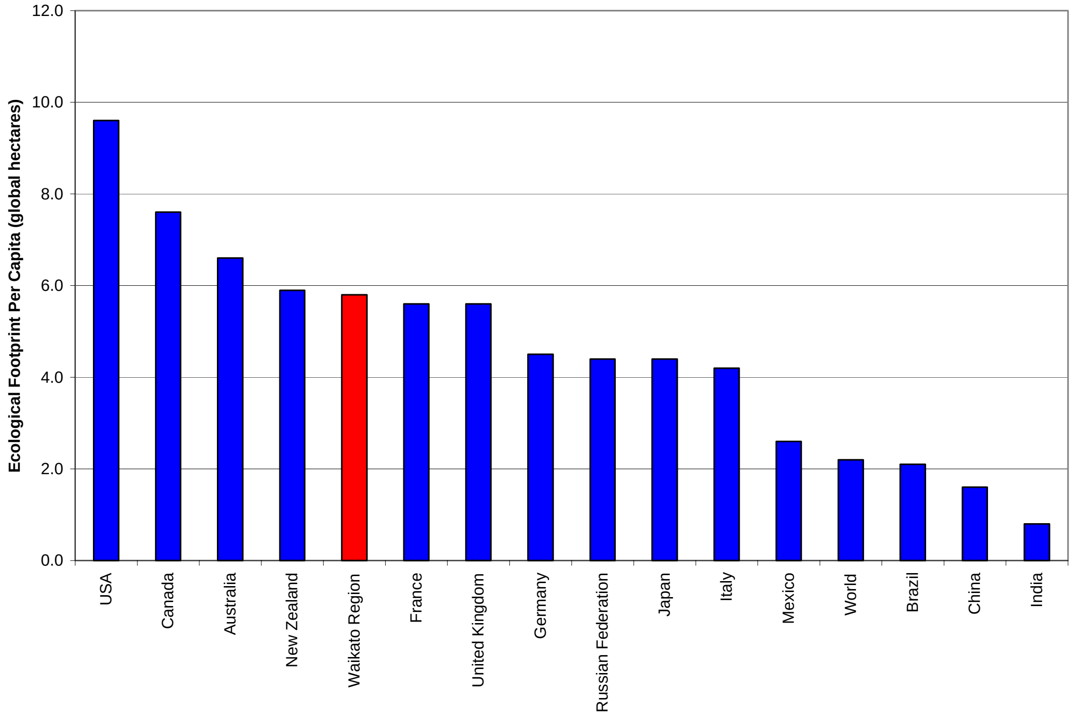

Figure 3.1 Ecological Footprints of Selected Nations, 2003 (Source: Hails (2006) and This Study)

The United Arab Emirates has the highest adjusted EF per capita at 11.9 gha per person followed by the United States at 9.6 gha per person. The average US citizen therefore has an EF 66 percent higher than the average resident of Waikato Region. This is due to the greater affluence and higher level of material consumption of US citizens. Not only do US citizens consume more products than an average Waikato resident (the US GDP per capita is about twice New Zealand's GDP per capita), US citizens live energy intensive lifestyles (largely based on fossil fuel consumption) as reflected in the high Energy Land component of their footprint. Other countries that have higher EFs per capita than Waikato include: Canada (6.1 gha per capita), Australia (6.6 gha per capita) and Sweden (6.1 gha per capita). These differences can be explained by the higher income and therefore higher material consumption of these countries.

A number of countries that have higher per capita GDP than the Waikato Region, but somewhat surprisingly have lower EFs per capita are United Kingdom (5.6 gha per capita), France (5.6 gha per capita), Switzerland (5.1 gha per capita) Ireland (5.0 gha per capita) and Japan (4.4 gha per capita). There seems to be a greater 'decoupling' between economic growth (GDP per capita) and the EF (embodied land per capita) in these countries than in the Waikato. There are a number of possible explanations for this. Firstly, a number of these countries have high population densities (the United Kingdom and Japan) which means that the energy used in transport is likely to be less and urban compaction also leads to other land-use efficiencies that do not occur in the Waikato Region. Secondly, in some cases lifestyle patterns and diet play a role, e.g. vegetarian diets have smaller energy and land requirements (Japan).

There could also be genuine technical efficiency improvements in these countries that reduce the size of their EFs.

There are a bracket of poorer countries in Figure 3.1 that have considerably lower EFs per capita than the Waikato Region: South Africa (2.3 gha per capita), Malaysia (2.2 gha per capita), China (1.6 gha per capita) and India (0.8 gha per capita). All of these countries have significantly less GDP per capita, and hence less expenditure on material goods and less resource intensive lifestyles. Most notably, the average Indian citizen has an EF over 7 times smaller than the average Waikato resident.

3.4 Ecological Footprint Disaggregated by Land Type

Grazing land consists of land used for sheep and beef, dairy and mixed livestock. The rich pastures of the Waikato region support intensive farming, with 75 percent (1,270,250 ha) of biologically available land in grazing, arable or fodder use. The region is one of the most significant dairy regions in New Zealand, with the majority of farms located in the Waikato Basin and in the Hauraki Plains. Domestic final demand for grazing land by Waikato residents appropriates 371,313 ha or 0.97 ha per Waikato resident (Table 3.1).

Crop land incorporates land used for horticulture, cropping, vegetable and fruit growing. Although the Waikato Region is New Zealand's second largest kiwifruit growing region (787 ha as at 30 June 2003), it accounts for only 10 percent of that grown by the largest region. The Region has little comparative advantage in fruit growing when compared with the Bay of Plenty (kiwifruit, avocados), Hawke's Bay (apples, wine grapes), Gisborne (wine grapes), Tasman (apples) and Marlborough (wine grapes). The Waikato Region has, however, the largest harvest of onions and potatoes. The Waikato Region is also the second largest grain growing region in the North Island (15,300ha), just behind the Manawatu Wanganui Region. In total Waikato residents appropriate 3,642 ha of crop land; 2,157 ha or 59 percent of this crop land is appropriated from within the Region itself. Overall, crop land appropriation amounts to 0.1 ha per resident or only 0.4 percent of the Region's EF (excluding fishing grounds).

Table 3.1 Waikato Region's Ecological Footprint by Land Type, 2003-04

Land type	Within region land	Land from other NZ	Land from other nations	Total land	Total land	Total land
	ha	ha	ha	ha	ha per capita	% of total
Grazing land	241,329	6,653	123,331	371,313	0.97	43.78
Crop land	2,157	56	1,429	3,642	0.01	0.43
Forest land	67,435	1,660	22,979	92,075	0.24	10.85
Degraded land	178,161	3,527	17,991	199,679	0.52	23.54
Energy land	147,990	2,166	31,361	181,516	0.48	21.40
Total	637,072	14,063	197,090	848,225	2.22	100.00
Fishing grounds	200,385	118,500	238,502	557,387	1.46	N/A
Total incl fishing grounds	837,457	132,563	435,592	1,405,612	3.68	N/A

Forest land includes exotic plantings used for commercial gain. It does not include the hypothetical forest planted to sequester CO_2 emissions. The Waikato region forms part of the largest forestry area in New Zealand, this is mostly *Pinus radiata* although small plantings of Douglas fir and some other varieties do exist. The majority of this estate is located on the volcanic plateau, with smaller holdings on the Coromandel Peninsula, Lower Waikato and King Country/West Coast. A total of 67,435 ha or 73 percent of total forest land is appropriated from within the region. On a per capita basis, forest land appropriation amounts to 0.24 ha, or 10.9 percent of the region's EF (excluding fishing grounds).

Degraded land represents built up areas that host human settlements. Degraded land accounts for 23.5 percent of the Waikato region EF (excluding fishing grounds) and equates to 0.52 ha of biologically productive land per Waikato resident. Some 178,161 ha or 89 percent is appropriated intra-regionally. This is comprised of land used for residential, commercial and governmental[10] purposes. It also captures the regions road network, which exceeds 10,000km including 1,600km of national highways, the highest of any region (Works Consultancy Services, 1996). This is the third highest of any region in New Zealand, accounting for in excess of 11.0 percent of the total national road length. This reflects the Region's importance as a corridor between the lower and upper North Island.

Energy land is a measure of the hypothetical planted forest needed to sequester CO_2 emissions. It accounts for 181,516 ha or 21.4 percent of the Region's EF. This is relatively low when compared to most developed nations, but coincides with other rural regions in New Zealand and the nation as a whole. Hail (2006), for example, estimates Australia's energy land contribution to be 52 percent, Canada's to be 54 percent and the United States' at 59 percent.

There are three main reasons why the Waikato Region energy land footprint is comparatively low. First, CO_2 emissions are very efficiently absorbed by New Zealand's commercial (*Pinus radiata*) forests. Hollinger *et al*. (1993) estimate that an average hectare of *Pinus radiata* in New Zealand absorbs 3.6 t of C per ha, which is considerably higher than the global average of 0.96 t of C per ha used by Wackernagel and Rees (1996). Secondly, the Waikato Region (as with the rest of New Zealand) has relatively low CO_2 emissions compared with energy consumption. This is because a significant proportion of the nation's electricity is generated from hydro-electric sources. In most developed countries however fossil fuels (which result in increased CO_2 emissions) are used to generate electricity. Thirdly, the Waikato economy focuses on less energy intensive agricultural production rather than more energy intensive industrial production.

The energy produced from the Huntly (coal fired) power station is excluded from this analysis on the basis that it enters the national electricity grid and is not solely consumed in the Waikato Region[11]. Instead, a proportional share of the Huntly emission are attributed to the Waikato Region based on industry and household electricity usage. Carbon dioxide emissions for electricity were calculated to be 620,930 t or 17.2 percent of total Waikato emissions. This figure was derived as a weighted mean of all sources of electricity in New Zealand (including hydropower,

[10] Large commercial land users include office space, private schools and hospitals, shopping malls and wholesalers/retailers, holiday parks, car parks, golf courses and so on. Large government land users include central government administration, local government administration, public schools and hospitals, justice (e.g. prisons) and defence (e.g. military camps and training grounds).

[11] This power station are thought to produce an annually combined CO_2 emission total of around 2.9 million tonnes (Piggot, 2000). Using Hollinger *et al*. (1993) CO_2 sequestration factor this equates to around 222,000 ha or 0.6 ha per capita.

natural gas, geothermal and so on). In this way, the New Zealand average CO_2 emission factor for electricity was applied.

3.5 Ecological Footprint Disaggregated by Goods and Services Purchased

The Waikato Region EF may also be viewed from the perspective of products consumed. Specifically, the region's EF consists of land embodied in various products purchased by households from economic sectors. For the purpose of reporting, these products have been grouped according to purchases from the:

- Agricultural sector
- Forestry sector
- Fishing and hunting sector
- Mining and quarrying sector
- Manufacturing sector
- Utilities and construction sector
- Service sector

A further category (domestic final demand) represents:

- Products purchased directly by households from abroad, including goods purchased from local retailers that are made overseas but sold only with an additional margin
- Land occupied directly by household dwellings and sections.

The majority of land (i.e. not including fishing grounds) appropriated, 75.1 percent (637,072ha), originated from within the region, while 23.2 percent and 1.7 percent were embodied respectively in international and inter-regional imports (Table 3.2). Interestingly, in excess of 54 percent (1.22 ha per person) of this land was appropriated by the manufacturing and service industries. In the case of manufacturing, which includes dairy, meat and timber processing, this is a consequence of backward linkage purchases of agricultural and forestry products.

Table 3.2 Environment Waikato's Ecological Footprint by Economic Products, 2003-04

Economic industry	Within region land	Land from other NZ	Land from other nations	Total land	Total land	Total land
	ha	ha	ha	ha	ha per capita	% of total
Agriculture	18,007	16	729	18,752	0.05	2.21
Fishing	12	0	1	14	0.00	0.00
Forestry	10,004	5	46	10,056	0.03	1.19
Mining & quarrying	630	3	134	767	0.00	0.09
Manufacturing	137,322	1,127	27,981	166,429	0.44	19.62
Utilities & construction	69,294	637	7,811	77,742	0.20	9.17
Services	262,249	2,480	34,803	299,532	0.78	35.31
Domestic final demand	139,555	9,794	125,584	274,933	0.72	32.41
Total	637,072	14,063	197,090	848,225	2.22	100.00

Service sector products are often 'considered' to have a small land component due to the limited land area that services directly occupy. This is however a deceptive indicator. The biologically productive land area appropriated by the Waikato Region services (excluding cultural recreation services) is 40 times greater than the actual land occupied by these services. This is because the service sector resides at the top of the production chain and is therefore characterised by significant upstream linkages – all of which appropriate land, e.g. land embodied in purchases of computers, paper, office equipment, furniture, carpet and catering.

The land embodied in the purchase of agriculture sector products by households amounts to 18,752 ha. This represents 2.1 percent of the Waikato's EF (excluding fishing grounds), and is much smaller than the purchase of manufacturing and service sector products. Most of the agriculture sector products require processing by the manufacturing sector before being sold to households. However, fresh fruit and vegetables for example, are sold to householders without any further processing and it is these types of purchases that are included in the region's footprint as land embodied in agriculture sector products.

The land embodied in the direct purchase of utilities (water, gas and electricity) and construction services by households is 77,742 ha, or 9.2 percent of the Waikato Region's EF. The majority (89.1 percent) is appropriated from within the Waikato itself. These sectors do require a significant amount of inputs (e.g. plant and equipment) from abroad.

Households (domestic final demand) directly purchase products that are imported from overseas eg, computers, electronics, motor vehicles, and so forth. This includes goods that are imported directly by retailers and wholesalers and then resold without further processing to households with an additional mark-up. The embodied land associated with such purchases is estimated to be 125,584 ha (with the retail margin for these purchases being included in the service sector). These purchases of imported products by householders make up 14.8 percent of the Region's footprint (excluding fishing grounds).

3.6 ECOLOGICAL BALANCE OF TRADE AND ECOLOGICAL INTERDEPENDENCIES

The Waikato Region economy not only produces products for its own consumption, but also provides products to other regions and countries. Similarly, it also requires products from elsewhere to meet its needs. Overall, the Waikato Region is a significant exporter of embodied land, or put alternatively, the Region has an ecological balance of trade surplus of 1,253,126 ha (refer to Table 3.3).

Table 3.3 indicates that 206,231 ha of land were appropriated from outside the region to support domestic consumption, while 1,459,357 ha were embodied in exported goods and services. Thus, the Waikato Region is a substantial net exporter of biologically productive land, exporting 7.0 times the land supporting domestic consumption. A total of 887,444 ha of land was embodied in goods/services exported internationally, with a further 571,912 ha embodied in goods/services exported inter-regionally. Land embodied in agricultural products is the Waikato Region's primary ecological export. This is not surprising given the region's comparative advantage in agricultural production.

3.6.1 Exports and Imports by Type of Land

The Waikato Region is a large net producer of agricultural land (refer to Table 3.3). Grazing land embodied in imports (118,504 ha) is considerable smaller than that embodied in exports (1,212,167 ha). Of the total exported grazing land, some 58.9 percent is exported to abroad. Much of the grazing land embodied in the Region's exports is associated with dairy farming.

Table 3.3 Environment Waikato's Ecological Balance of Trade by Land Type, 2003-04

Land type	Land embodied in	Land embodied in	Balance of trade
	ha	ha	ha
Interregional trade			
Grazing land	9,709	498,267	488,558
Crop land	75	1,197	1,122
Forest land	2,570	41,737	39,167
Degraded land	5,574	8,193	2,619
Energy land	2,710	22,519	19,808
Interregional balance of trade	20,639	571,912	551,273
International trade			
Grazing land	108,795	713,901	605,105
Crop land	539	6,054	5,515
Forest land	24,912	77,719	52,807
Degraded land	14,456	25,283	10,828
Energy land	36,890	64,487	27,598
International balance of trade	185,591	887,444	701,853
Balance of trade	206,231	1,459,357	1,253,126

The remaining land types all have relatively small trade surpluses in comparison with grazing land: crop land (6,637 ha), forest land (91,973 ha), degraded land (13,446 ha), and energy land (47,406 ha). Most notable is the forestry land embodied in the Region's exports (119,456 ha) – this is not surprising however given the Region comparative advantage in forestry production.

3.7 Comparison of Waikato Region Ecological Footprints Across Time

The 2004 EF for the Waikato Region of 848,225 ha (excluding fishing grounds) is a quite significant reduction (approximately 20 percent) from the 1997/98 EF calculated for the Waikato Region of 1,048,760 ha (McDonald, 2001). There is however limited value that can be obtained in undertaking direct comparisons between the two EFs. This is due to:

- *1986/87 NZSIC based IO versus 1995/96 ANZSIC based IO.* The original 1997/98 EF study, conducted on a 23 industry level, was based on Statistic

New Zealand's 1986/87 inter-industry study of the New Zealand economy. The central government reforms of the fourth Labour government were only just underway at this time and thus the economy of the era was highly regulated with significant inefficiencies, as captured in inter-industry linkages i.e. indirect effects were much larger than they are today. By comparison, the current EF study is based on the 1995/96 ANZSIC inter industry study. At this date the New Zealand economy had undergone significant restructuring with the emergence of a more '*Laissez Faire'* economy with lesser interconnections (ie indirect effects).

- *Aggregation bias.* Importantly, the 1998 model was based on 23 industries while the current study is based on 48 industries (disaggregation to 48 industries was not possible due to technical constraints in the earlier (McDonald, 2001) study. The greater the aggregation of industries within the local economy, the greater the assumed self sufficiency. This is because different sub-industries do not produce homogenous products despite being classified in the same industry. The greater the self-sufficiency the greater the assumed connectivity within the local economy and therefore indirect effects. This results in overestimation of the land appropriated within the local economy.

Given these limitations, one should focus not on direct comparisons between absolute EFs and per capita EFs, but rather on the changes that have occurred in the types of land appropriated and the proportions appropriated by different industries. The results show that there has been relatively little change in the types of land appropriated by Waikato residents. The proportions of energy land and forest land in the 1997/98 EF (20.0 percent and 11.3 percent respectively) are, for example, very similar to the proportions of energy land and forest land in the current EF (21.4 percent and 10.3 percent) respectively. There has however been some decrease in the proportion of agricultural land appropriated; in the 1997/98 study agricultural land accounted for 54.6 percent of the total EF while in the current study, the two agricultural land categories (grazing land and crop land) account for only 44.2 percent. This is primarily the result of fewer inter-linkages between industries and, thus, less embodied land requirements through indirect effects.

In terms of land appropriated by different industries, the Agriculture, Forestry, Mining and Quarrying and Utilities and Construction industries have remained relatively small appropriators of land (respectively 4.9 percent, 0.5 percent, 0.0 percent and 7.2 percent in 1997/98 and 2.2 percent, 1.2 percent, 0.1 percent and 9.2 percent in the current study). The proportion of land appropriated by the Manufacturing industry has however fallen quite considerably from 41.8 percent to 19.6 percent. This has been compensated by increases in the proportion of land appropriated by Services (from 27.6 percent to 35.3 percent) and Domestic Final Demand (from 18.0 percent to 32.4 percent).

3.8 FOOTPRINTING OF OTHER RESOURCES

Although the EF, as applied in this report, refers to the land embodied in goods and services consumed by Waikato residents, it is also relevant and possible to footprint other resources (e.g. water, energy, biodiversity etc) and emissions (wastes, pollutants etc). Furthermore, for footprinting to be useful as a policy tool it is necessary that greater detail is provided. As a first step toward this 'wider' definition of footprinting, Tables 3.4 to 3.14 to illustrate footprints for energy use, electricity use, petrol use, diesel use, energy related CO_2 emissions, energy related N_2O emissions, energy related CH_4 emissions, and solid waste (excluding cleanfills).

The delivered energy embodied in service industry products (7,976,652 GJ) and products consumed by households (19,028,493 GJ) account for the two largest proportions of the delivered energy footprint (20.9 percent and 49.9 percent respectively). In both instances, the majority of this delivered energy is appropriated from within the Region itself (88.2 percent for Services and 81.0 percent for Domestic Final Demand). It is notable that the products from each of the primary industries, Agriculture, Fishing, Forestry and Mining and Quarrying, are negligible (Table 3.4).

Table 3.4 Waikato Region's Delivered Energy Footprint by Economic Industries, 2003-04

Economic industry	Within region delivered energy	Delivered energy from other NZ regions	Delivered energy from other nations	Total delivered energy	Total delivered energy	Total delivered energy
	GJ	GJ	GJ	GJ	GJ per capita	% of total
Agriculture	120,197	382	15,310	135,890	0.36	0.40
Fishing	1,498	17	109	1,623	0.00	0.00
Forestry	59,560	136	1,777	61,474	0.16	0.18
Mining & quarrying	56,746	96	4,530	61,372	0.16	0.18
Manufacturing	2,573,134	38,369	951,348	3,562,851	9.33	10.40
Utilities & construction	3,035,447	13,820	382,085	3,431,352	8.98	10.02
Services	7,033,931	53,982	888,739	7,976,652	20.89	23.28
Domestic final demand	15,419,280	306,916	3,302,297	19,028,493	49.83	55.54
Total	28,299,793	413,717	5,546,195	34,259,705	89.71	100.00

Service industry products and products consumed by households account for the largest proportions of electricity use (Table 3.5) and its associated CO_2 emissions (Table 3.6) appropriated in the Region (25.7 percent and 27.3 percent respectively). Service sector industries reside near the top of the production chain and have significant backward linkages. In this way, service industry purchases (e.g. paper, equipment, machinery etc) can account for substantial amounts of electricity. By contrast, the electricity embodied in purchases from the remaining industries of the economy is relatively small.

Table 3.5 Waikato Region's Delivered Energy Electricity Footprint by Economic Industries, 2003-04

Economic industry	Within region electricity	Electricity from other NZ regions	Electricity from other nations	Total electricity	Total electricity	Total electricity
	GJ	GJ	GJ	GJ	GJ per capita	% of total
Agriculture	19,527	68	3,533	23,129	0.06	0.28
Fishing	101	2	8	111	0.00	0.00
Forestry	8,883	23	576	9,483	0.02	0.11
Mining & quarrying	11,749	12	1,326	13,087	0.03	0.16
Manufacturing	441,477	4,274	276,723	722,473	1.89	8.69
Utilities & construction	529,551	2,595	115,009	647,156	1.69	7.78
Services	1,913,306	10,770	213,280	2,137,357	5.60	25.70
Domestic final demand	3,960,363	64,605	738,245	4,763,212	12.47	57.28
Total	6,884,958	82,350	1,348,700	8,316,007	21.78	100.00

Table 3.6 Waikato Region's CO_2 Electricity Footprint by Economic Industries, 2003-04

Economic industry	Within region electricity CO_2	Electricity CO_2 from other NZ regions	Electricity CO_2 from other nations	Total electricity CO_2	Total electricity CO_2	Total electricity CO_2
	t	t	t	t	t per capita	% of total
Agriculture	1,113	4	201	1,318	0.00	0.28
Fishing	6	0	0	6	0.00	0.00
Forestry	506	1	33	540	0.00	0.11
Mining & quarrying	669	1	76	746	0.00	0.16
Manufacturing	25,154	244	15,767	41,165	0.11	8.69
Utilities & construction	30,173	148	6,553	36,874	0.10	7.78
Services	109,017	614	12,152	121,783	0.32	25.70
Domestic final demand	225,654	3,681	42,064	271,399	0.71	57.28
Total	392,292	4,692	76,846	473,830	1.24	100.00

The vast majority of petrol use (Table 3.7) and its associated CO_2 emissions (Table 3.8) are appropriated through household purchases (89.9 percent). The service industry is the only other industry from which product purchases account for more than 5 percent of the total petrol use and associated CO_2 emission footprints. In all instances, the energy and associated CO_2 emissions appropriated from within the Region itself are significantly higher than that appropriated from other regions within New Zealand e.g. in the case of manufacturing, 80.8 percent is appropriated from within the Waikato Region and only 1.4 percent from other New Zealand regions.

Table 3.7 Waikato Region's Delivered Energy Petrol Footprint by Economic Industries, 2003-04

Economic industry	Within region petrol	Petrol from other NZ regions	Petrol from other nations	Total petrol	Total petrol	Total petrol
	GJ	GJ	GJ	GJ	GJ per capita	% of total
Agriculture	14,798	26	364	15,188	0.04	0.16
Fishing	12	0	1	13	0.00	0.00
Forestry	6,848	9	52	6,909	0.02	0.07
Mining & quarrying	2,503	4	84	2,591	0.01	0.03
Manufacturing	90,245	1,597	19,823	111,666	0.29	1.15
Utilities & construction	188,988	1,046	8,081	198,116	0.52	2.04
Services	612,380	3,169	28,386	643,936	1.69	6.63
Domestic final demand	8,441,030	76,429	215,243	8,732,702	22.87	89.92
Total	9,356,805	82,280	272,035	9,711,120	25.43	100.00

Table 3.8 Waikato Region's CO_2 Petrol Footprint by Economic Industries, 2003-04

Economic industry	Within region petrol CO_2	Petrol CO_2 from other NZ regions	Petrol CO_2 from other nations	Total petrol CO_2	Total petrol CO_2	Total petrol CO_2
	t	t	t	t	t per capita	% of total
Agriculture	986	2	24	1,012	0.00	0.16
Fishing	1	0	0	1	0.00	0.00
Forestry	456	1	3	460	0.00	0.07
Mining & quarrying	167	0	6	173	0.00	0.03
Manufacturing	6,010	106	1,320	7,437	0.02	1.15
Utilities & construction	12,587	70	538	13,195	0.03	2.04
Services	40,785	211	1,891	42,886	0.11	6.63
Domestic final demand	562,173	5,090	14,335	581,598	1.52	89.92
Total	623,163	5,480	18,118	646,761	1.69	100.00

Diesel use (Table 3.9) and its associated CO_2 emissions (Table 3.10) are appropriated by four main industry groupings in the Waikato Region, namely: Domestic Final Demand (34.9 percent), Services (32.8 percent), Utilities and Construction (16.7 percent) and Manufacturing (13.3 percent). Compared with petrol use a greater proportion of diesel and its associated CO_2 emissions are embodied goods and services purchased from abroad.

Table 3.9 Waikato Region's Delivered Energy Diesel Footprint by Economic Industries, 2003-04

Economic industry	Within region diesel	Diesel from other NZ regions	Diesel from other nations	Total diesel	Total diesel	Total diesel
	GJ	GJ	GJ	GJ	GJ per capita	% of total
Agriculture	68,631	114	2,497	71,243	0.19	1.21
Fishing	1,025	9	70	1,105	0.00	0.02
Forestry	38,755	35	329	39,119	0.10	0.66
Mining & quarrying	31,086	26	673	31,784	0.08	0.54
Manufacturing	617,324	20,086	146,016	783,426	2.05	13.25
Utilities & construction	919,386	3,829	63,602	986,817	2.58	16.69
Services	1,744,135	15,230	178,839	1,938,204	5.08	32.78
Domestic final demand	1,160,606	71,252	828,591	2,060,450	5.40	34.85
Total	4,580,949	110,581	1,220,617	5,912,147	15.48	100.00

Table 3.10 Waikato Region's CO_2 Diesel Footprint by Economic Industries, 2003-04

Economic industry	Within region diesel CO_2	Diesel CO_2 from other NZ regions	Diesel CO_2 from other nations	Total diesel CO_2	Total diesel CO_2	Total diesel CO_2
	t	t	t	t	t per capita	% of total
Agriculture	4,715	8	172	4,894	0.01	1.21
Fishing	70	1	5	76	0.00	0.02
Forestry	2,662	2	23	2,687	0.01	0.66
Mining & quarrying	2,136	2	46	2,184	0.01	0.54
Manufacturing	42,410	1,380	10,031	53,821	0.14	13.25
Utilities & construction	63,162	263	4,369	67,794	0.18	16.69
Services	119,822	1,046	12,286	133,155	0.35	32.78
Domestic final demand	79,734	4,895	56,924	141,553	0.37	34.85
Total	314,711	7,597	83,856	406,165	1.06	100.00

CO_2 emissions embodied in good and services appropriated by Waikato Region residents are recorded in Table 3.11. Like delivered energy use, service industry products (54,915 t) and products consumed by households (1,279,321 t) account for the two largest proportions of the CO_2 footprint (22.6 percent and 53.4 percent respectively). In both cases, the majority of this CO_2 is appropriated from within the Region itself (86.8 percent for Services and 79.3 percent for Domestic Final Demand). Overall, Waikato Region residents appropriate on average 6.27 t of CO_2 per annum.

Table 3.11 Waikato Region's CO_2 Footprint by Economic Industries, 2003-04

Economic industry	Within region energy related CO_2	Energy related CO_2 from other NZ regions	Energy related CO_2 from other nations	Total energy related CO_2	Total energy related CO_2	Total energy related CO_2
	t	t	t	t	t per capita	% of total
Agriculture	8,297	26	1,205	9,528	0.02	0.40
Fishing	104	1	8	112	0.00	0.00
Forestry	4,013	9	130	4,152	0.01	0.17
Mining & quarrying	3,928	7	332	4,267	0.01	0.18
Manufacturing	213,575	2,666	72,607	288,848	0.76	12.06
Utilities & construction	238,016	982	28,423	267,422	0.70	11.17
Services	469,359	3,781	67,774	540,915	1.42	22.59
Domestic final demand	1,014,989	21,100	243,231	1,279,321	3.35	53.43
Total	1,952,282	28,573	413,710	2,394,565	6.27	100.00

Waikato residents appropriated some 212,381 kg of embodied N_2O per annum through energy related uses (Table 3.12). Or put alternatively, 0.56 kg per capita. As with the above categories domestic final demand (i.e. households) is the largest appropriator accounting for 53.9 percent of total N_2O emissions. Household emissions of N_2O are primarily generated through the combustion of transport related fossil fuels.

Table 3.12 Waikato Region's N_2O Footprint by Economic Industries, 2003-04

Economic industry	Within region energy related N_2O	Energy related N_2O from other NZ regions	Energy related N_2O from other nations	Total energy related N_2O	Total energy related N_2O	Total energy related N_2O
	kg	kg	kg	kg	kg per capita	% of total
Agriculture	749	2	92	844	0.00	0.40
Fishing	14	0	1	16	0.00	0.01
Forestry	377	1	14	393	0.00	0.18
Mining & quarrying	487	1	45	533	0.00	0.25
Manufacturing	15,563	326	7,473	23,362	0.06	11.00
Utilities & construction	23,164	91	3,804	27,059	0.07	12.74
Services	39,426	334	6,006	45,765	0.12	21.55
Domestic final demand	88,572	1,959	23,879	114,410	0.30	53.87
Total	168,353	2,714	41,314	212,381	0.56	100.00

Energy related CH_4 emissions appropriated by Waikato residents are recorded in Table 3.13. This table shows that Services and Domestic Final Demand (i.e. households) account for the greatest proportion of emissions. Notably, this table records only CH_4 emissions generated though energy use with other sources of CH_4, such as that released through dairy farming, not included. As with N_2O emissions, household emissions of CH_4 are generated though combustion of transport related fossil fuels and also through purchases of goods and services which involve energy use in their production.

Table 3.13 Waikato Region's CH_4 Footprint by Economic Industries, 2003-04

Economic industry	Within region energy related CH_4	Energy related CH_4 from other NZ regions	Energy related CH_4 from other nations	Total energy related CH_4	Total energy related CH_4	Total energy related CH_4
	kg	kg	kg	kg	kg per capita	% of total
Agriculture	1,886	6	228	2,119	0.01	0.27
Fishing	13	0	1	15	0.00	0.00
Forestry	885	2	26	912	0.00	0.12
Mining & quarrying	676	1	57	734	0.00	0.09
Manufacturing	41,129	440	13,391	54,961	0.14	7.05
Utilities & construction	45,489	210	5,023	50,722	0.13	6.50
Services	124,579	736	12,538	137,853	0.36	17.68
Domestic final demand	479,502	6,325	46,703	532,530	1.39	68.29
Total	694,159	7,720	77,967	779,846	2.04	100.00

Table 3.14 shows how Waikato Region residents appropriate embodied solid waste (excluding cleanfill waste) through the purchase of goods and services. Once again, domestic final demand (i.e. households) is the greatest appropriator, capturing some 58.7 percent of total tonnage. Services, which have little direct solid waste production, accounts for the second largest contribution of solid waste. Overall, domestic consumption accounts for 267,894 tonnes of solid waste annually, or 0.70 tonnes per capita.

Table 3.14 Waikato Region's Solid Waste (excl Cleanfill) Footprint by Economic Industries, 2003-04

Economic industry	Within region solid waste	Solid waste from other NZ regions	Solid waste from other nations	Total solid waste	Total solid waste	Total solid waste
	t	t	t	t	t per capita	% of total
Agriculture	369	0	12	381	0.00	0.14
Fishing	1	0	0	1	0.00	0.00
Forestry	98	0	1	100	0.00	0.04
Mining & quarrying	55	0	2	57	0.00	0.02
Manufacturing	23,622	0	511	24,133	0.06	9.01
Utilities & construction	37,839	0	215	38,054	0.10	14.20
Services	47,302	0	573	47,875	0.13	17.87
Domestic final demand	152,167	1,137	3,989	157,293	0.41	58.71
Total	261,452	1,137	5,304	267,894	0.70	100.00

3.9 FOOTPRINTING, POLICY AND RESOURCE REDUCTIONS

3.9.1 Footprinting as a Policy Tool

As discussed in the preceding section of this report, the techniques currently used in EF studies focus only on the appropriated land that is embodied in human activities. In order to obtain a better understanding of the limits to economic growth and also a more accurate indicator of sustainability, it is however important for other scarce natural resources and pollutants, such as water, energy and greenhouse gas emissions, to be taken into account. The consideration given in this report to Waikato's energy use, CO_2 emissions, solid waste generation and other important environmental resources and pollutants is a first step towards a 'wider' footprinting analysis. Further work is required in this area in order to provide policy makers with a more complete and integrated picture of environment-economy interactions.

Despite the foregoing limitations, the EF concept has proven worldwide to be a very effective in helping to promote public awareness and discussion on sustainability issues. This is primarily because it manages to capture current human resource use and the finite dimensions of human activity in a manner that is easily digested by the wider public. It can thus be used as an effective pedagogic tool by public administrators.

Footprinting has also been widely promoted as a sustainability indicator that can assist policy makers and government planners in making informed decisions. In these respects, an EF provides a broad measure of the direct and indirect environmental impacts (typically measured in embodied land appropriation) associated with an area of study (e.g. a city, region or nation). The footprinting method then offers a means by which these impacts can be compared against ecological capacity. As illustrated in this report, a footprint analysis can also provide information on the relative extent of resource appropriation by different industries within an economy, allow for comparisons to be made between different populations with respect to resource use, and provide an indication of the extent to which an area of study relies on other regions or nations for the provision of ecological resources. These are all matters of relevance to policy development and planning.

Importantly, the generation of EF models also provides a means through which policy analysts and, if utilised in a commercial context, businesses can explore the implications of different policy options. That is, EF models provide analysts with a common method to compare the consequences of various material and energy use scenarios, and to test sustainability strategies. The EF model developed in this project could, for example, be used to assess the footprint implications of economic change associated with the different scenarios put forward in the Waikato 'Choosing Regional Futures' FoRST project. Using the input-output approach, it will be possible to trace the flow on effects of growth in household and/or export demand associated with different scenario options.

3.9.2 Reducing our Footprint

In the worldwide EF study by Hails (2006), it is concluded that the world has been overshoot since the 1980s, with the current EF exceeding the Earth's biocapacity by approximately 25 percent. In effect this means that the world's economy is over-appropriated resources and depleting natural resource stocks. This study has also shown that the average Waikato resident's EF of 5.8 global ha is significantly higher than that of the average world citizen who appropriates 2.2 global ha per annum.

The EF analysis thus provides a strong indication of the Waikato Region's comparatively high resource use.[12]

There are numerous policy options and other methods through which an EF of a community, region or nation may be reduced. Please note that it is beyond the scope of this report to provide a comprehensive assessment of the most appropriate methods in the context of the Waikato Region. Examples of different methods are however provided in this Section as a starting point for further discussion and consideration.

Broadly speaking, there are four types of approaches for reducing an EF (Hails, 2006):

> *Population* – Most obviously, a lower population is likely to translate into a lower total EF. In the case of the Waikato Region, it is not envisaged that population will decline over the next 20 years (see Economic Futures Report). It is however possible that population growth will be slowed in the future by, for example, the choice of families to have fewer children.
>
> *Consumption of goods and services* – The consumption of fewer goods and services will clearly translate into a smaller EF. Residents can reduce their consumption by, for example, re-using goods (e.g. re-using plastic bags and lunch box containers, buying second-hand goods from garage sales and re-cycle stores); avoiding unnecessary vehicle travel (i.e. use public transport, bike or walk wherever possible and car pool with friends or colleagues when you have to travel by car); reducing energy use (e.g. though ensuring that homes are well insulated and thus require limited heating, switching off lights and computers when not in use, and buying energy efficient appliances); and avoiding the purchase of goods that are attached to disposable packaging and such like (e.g. buy only loose fruit and vegetables, write to manufacturers requesting the use of less packaging on products).
>
> *Footprint intensity* – A region's EF can be condensed through reductions in the amounts of resources required for the production of goods and services. On an individual level, this might be achieved though ensuring that a diet consists of food items requiring relatively low resources for production (e.g. a vegetarian diet or buying only food that is in season and grown locally thus requiring limited transportation). Similarly, industries can help to reduce the total footprint by incorporating energy efficiency gains in manufacturing. At the governmental level, EFs can also be reduced through the promotion of urban forms that reduce transport requirements (e.g. mixed use development incorporating high density housing with nearby transportation, retail and entertainment facilities which reduces the need for residents to travel).

[12] Global hectares are used in this analysis. It should however be noted that Waikato Region's land is highly productive compared with the world average; thus, when translated to global equivalents Waikato Region's land appropriation undergoes significant inflation.

Bioproductive area and bioproductivity – While not reducing the magnitude of an EF *per se*, measures to increase the area of bioproductive land or the productivity of land will help to reduce the impact of an EF.

4 CONCLUSIONS AND RECOMMENDATIONS

Over the last few years the EF has gained popularity as one possible indicator for monitoring progress toward sustainable development. The EF tells us the area of biologically productive land that ecosystems require to produce the resources we consume, and to assimilate the wastes that we produce (Wackernagel and Rees, 1996). The EF is considered to be a sustainability indicator on the grounds that it measures 'carrying capacity'. Supporters of the EF argue that a given population should not 'overshoot' the bio-capacity of the land on which it resides. The EF for a population is usually expressed in hectares, or hectares per capita, for a given year.

4.1 REVIEW OF METHODOLOGICAL FRAMEWORK

This report represents an update to the earlier Waikato Region Ecological Footprint work undertaken by McDonald (2000). It is useful to review the key strengths and issues associated with the footprinting as they relate to this current report.

4.1.1 Key strengths of the Ecological Footprint

The EF can be used to create awareness about issues concerning sustainable development. In particular, the EF invokes discussion on issues such as (a) the scale of human impact on the environment, (b) the key environmental resources and ecosystem functions required for sustainable development, and (c) the role played by trade in distributing environmental resources and pressures.

The EF provides a broad level measurement of environmental impact. It may be used to 'signal' the relative ecological cost of different policy options. Careful consideration of the makeup of the EF may also help to evaluate ecological costs associated with different economic uses of land.

4.1.2 Key Strengths of Adopting an Input-Output Framework

An input-output framework has been used in this report to calculate Waikato Region's EF. There are several advantages to this framework:

- It provides a consistent and comprehensive structure from which footprints may be derived. The framework is consistent in that all resources/emissions are classified according to the ANZSIC system – permitting comparisons on an industry basis between different resources/emissions, and with financial aggregates such as GDP, balance of trade and so on. Furthermore, the ANZSIC system will aid in producing replicable results through time and across space. The framework is comprehensive in that it implicitly requires that all resources/emissions be accounted for i.e. inaccuracies (particularly underestimation) resulting from omissions and partial coverage are unlikely to occur.
- Other strengths associated with its formal structure include (a) it avoids issues of double counting, (b) it deals with complicated networks of indirect flows comprehensively, and (c) it can cope with 'top down' as well as 'bottom up' information.

4.1.3 Key Issues with the Ecological Footprint

- *Why use land as the numeraire?* The EF method concentrates purely on land, however this is not the only scarce resource. In understanding sustainability and the limits to economic growth, it is critical that other resources and pollutants be considered. For this reason it would be useful to calculate 'water', 'carbon' 'energy' and other footprints. This wider definition of footprinting would undoubtedly deliver a variety of messages to policy makers than the land footprint, and a combined study of all of these footprints would provide a more holistic and richer analysis of the sustainability issue. Section 3.7 of the report acknowledges this and provides preliminary footprints for energy by delivered types, energy related air emissions and solid waste.
- *Is all land the same?* The EF uses hypothetical global average yields and equivalence factors to equate different uses of land at the global level – such factors are however too crude to apply in the case of the Waikato Region. This limits the ability to meaningfully compare the Waikato Region's EF with other regions, cities and the nation itself. Commensuration of land quality in terms of 'net primary productivity'[13] is probably the best way forward in overcoming this limitation, e.g. under this approach 3 hectares of Class A land would be deemed equivalent to, say, 1 hectare of Class C land. The development of such equivalences would require a major research effort – well beyond the scope of this report.
- *What about the future*? The EF provides only a static snapshot of a population's use of land. In this respect it tells us only 'yesterday's news'. It cannot tell us about the future nor can it tell us about the dynamics of nature, eg, changes to complex adaptive systems. This requires the use of methods explicitly designed to deal with the dynamics of complex systems. This pathway is fortunately being addressed through EW's choosing to undertake the Regional Futures FoRST Project where 'spatial dynamic' models are being constructed to investigate economy-environment effects through the use of scenarios.

4.2 Key Findings

The key findings of this report are noted below:

- The Waikato Region's EF was estimated to be 848,225 ha or 2.22 ha per capita (excluding fishing grounds) for the year ending March 2004.
- The Waikato Region's estimated productive land area is 1,689,100 ha, meaning that the Region's EF 'undershoots' its productive land area by 50 percent.
- The Waikato Region's per capita EF of 2.2 ha (excluding fishing grounds) is lower than the New Zealand average of 3.4 ha. This is because the Waikato Region has some of the most biologically productive land in New Zealand.
- Grazing land accounts 43.8 percent of the Waikato EF (excluding fisheries). This is predominantly land embodied in food products.
- Energy land (which is defined as the hypothetical land required to sequester CO_2 emissions) accounts for 21.4 percent. This is lower than most Western nations

[13] Net primary productivity represents the rate at which biomass is produced by photosynthetic plants.

where energy land often constitutes more than 50 percent of the footprint. There are two reasons for this (1) Pinus radiata (production forest) has higher CO_2 absorption rates, and (2) the ratio between CO_2 emissions and energy consumption is lower due to the relatively high generation of electricity from hydro sources.

- Degraded/built-up land (which includes the Region's residential properties) and forest land make up 23.8 percent and 10.9 percent respectively.
- Products purchased from the manufacturing sector account for 19.6 percent of the EF. Most of this land is embodied in food products appropriated from within the Region.
- Services also embody significant amounts of land. This accounted for 35.3 percent of the Region's EF. Services reside near the top of the production chain and are therefore characterised by significant up-stream linkages - all of which appropriate land. Much of the land embodied in service sector products originates from abroad.
- Households require large amounts of land to support them, accounting for 32.4 percent of the Waikato Region's EF. A significant proportion of this land is embodied in international imports, including goods purchased by wholesalers/retailers from abroad, but sold only with an additional mark-up.
- The Waikato Region has an Ecological Balance of Trade surplus of 1,253,126 ha. Some 206,231 ha of land are embodied in goods/services imported into the Region, while 1,459,357 ha are embodied in goods/services exported from the Region.
- If adjusted for global yields, biological equivalence factors and the global sequestration rate, Waikato Region's EF per capita can be compared with the EFs of other nations. The Waikato's adjusted EF is 5.80 ha per capita. This is lower than the United States, Denmark and Ireland, but higher than Australia, the United Kingdom and Japan.

4.2.1 Updating the Ecological Footprint Analysis

In the process of estimating the Waikato Region's footprint, it became apparent that further extensions and refinements to the analysis should be undertaken, which are beyond the immediate scope of this report:

- It is recommended that the analysis be updated biannually. A key reason for this is that international standards pertaining to Ecological Footprinting are currently being developed. This includes acceptance of both 'process' and 'input-output' based methods for calculating the EFs at sub-national levels.
- It is recommended that the analysis be updated so that scarcities/ imports associated with other resources and emissions are not overlooked. In particular, the development of multi-dimensional EF[14] (see Patterson and McDonald forthcoming).

[14] The multi-dimensional footprint recognises that land is not the only scare resource – other resource should also be entered into the derivation of a sustainability indicator.

- That Environment Waikato, perhaps in conjunction with other institutions (e.g. Statistics New Zealand), invest in protocols for developing environmental accounts for other critical resources/ emissions. In particular: water use, water discharge – including water based pollutants, (both point source and non-point source), ecosystem services, and soils. Currently, collection of data for the development of these strategic accounts is limited. Without such accounts key regional issues cannot be adequately analysed.

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