# An application of the Ecological Footprint Method

# to an Eco-tourism Resort:

## A Case Study of Kingfisher Bay Resort and Village, Fraser Island.

Melissa Nichols

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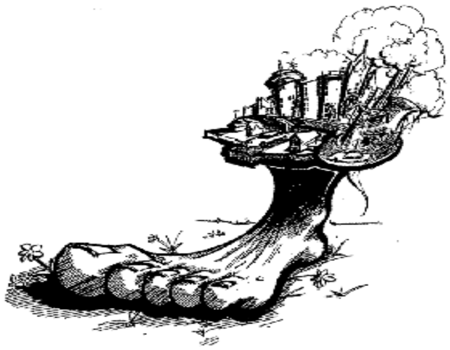
**B.Sc. (Public Health)**



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# ABSTRACT

Today, one decade since the World Summit in Rio de Janiero in 1992, sustainable development has become a permanent fixture on the global policy agenda. Ecological footprint analysis is a tool that has been identified for use as an index to measure progress towards the goal of sustainable development, converting consumption and waste production into units of equivalent land area (Wackernagel and Rees, 1996). Unfortunately, over-simplistic interpretations of what the ecological footprint represents and widespread use of the ‘footprint’ metaphor have resulted in criticisms from parts of the scientific community (van den Bergh and Verbruggen, 1999). These range from criticisms about the ‘footprint’ metaphor itself, to more specific criticisms concerning the inadequacy of the ecological footprint to accurately assess aspects of ecosystem condition (van den Bergh and Verbruggen, 1999; van Vuuren and Smeets, 2000; Lenzen and Murray, 2001).

The critical examination of both the ecological footprint concept and current methods of calculating it became the primary aim of this research, while its specific objectives were to:

1. Calculate the ecological footprint of the eco-tourism resort, Kingfisher Bay Resort and Village (KBRV), and examine the sensitivity of the ecological footprint to alternative calculation methods.
2. Identify and prioritise the key contributing factors to the ecological footprint for KBRV.
3. Evaluate the potential of using the ecological footprint as an indicator of progress towards sustainable development.

Following a review of the evolution of the ecological footprint method, it was decided that an input-output based approach, in conjunction with a land disturbance model, was the best available to date. Consequently, this method was used to calculate KBRV’s ecological footprint, which was determined to be approximately 3329 hectares in terms of land disturbance. In addition, KBRV’s ecological footprint was calculated using a range of alternative methods and was shown to be highly sensitive to methodological differences. Through a detailed examination and assessment of KBRV's operational inputs, the key contributing factors to its ecological footprint were identified and ranked in order of their importance. The most significant operational inputs identified were beef and lamb inputs, electricity supply, water transport and on-site fuel use impacts. Some paths were shown to be amenable to management, while others revealed a need for further research.

In addition, a critical analysis of the ecological footprint's theoretical base revealed that it is not sufficient as a stand-alone indicator of progress towards ESD. This was shown to be due, in part, to its inability to capture important aspects of ecological integrity. However, it was demonstrated that it could be used effectively in conjunction with other indicators of ESD, within a composite measure such as the AMOEBA approach.

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This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

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Melissa Nichols
3 November, 2003.

# CHAPTER 1: INTRODUCTION

***Nobody made a greater mistake than he who did nothing because he could only do a little***

Edmund Burke, Whig MP for Bristol 1774-1780

With documented declines in the biophysical state of the planet, there is an urgent need to develop indicators of sustainable development (United Nations Environment Programme, 2002). The ecological footprint has been identified as a quantifiable sustainable development indicator to assess and monitor sustainable development performance (Wackernagel and Rees, 1996; Chambers et al., 2000; Charlton, unpublished). In essence, a calculated ecological footprint represents the amount of land required for (or the ‘footprint’ resulting from) the provision of natural resources and absorption of wastes for a specified population (Chambers et al., 2000).

The metaphor of a footprint has done much to increase awareness of this tool. However, the simplicity and elegance of this metaphor disguises the complexity of the sustainable development issues that the ecological footprint attempts to capture. The widespread use of the metaphor has attracted criticism from the scientific community, as uncritical applications may lead to overly simplistic approaches regarding ecological footprint calculation, thereby limiting its application value to managers (van den Bergh and Verbruggen, 1999). These criticisms range from those targeting the ‘footprint’ metaphor itself, to more specific criticisms concerning the ability of the ecological footprint to accurately assess aspects of ecosystem condition (van den Bergh and Verbruggen, 1999; van Vuuren and Smeets, 2000; Lenzen and Murray, 2001).

In light of these criticisms of the ecological footprint, the aim of this research is to critically examine the theoretical base of the ecological footprint, issues and problems surrounding its calculation, and its potential for guiding strategic environmental management.

Having established a clear aim for the research, the next decision involved selecting a focus area for the application of the ecological footprint method. To date, the ecological footprint has been calculated in many places and on many scales (Lenzen et al., 2003). Nevertheless, no ecological footprint has been conducted within an eco-tourism setting. The eco-tourism industry represents an important focus area for ecological footprint research, given that eco-tourism resorts (and activities) are typically located in fragile and highly valued natural environments. In addition, this industry sector is encouraged to demonstrate its commitment to sustainable development in a substantial and quantitative manner (Eco-tourism Australia, 2000). Consequently, an eco-tourism setting was chosen as a site to critically evaluate the ecological footprint as a management tool. The eco-tourism resort, Kingfisher Bay Resort and Village (KBRV), was selected as the case study, primarily due to its location in the World Heritage listed area of Fraser Island.

As a focused research project, this study had three specific research objectives:

1. To calculate the ecological footprint of the eco-tourism resort, KBRV, and examine the sensitivity of the ecological footprint to alternative calculation methods.
2. To identify and prioritise the key contributing factors to the ecological footprint for KBRV.
3. To evaluate the potential of using the ecological footprint as an indicator of progress towards sustainable development.

With these objectives in mind, the thesis is structured in the following way. The literature review (Chapter two) traces the emergence of the sustainable development construct and examines the need for indicators to measure its progress. It also describes how the scientific community has responded to this need by contributing to the development of a sustainable development information system. The chapter then introduces the ecological footprint as a potential indicator within such a system, and reviews it from a historical perspective to show how the method has evolved in response to its identified weaknesses.  The chapter closes by briefly reviewing a number of existing ecological footprint applications, and highlighting the research need within the ecological footprint domain.  The methods chapter (Chapter three) describes the intricacies of the ecological footprint method and provides a rationale for the methodological decisions made in this research.  Chapter four then presents the results of this analysis, distinguishing between each of its phases.  The discussion chapter (Chapter five) considers these results in light of the study's objectives and places this research in the wider context of sustainable development research.  In addition, areas for further improvement of the ecological footprint methodology are identified and its use as an indicator for sustainable development evaluated.

# CHAPTER 2: REVIEW OF THE LITERATURE PERTAINING TO THE ECOLOGICAL FOOTPRINT

## 2.1 The context of sustainable development

The world environment has experienced serious declines in environmental quality as a direct result of human exploitation (United Nations Environment Programme [UNEP], 2002). The combination of an increasing population and an increase in per capita consumption is the driving force behind much of this deterioration, which is occurring at scales ranging from local to global (Rapport et al.,1998). The United Nations Conference on Environment and Development (UNCED, 1992) produced 'Agenda 21' (an action plan for the 21st century) which emphasised that unsustainable patterns of consumption and production were the key causes of global environmental degradation. Similarly, the Australian State of the Environment Report (2001), prepared independently by the Australian State of the Environment Committee (ASEC), identified the sustainable use of resources as one of the major challenges facing Australia in order to achieve minimise environmental impacts. It revealed that:

(a) Australians have a high per capita level of greenhouse gas emissions by world standards (an increase of 16.9 per cent between 1990 and 1998),
(b) There has been an accelerated rate of land clearance in Australia (exceeded by only four other countries in the world), and
(c) Dryland salinity, one of the legacies of broad-acre clearing, is predicted to affect some two million hectares of native vegetation by 2050.

The global response to addressing significant environmental issues such as these has been the emergence of the goal of ecologically sustainable development (ESD). The phrase ESD was first brought to the world's attention in 1987 through the report titled 'Our Common Future', produced by the World Commission on Environment and Development (WCED). This report acted as a catalyst for the ESD movement and defined ESD as:

“*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*” (WCED, 1987).

Since then, a framework for achieving progress towards the goal of ESD has been developed through the creation of the Rio Declaration and subsequent Agenda 21 report (UNCED, 1992), resulting in a further impetus for the ESD movement. Today, ESD has become the ‘catchword’ for politicians, policy-makers, business executives, scientists, economists and environmentalists alike. Sheer masses of literature have appeared, some of it contradictory, further analysing and redefining the concept (see, for example, Wackernagel and Rees, 1996; Costanza et al., 1997; Daly and Cobb, 1989; Solow, 1993 and Pearce and Atkinson, 1993). However, there is consensus regarding three essential elements which can be found in most statements about ESD:

(1) Natural resources are finite and there are limits to the carrying capacity of the Earth’s ecosystems,
(2) economic, environmental and social goals must be pursued within these limits, and
(3) there is a need for inter- and intra-generational equity.

At the crux of the ESD movement lies the recognition that the environment has been sidelined in pursuit of rapid economic development. Poverty and excessive consumption continue to put enormous pressure on the environment (UNEP, 2002). For example, Harrison (1992) indicated that population growth in developing countries accounted for 79 per cent of deforestation between 1970 and 1988, as impoverished people sought to build an existence from personal farming. Furthermore, many governments of developing countries participate in this ‘plunder’ because of debt imposed by international institutions and western countries (Shearman and Sauer-Thompson, 1997). In addition, people from developed nations consume commodities produced as a result of land clearance. Ninety per cent of total personal consumption is consumed by just one-fifth of the world population (residing primarily in developed nations), while the remainder live in extreme poverty on less than US$1 per day (UNEP, 2002).

As in many countries, ESD gained official endorsement within Australia with the release of the National Strategy for ESD in 1992 (ESD Steering Committee, 1992), and can now be found in Australian legislation, including the Commonwealth's Environmental Protection and Biodiversity Conservation Act 1999 (Australian State of the Environment Committee, 2001). Despite the worldwide recognition of ESD and its importance, commitment to ESD has remained largely rhetorical and the extensive popularity of the concept has often been purchased at the expense of specificity (Chambers et al., 2000). Perhaps this can be attributed to the ambiguity of the ESD concept, which has resulted in contradictory interpretations of what it means, and its consequent implications for current economic development (Wackernagel and Rees, 1996). For example, depending upon one's paradigm, ESD may be interpreted as a call for ecological stability and social justice, or merely more sensitive, sustained development. Additionally, some of the equivocation surrounding ESD is due to the failure to distinguish between true development and growth (Wackernagel and Rees, 1996). Daly and Cobb (1989) clarify the difference by defining 'growth' as an increase in size through material accumulation, while 'development' is the realisation of fuller and greater potential.

These conflicting interpretations are reflected in the 'strong' and 'weak' views of sustainability. A 'strong' sustainability approach (also referred to as the 'narrow' version of sustainability in the economic literature) acknowledges that in order to achieve ESD, conservation and/or enhancement of natural capital stocks is required, rather than accepting and justifying the losses of natural through human capital substitution (Getzner, 1999; Ekins et al., 2003). Therefore, initiatives based on a 'strong' sustainability view tend to be concerned primarily with the environmental dimension of ESD, typically assessing natural capital stocks and their subsequent depreciation over time. The precautionary principle plays an integral role in the 'strong' sustainability approach, which states that rather than await certainty, action should be taken in anticipation of any potential environmental harm, in order to prevent it (Costanza et al., 1997).

Conversely, 'weak' sustainability (also referred to as 'broad' sustainability in economic literature) is concerned with maintaining total capital stock, where one kind of capital is substitutable for another (Gutes, 1996; Bell and Morse, 1999). There is no 'special role' for natural capital, and gains from the economy can compensate for environmental losses. The approach allows for the stock of natural capital (including mineral and fossil fuel deposits, and biodiversity stocks), human capital (intellectual and labour) and financial capital to change over time, provided the ability to maintain consumption levels is sustained through time (Solow, 1993). Therefore, initiatives based on a ‘weak’ sustainability view typically assess the economic, social and environmental dimensions of ESD in order to enable and evaluate substitution. This substitution of natural capital is a major flaw in the weak sustainability approach, as it is difficult to conduct a non-subjective, monetary valuation of natural goods (Getzner, 1999).

Failure to clarify how the term ESD is being used within a specific context can cause confusion and misunderstanding (Wackernagel and Rees, 1996). As aforementioned, this has resulted in ESD remaining largely theoretical and rhetorical. Considering that the concept of ESD was formally introduced well over a decade ago, little has been done in terms of progressing beyond the concept to implementation. In order to progress towards the goal of ESD, the term must be operationalised. One means of achieving this is to develop sustainability indicators to measure progress towards achieving ESD.

“*Indicators of sustainable development need to be developed to provide solid bases for decision-making at all levels, and to contribute to a self regulating sustainability of integrated environment and development systems*” (UNCED, 1992).

Clearly, there is an imminent need to move beyond rhetoric to objective, transparent and analogous indicators of ESD, so as to assess, benchmark, monitor, evaluate and compare the effectiveness of sustainable development initiatives (PASTILLE, 2002).

## 2.2 Indicators for ESD

Many indicators have evolved in response to the internationally recognised need for indicators of ESD (Chambers et al., 2000). Unfortunately, no comprehensive studies exist that evaluate the effectiveness of the wide range of current ESD indicators against either standardised criteria of indicator assessment or each other. The extensive task of comparing and evaluating the full range of ESD indicators available is beyond the scope of this review. However, the remainder of this section introduces the notion of an ESD indicator (Section 2.2.1), presents a credible set of criteria for processes of indicator assessment (Section 2.2.2), and then briefly reviews a selection of ESD indicators representative on different levels of scale according to the indicator assessment criteria (Section 2.2.3).

### 2.2.1 The ESD indicator system

The packaging of data into indicators is a way of simplifying complex and detailed information (Chambers et al., 2000). In general, an indicator is something that provides useful information about a physical, social, or economic system, usually in numerical terms (Farrell and Hart, 1998). Potential uses for indicators of ESD include alerting decision-makers to priority issues, guiding policy formation, simplifying and improving communication, and fostering a common understanding of key trends with a view to initiating necessary action (Gallopin, 1997). Since ESD is a multi-dimensional construct involving large amounts of complex information, many indicators for ESD have been developed that encompass differing versions of ESD and geographical scales. Upon review of much of the ESD indicator literature, indicators are typically found to be reported in one of three ways: individually, as part of an indicator set, or in the form of a composite index that combines various individual indicators into a single number (Farrell and Hart, 1998).

The European Union ‘Promoting Action for Sustainability Through Indicators at the Local Level in Europe’ (PASTILLE) consortium produced a practitioner’s guide for the implementation of sustainability indicators in May, 2002, in response to the need for clarification of the ESD indicator information system. This guide defines the sustainable development information system as a pyramid as illustrated in Figure 2.1. At the base of the pyramid lie raw data, which can be transformed into statistics. In turn, statistics form the basis of individual indicators, which can be grouped into indicator sets. Situated at the top of the pyramid is the indicator index – a highly aggregated measure that combines individual indicator values, by adding and weighing, to obtain one single new figure (PASTILLE, 2002).

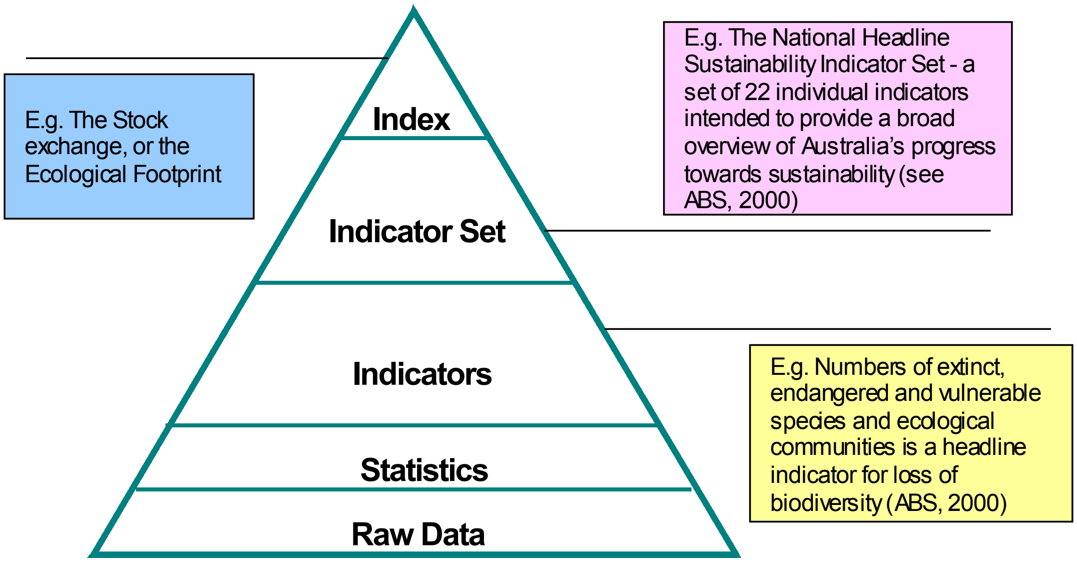


**Figure 2.1 The sustainable development indicator information pyramid**

Source: adapted from PASTILLE, 2002.

### 2.2.2 Evaluation of ESD indicators

Although many indicators claim to provide an overall assessment of progress, there has been no consensus on what constitutes an ideal ESD indicator/s (Hardi and Zdan, 1997). In response to the need for improved ESD indicators, the International Institute for Sustainable Development (IISD) convened an international meeting at Bellagio, Italy (1996) where ESD indicator experts from five continents discussed the overarching principles necessary to provide a link between ESD theory and practice (Hardi and Zdan, 1997). The outcome of the meeting was the Bellagio Principles for Assessment, representing the first guidelines for developing assessment criteria for ESD (McGregor, 2003). The principles serve as a set of ten quality standards for processes of indicator assessment, including initial system design and indicator/s identification, the processes of field measurement and compilation, and the interpretation and communication of results (Hardi and Zdan, 1997).

These principles involve:

(1) Clearly defining what is meant by the term ESD
(2) Viewing ESD from a holistic perspective, including the social, ecological and economic sub-systems
(3) Including the essential elements (for example, recognising ecological limits)
(4) Using adequate scope, both geographically and temporally
(5) Maintaining a practical focus
(6) Ensuring ‘openness’ of methods, data and associated assumptions and uncertainties
(7) The effective communication of results
(8) Broad participation

Refer to Appendix 1 for complete set of Bellagio Principles for Assessment.

The Bellagio Principles adequately capture the essential elements required for assessing progress toward ESD (Hardi and Zdan, 1997; McGregor, 2003). A wider adoption of the internationally-endorsed (IISD) assessment criteria is required in order to produce consistent outcome assessments and indicator comparisons. By standardising the ESD indicator system, the process of moving from ESD theory to practice will be accelerated.

When assessing indicators of ESD using the Bellagio Principles, the context of the indicator must be taken into account. For example, an indicator set developed by authors from an economic background may measure for a form of ‘weak’ sustainability, allowing for substitution between natural and man-made resources (refer to Section 2.1). Conversely, an index developed in light of the ‘strong’ sustainability view may specifically focus on the consumption of natural capital stocks over a period of time. Some of the more widely known indicator sets and indicator indices have been evaluated according to the Bellagio Principles for Assessment (refer to Table 2.1).

## Table 2.1 An evaluation of selected ESD indicators

| Name | Type | ESD view | Summary of main features | Strengths and Weaknesses according to the Bellagio principles for assessment |
|---|---|---|---|---|
| **NATIONAL SCALE** | | | | |
| **(Australian) National Headline Sustainability Indicators**<br>(See Environment Australia, 2002) | Indicator Set | Weak | • 24 indicators that aim to measure Australia's performance collectively against the core objectives of the NSESD (Environment Australia, 2002).<br>• Attempts to address economic, social and environmental aspects of ESD, for example economic security, education and land health. | • Bellagio Principle (BP) 1: Does not clearly specify which version of ESD is being used (McGregor, 2003)<br>• BP 2: Includes social, ecological and economic sub-system categories, but ignores some notions of equity, such as over-consumption, poverty and human rights<br>• BP 3: Does not recognise the ecological limits of natural capital, because it is a 'weak' ESD indicator (McGregor, 2003)<br>• BP 5: Broad indicator sets can create confusion about achieving multiple goals (Chambers et al., 2000), decreasing practicability<br>• BP 7: Difficult for general public to 'identify' with |
| **Environmental Space (ES)**<br>(See Hille, 1998) | Indicator Set | Strong | • A set of resource consumption indicators that measure the 'fairness' of resource allocation and consumption world-wide (Hille, 1998).<br>• Uses a 'distance to target' approach, estimating the amounts of resources to be used to reach the global target of ESD. | • BP 1: Does not clearly specify which version of ESD is being used (meanwhile ignoring economic and social subsystems)<br>• BP 3: Effective in communicating issues of 'fair shares' of resources (strong ESD indicator)<br>• BP 4: Considers local and long distance impacts<br>• BP 6: Internal validity problems – uses subjective estimates and some unrealistic goals. For example, a global target of completely phasing out chemical fertiliser products is prescribed (Chambers et al., 2000).<br>• BP 7: Easy for general public to 'identify' with<br>• Not applicable on smaller scales, thereby limiting its application as an ESD indicator |
| **GPI (Genuine Progress Indicator)**<br>(See Redefining Progress, 1995) | Index | Weak | • Measured in monetary terms, thereby allowing for direct comparisons with the widely used economic index, Gross Domestic Product (GDP)<br>• Starts with real personal consumption spending, adjusts for income distribution, and then adds or subtracts to reflect ecological and social benefits or costs | • BP 1: Does not clearly define version of ESD chosen<br>• BP 2: Aims to capture the missing social and environmental dimensions from the economic GDP<br>• BP 3: Does not recognise the ecological limits of natural capital, because it is a 'weak' ESD indicator<br>• BP 4: Does not consider long distance impacts (for example on the ecosystems of other countries via consumption of imports)<br>• BP 6: Financial costs need to be assigned to non-financial impacts such as pollution, causing internal validity and subjectivity problems<br>• BP 7: Difficult for general public to 'identify' with<br>• Not applicable on smaller scales, thereby limited application |

**Table 2.1 continued**

| | | | | |
|---|---|---|---|---|
| **REGIONAL SCALE** | | | | |
| **(the city of) Den Haag's 'Environmental Thermometer'**<br>(see Webb, 1998) | Indicator Set | Strong | • 11 environmental categories (such as water, waste, soil, greenery) that each contain several indicators.<br>• Used for the city of Den Haag (Netherlands) to assess the effectiveness of local sustainability policy and chart progress towards the city's sustainability targets. | • BP 1: Does not clearly specify which version of ESD is being used, meanwhile ignoring the social and economic subsystems<br>• BP 2: Only examines environmental sub-system of ESD, yet still does not address issues such as the over-consumption of natural resources<br>• BP 4: Does not consider long distance impacts (for example on the ecosystems of other countries via consumption of imports)<br>• BP 5: Indicator sets can create confusion about achieving multiple goals (Chambers et al., 2000), decreasing practicability |
| **PRODUCT SCALE** | | | | |
| **The Eco-indicator 99**<br>(see Goedkoop et al., 2000) | Index | Strong | • A Life Cycle Assessment (LCA) weighing method for assessing the environmental aspects of product systems by aggregating LCA results into standard units called eco-indicators (Goedkoop et al., 2000)<br>• Weighting is based on three categories of damage – human health, ecosystem quality and resources (Goedkoop et al., 2000) | • BP 1: Does not clearly specify which version of ESD is being used, meanwhile ignoring the social and economic subsystems<br>• BP 2: Does not include some notions of equity, namely over-consumption, poverty and human rights Only applicable on a 'product' scale<br>• BP 3: Not a comprehensive measurement of the ecological limits of natural capital. Eg., damage to resources is expressed as the surplus energy required for future extractions of minerals and fossil fuels.<br>• BP 6: Weighting, according to damage model is subjective. For example, damage to human health and ecosystem quality is equally important, whilst damage to resources is calculated to be half as important.<br>• BP 7: Difficult for general public to 'identify' with |

A common trend in a number of ESD indicators (including those examined in Table 2.1) is the failure to capture the interrelationships of ESD (Haberl et al., 1999), especially between the biophysical environment and the socio-economic environment that are apparent in Figure 2.2.

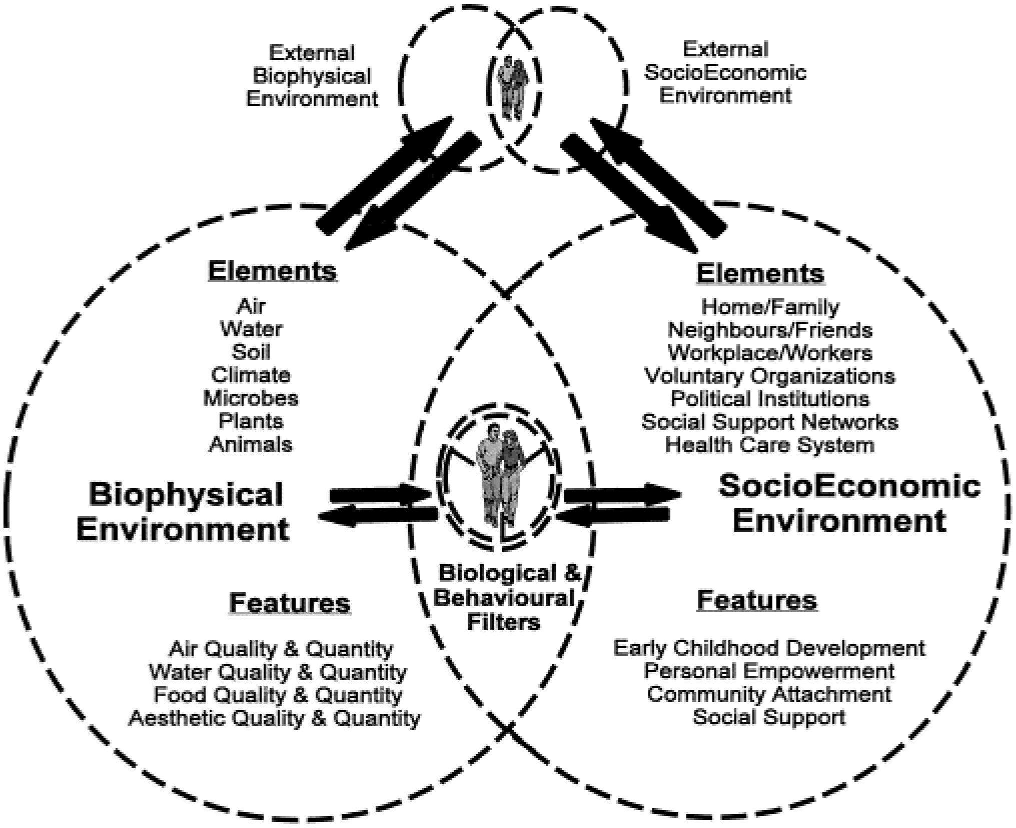


**Figure 2.2 The Butterfly Model of Health for an ecosystem context**
Source: van Leeuwen et al. (1999)

In other words, they are unable to link human-induced pressures, resulting from the social and economic dimensions of ESD, to ecologic consequences, wherever they may occur. This point is reflected in principles three (essential elements) and in particular four (adequate scope) of the Bellagio Principles for Assessment (Hardi and Zdan, 1997; p76):

"*It is important to use indicators connecting human induced pressures to ecological time frames in order to correctly assess impacts of human action on the environment*".

The most obvious socio-economic interrelationship with the environment has been referred to as the 'colonization of natural systems', a term encompassing the effects of human interventions on the natural environment in comparison with the state of the environment prior to intervention (Fischer-Kowalksi and Haberl, 1997; Haberl et al., 1999). Changes in nutrient cycles, species composition, soil conditions, hydrologic features and energy flows are just a few examples of possible effects of colonisation (Haberl et al., 1999). Land use can be seen as an essential component of colonization, as it is an important driving force from the socio-economic dimensions for the evolution of land cover patterns (Darwin et al., 1996; Graetz et al., 1995). For instance, land areas are needed for material extraction and waste disposal, and building and road infrastructure (Wackernagel and Rees, 1996). From an energy perspective, land area is also required for the gathering of energy-rich material such as fossil fuels or biomass, and land for built infrastructure is required for harnessing immaterial forms of energy such as solar radiation or wind power (Haberl et al., 1999). This is reflected in the arrows towards the left sphere (the biophysical environment) of Figure 2.2.

### 2.2.3 The ecological footprint as an index for ESD

The ecological footprint is a tool that has been identified for use as one index for measuring progress towards ESD (Wackernagel and Rees, 1996; Chambers et al., 2000; Charlton, unpublished). The concept was initially proposed in 1992 (Rees, 1992), with the most comprehensive documentation, so far, being in Wackernagel and Rees (1996). It uses a carrying capacity approach (the ability of earth to support life) by providing an estimate of the land area necessary to sustain current levels of resource consumption for a given population (Wackernagel and Rees, 1996).

Wackernagel and Rees (1996, p51) define the ecological footprint of a specified population as:

> "*the area of ecologically productive land (and water) in various classes –*
> *cropland, pasture, forests, etc – that would be required on a continuous basis to*
> *(a) provide all the energy/material resources consumed, and*
> *(b) absorb all the wastes discharged by that population with prevailing technology,*
> *wherever on Earth that land is located*".

Using area equivalence, the ecological footprint aims to express how much of nature's 'interest' an area is currently appropriating. As human settlements are not confined by the carrying capacity of their boundaries, the nature's 'interest' can include areas outside the study boundary required to produce the resources consumed by the target population (Charlton, unpublished). If more bioproductive space is required than is physically available, then the rate of consumption is deemed unsustainable (Chambers et al., 2000).

Arguably, the most advantageous feature of the ecological footprint over other sustainability indicators is that it is conceptually simple, with aggregated flows expressed in an easily digestible form – as land area (Moffat, 2000; Rees, 2000). Over recent decades, society has experienced significant advances in technology. A notable consequence of this progression is that society has become isolated from the physical realities of the land on which they live (Rees, 2000). In using a single land-based indicator, the ecological footprint "reconnects people to the land" and allows for ease of understanding, by utilising an indicator that most people can identify with (Rees, 2000, p371).

Furthermore, by focusing on consumption, the ecological footprint concept "personalises sustainability", as we are all consumers (Rees, 2000, p372). The ecological footprint has thus been described as a powerful indicator for communicating sustainability issues to the wider community (Wackernagel and Rees, 1996; Chambers et al., 2000; Charlton, unpublished). Rees (2000) identified the popular understanding of the ecological crisis as a prerequisite to any politically viable solutions, and as a crucial aspect for achieving progress towards ESD. Additionally, because the ecological footprint focuses on resource consumption and waste assimilation patterns, and allocates ecologic impacts to these patterns, it is one of a few ESD indicators that considers the interrelationships between the socio-economic and ecological dimensions of ESD that are represented in Figure 2.2.

Another reported strength of the ecological footprint is that it is one of the few measures that aggregates a variety of human impacts in consistence with thermodynamic and ecologic principles (Wackernagel and Rees, 1996). For instance, the ecological footprint is consistent with the second law of thermodynamics, which states that the entropy (level of disorder) of an isolated system always increases (Wackernagel and Rees, 1996). In other words, the level of order of a system is always deteriorating. Thus, for a system to develop and grow more complex, it must be at the expense (that is, decreasing order) of the system it is embedded within. For example, the economy is a system that develops and grows at the expense of the ecosphere, via the depletion of natural capital and reduced biodiversity, to name a few. The ecological footprint is therefore consistent with the second law of thermodynamics and by focusing on resource consumption patterns, it clearly highlights the dependence of the economy on the environment.

The ecological footprint also corresponds closely with the principles of the widely accepted ecological IPAT model, where I (Impact) = P (Population) x A (Affluence) x T (Technology) (Ehrlich and Holdren, 1971). The model clearly demonstrates the relationship between environmental impact, the number of consumers, the level of consumption and the technological efficiency in delivering a particular product or service (Chambers et al., 2000). The ecological footprint is therefore consistent with the IPAT model, by revealing how much land is required for a particular level of consumption.

The ecological footprint is also aligned with the strong sustainability approach, by not permitting the substitution of natural capital for man-made forms of capital in calculating the total ecological footprint (refer to Section 2.1.1 for more detail on the strong and weak views of sustainability). The ecological footprint can also be used as a temporal indicator for measuring progress towards the goal of ESD. van Vuuren and Smeets (2000) have demonstrated this in their assessment of four countries (Benin, Bhutan, Costa Rica and the Netherlands). They concluded that both the ecological footprint value itself, and the disaggregated ecological footprint, can be compared to determine changes (van Vuuren and Smeets, 2000).

On the local scale, the ecological footprint has been identified as a useful tool for identifying which impacts (and subsequent aspects) are significant and, therefore, those aspects which should be managed in a company's environmental management system (EMS; see Lenzen et al., 2003a). To date, corporate sustainability efforts have focused heavily on environmental aspects (Viebahn, 2002). In Australia, EMS's are increasingly being adopted, partly driven by the advent of ISO 14001 (Lenzen et al., 2003a). EMS's, such as those developed in line with the ISO 14001, require companies to identify their significant environmental impacts and the activities or aspects that give rise to those impacts. While there are many existing ways of deriving 'significance', most companies currently focus on regulated emissions and pollution. Few take into account flows of materials and energy. As Schmidt-Bleek (1993: in Chambers and Lewis, 2001) reports, "it is high time to look at the megatonnes (of resource consumption) rather than the nanograms (of pollution)". Thus the ecological footprint has significant potential for application within company EMS's, particularly in the area of eco-efficiency or reduced resource use.

On the basis of the above it can be seen that the ecological footprint can be applied on numerous scales. Traditionally, ecological footprint studies have generally focused on geographical entities such as countries, regions and cities. More recently, ecological footprinting has been applied at a more localised level, including some universities and water service providers (refer to Section 2.4 for a more detailed overview of ecological footprint applications). To date, however, there have been very few cases of ecological footprinting to indicate the environmental sustainability of commercial organisations. Furthermore, there have been no ecological footprint assessments conducted (either nationally or internationally) to indicate the environmental sustainability of tourist resorts.

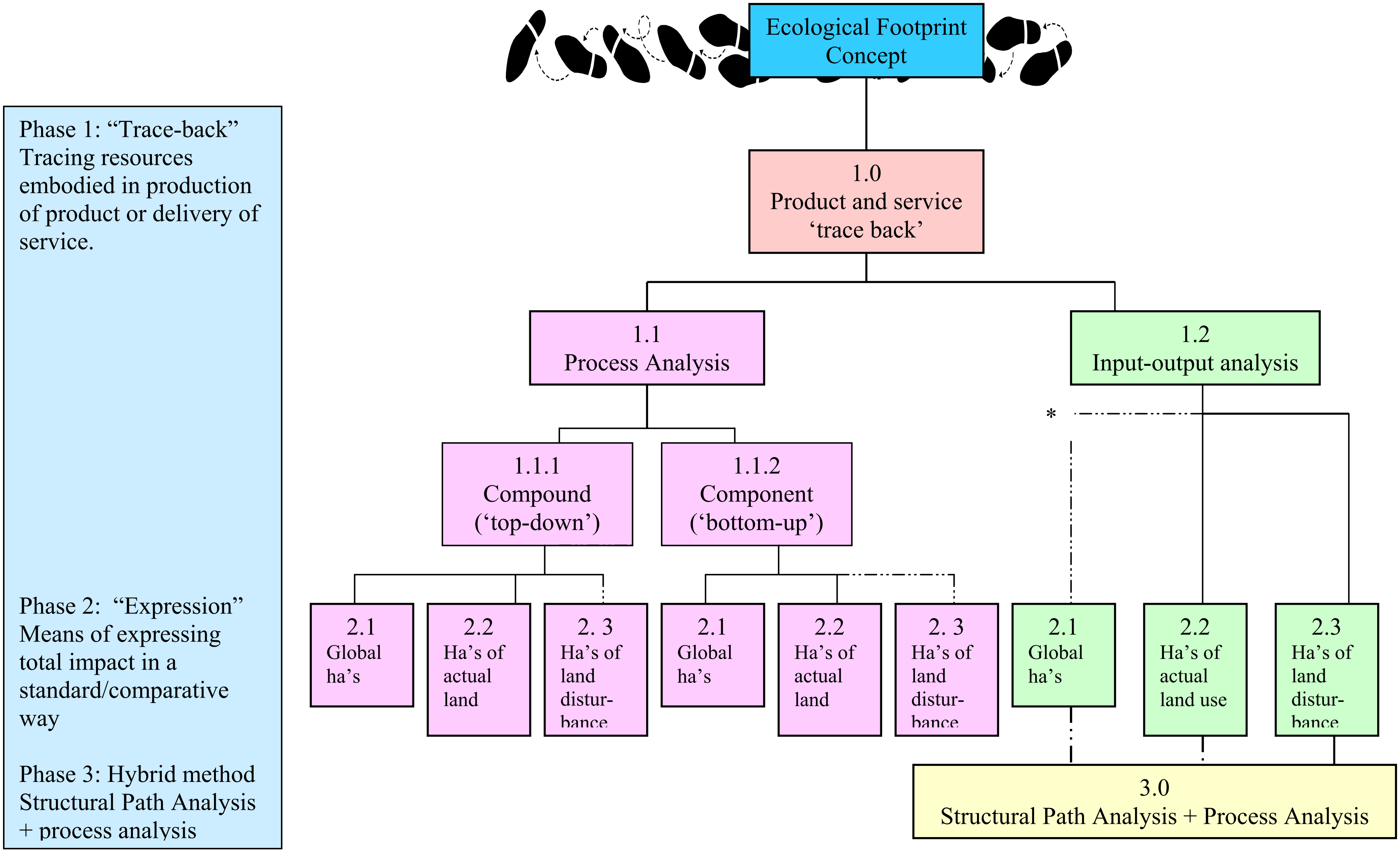
## 2.3 Evolution of the ecological footprint method

The ecological footprint method has undergone significant changes since it was first introduced in 1992 (Rees, 1992). Figure 2.3 presents the range of ecological footprint methods available, and will be referred to frequently throughout Section 2.3. This section will summarise these methodological changes in terms of (a) method of 'trace-back' of resources through production layers (Figure 2.3, Phase 1), and (b) means of expressing the ecological footprint in a standard way (Figure 2.3, Phase 2). A hybrid ecological footprint method that has evolved in response to conventional methodological limitations will also discussed (Figure 2.3, Phase 3).

### 2.3.1 Process analysis

The aim of the ecological footprint is to measure the amount of resources, expressed in hectares, that is needed to sustain a given population indefinitely (Wackernagel and Rees, 1996). This involves the tracing of resources and energy 'embodied' in the production of the commodity, delivery of service or the operations of a city (refer to Figure 2.3, Phase 1). To date, this process has been performed by either one of two methods – process analysis (1.1) or input-output analysis (1.2). Both methods are susceptible to different types of error and have different benefits. Process analysis begins by identifying the primary unit of analysis (for example, an institution, town or country). A list is then created of all the goods and services required for the maintenance or production of the primary unit of analysis. The direct energy and resource use is tallied, while each indirect input is further examined to determine the energy and resource inputs required for its production (and its subsequent ecological footprint). This process continues, tracing back from the unit of analysis through each production layer (PL). Figure 2.4 displays the successive stages in a process analysis.

**Figure 2.3 The range of ecological footprint methods**



* The dashed line represents the possibility of a particular phase being conducted, though in reality it has never been done before

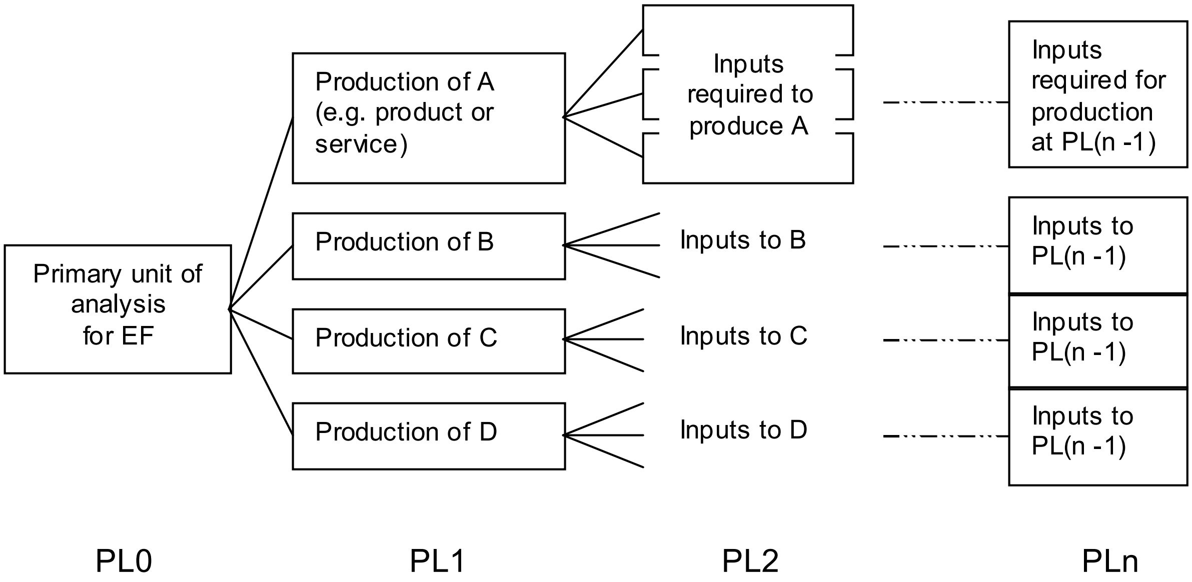


**Figure 2.4 Successive stages in process analysis-based ecological footprint methods**

(adapted from Bullard et al., 1978)

PL 1 = includes n first order direct resource inputs (n dependant on boundary definition)
Key: PL 2 = includes $n^2$ second order upstream resource input paths
PL n = where n equals the nth production layer

There are two complementary methods for calculating conventional ecological footprint studies, termed the compound and component-based methods (Chambers et al., 2000). The compound method is a top down approach and is more suited to larger scale footprint studies, while the component-based method, being a bottom-up approach, is more applicable to smaller scale studies. However this is not always the case. In both approaches, a consumption-land-use matrix is used to calculate the ecological footprint of a given unit of study, where consumption and land-use are divided into broad categories (refer to Appendix 2). These categories combine to form a matrix for the 'appropriated' land area for each consumption category (Simpson et al., 2000). The total ecological footprint is simply the sum of all consumption categories.

### (a) Compound-based footprinting

Compound footprinting involves the examination of a nation or state and calculating consumption by reference to trade flows and energy data before completing the consumption-land-use matrix (see, for example, the method outlined in Wackernagel and Rees, 1996, and the ecological footprint analysis of Australia by Simpson et al., 2000). Trade flow examination consists of a consumption analysis of approximately 50 biotic resources (for example, meat, dairy produce and wood products). Consumption is calculated by adding imports to production and subtracting exports (Chambers et al., 2000). Energy calculations are determined by considering locally generated energy and energy embodied in approximately 100 categories of traded goods (Chambers et al., 2000). The data obtained are then entered into a consumption-land-use matrix, expressed in hectare/capita (where land appropriated in hectares per capita equals the annual consumption of item $x$ divided by the world average land yield of $x$). The total footprint of the nation is obtained by multiplying the per capita data by the country's total population (Chambers et al., 2000

### (b) Component-based footprinting

In the component-based method, a 'bottom-up' approach is taken to assess the footprints of typically smaller scale entities such as cities or institutions (see, for example, Chambers and Lewis, 2001, and Flint, 2001). In this method, a number of individual components of consumption, or activities (typically 24, refer to Appendix 3) are identified and basic life cycle data are collated and converted to derive the footprints for each component. Thus the aim is to account for most consumption with a series of component analyses. Adjustments are made to categories based on assumptions about the sources of embodied energy and built land (Chambers et al., 2000). As in compound footprinting, the data obtained are entered into the consumption-land use matrix, but as a total hectare value per component. The total footprint for the area of study is calculated by determining the sum total (in hectares) of the components studied.

### (c) Disadvantages of process analysis

In theory, all of the inputs in each successive production layer are summed to obtain the total ecological footprint. However, in practice, large numbers of production layers are not computed due to cost, labour and time constraints, which may potentially underestimate the size of the ecological footprint. It is common practice for a system boundary to be developed, so that only those production layers and inputs that the researcher believes would contribute most to the ecological footprint are included. As a consequence, process analyses rarely extend further than a few production layers upstream and tend to ignore many inputs at each stage (Lave et al., 1995). This subjective system boundary incompleteness is a major limitation of the process analysis method. Indeed, studies have shown that contributions from higher order production layers are significant. Life cycle analyses, which have traditionally used process-analysis techniques to compile life-cycle inventories, have been shown to suffer from a systematic truncation error caused by the exclusion of resource requirements and/or pollution releases from higher-order upstream stages of the production process (Lenzen, 2001b).

Lenzen (2001b) demonstrated these shortcomings of process analysis in his study of Australian primary fossil energy consumption. An input-output analysis study was compared to a process analysis study that incorporated PL 0 and PL 1 (n=132 first order upstream energy inputs) and the associated truncation error of the process analysis study was above 50%. Expanding the process analysis system boundary to include PL 2 (n=17,424 second order energy inputs) only resulted in decreasing the truncation error to 30% (Lenzen, 2001a). Thus, further reductions could only be made by considering third-order, fourth-order… nth-order paths (Lenzen, 2001b).

Therefore, process analysis-based studies suffer from an “irreducible systematic error caused by the truncation of the production system boundary” (Lenzen, 2001b, p144). The magnitude of the truncation error is case-dependant, but Lenzen (2001b) has shown that it can be in the order of 50%. As a consequence, the results of process analysis-based studies are potentially unreliable and misleading.

In terms of process analysis-based ecological footprinting, only land used directly by the first-order supplier is generally included in the assessment. That is, the analysis is only "one or two production layers deep" (Lenzen et al., 2003b, p117). Consequently, an underestimation of the ecological footprint will result due to the systematic truncation error. The magnitude of the truncation error is evident when comparing the results of two studies that calculated the ecological footprint for Australia. The first ecological footprint of Australia was conducted by Simpson et al. in 2000, and utilised a compound-footprinting approach (a process analysis technique) in order to calculate the total ecological footprint based on world average productivities[1] (refer to Section 2.3.4(a) for more information on world-average productivities). In 2001, Lenzen and Murray also conducted an ecological footprint of Australia based on actual land use[2] for comparative value, but utilised an input-output analysis technique to calculate the total ecological footprint.

When comparing the consumption-land-use matrix of both studies, there is a clear difference between them. Many of the fields of the consumption-land-use matrix produced by Simpson et al. (2000) are empty, where as Lenzen and Murray (2001) calculated non-zero values for all land types in all consumption categories. Lenzen and Murray (2001) attribute this to a fundamental difference in the analysis technique. Simpson et al. (2000) directly allocated land use to final consumption categories, ignoring intermediate industrial land usage (Lenzen and Murray, 2001). This is a classic case of system boundary truncation – an incomplete assessment has been conducted on all of the upstream production land requirements needed to produce that particular item or service for final consumption. In other words, only the first production layer (PL1) incorporating direct land requirements is generally considered, thus ignoring the remaining upstream production layers (PL2…PLn – refer to Figure 2.4). Therefore, the results presented from the Lenzen and Murray (2001) ecological footprint study differed from those given by Simpson et al. (2000) on account of the contrasting analysis techniques used. The main differences occurred within those consumption categories with a high proportion of indirect land requirements, such as Housing (20) and Resources in Services Received (50) from the consumption-land-use matrix (refer to Appendix 2).

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[1] Simpson et al. (2000) also calculated the ecological footprint for Australia based on actual land use (refer to Section 4.3)

[2] Lenzen and Murray (2001) also calculated the ecological footprint for Australia based on a land disturbance approach (refer to Section 4.3)

This limitation was used as the rationale by Bicknell et al. (1998) to introduce the input-output analysis technique to the ecological footprinting arena. Bicknell et al. (1998) were the first authors to apply the input-output analysis method for calculating ecological footprints in their assessment of the New Zealand population. Several other authors have since adapted and modified the input-output analysis technique for its use within ecological footprinting (see Lenzen and Murray, 2001; Ferng, 2002; Lenzen et al., 2003b; Hubacek and Giljum, 2003; Wood and Lenzen, 2003).

### 2.3.2 Input-output analysis

Input-output analysis was introduced by Wassily Leontief in 1941 as an economic modelling technique and has been used extensively in economic research (Leontief, 1941). It has since been adapted to analyse energy and labour intensities (Bullard et al., 1978), environmental pollution (Leontief, 1970; Lange, 1998; Forsund and Strom, 1976), environmental impact assessments (Lenzen et al., 2003a), life cycle analyses (Treloar, 1997; Joshi, 2001; Hendrickson, 1998) and ecological footprints (Bicknell et al., 1998; Lenzen and Murray, 2001; Ferng, 2001, 2002; Lenzen et al., 2003b).

Input-output analysis utilises standard input-output tables which map the flows of goods and services between sectors or industries of an economy in economic units (see ABS, 1999). The model is in the form of a large linear network, and remains the same for any given variable (for example ecological footprinting, life cycle assessment, labour intensities). Initially the economy is disaggregated into *n* major sectors, each producing a unique good or service and each characterised by a node in the network (Dixon, 1996). Therefore in calculating an ecological footprint via the input-output analysis method, a detailed commodity (or component-based approach) is adopted.

A major advantage of input-output analysis is that it provides a view of interdependence caused by the passage of intermediate goods and services between industries, before they reach the final consumer (Dixon, 1996). In other words, it allows for the comprehensive incorporation of indirect resource requirements. The system boundary used in input-output analysis encompasses the entire economic system, in comparison to the truncated system boundary used in process analysis-based ecological footprint studies (refer to Figure 2.5). For example, consider the ecological footprint of an institution. There are 50 direct supplier paths to the insitution – that is, PL 1 or first order representing the immediate suppliers, equals 50 paths. Utilising an input-output model of 135 industries, the second order (PL2, or suppliers of suppliers) would potentially contain 50 x 135 paths, equalling 6750 paths. Therefore, the third order (PL3, or the suppliers of suppliers of suppliers) may contain 50 x 135 x 135 paths – 911, 250 paths, and so on though all layers of production contained within the boundary of the economic system. Therefore, the input-output approach secures the complete coverage of upstream land and emissions requirements up to an infinite order (Lenzen, 2001a).

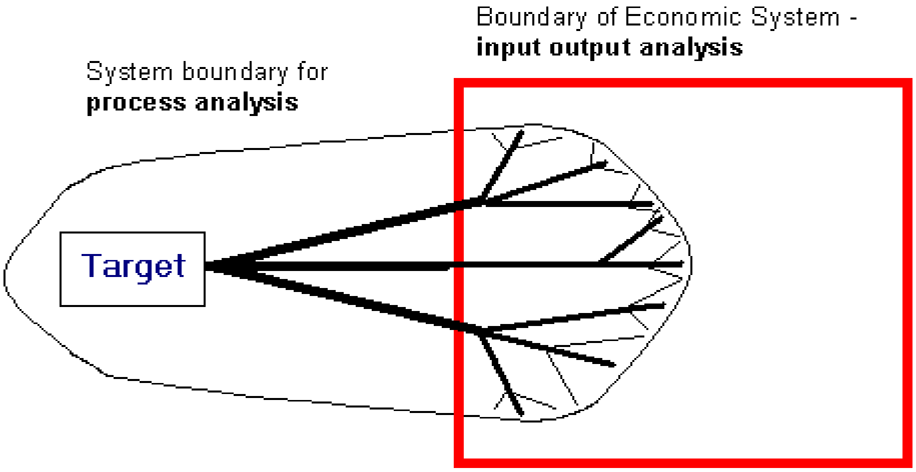

**Figure 2.5 System boundaries for process and input-output analyses**

Another advantage of input-output analysis is that imports and exports can be easily distinguished. In process-based ecological footprint studies, it is not specified where the main ecological footprint impacts are occurring. For example, what proportion of the ecological footprint is attributable to the production of imported goods, domestically produced goods or the production of exports (Bicknell et al., 1998)? The nature of input-output analysis allows for the disaggregation of accounts to differentiate between the impacts of imports, domestic consumption and exports (Lenzen and Murray, 2001).

Additionally, input-output analysis uses data sets that are regularly collected by government statistical agencies, such as input-output tables (see ABS, 1999). Researchers utilising process analysis-based techniques (particularly in component ecological footprint studies, refer to Section 2.3.1b) have identified problems associated with a general lack of data, and methodological problems such as boundary selection and double counting (Simmons and Chambers 1998; Simmons et al., 2000; Barret, 2001; Chambers and Lewis, 2001). However, input-output analysis does have some uncertainties associated with the method (refer to Table 2.2).

In response to the allocation uncertainty identified in Table 2.2, a hybrid methodology has been developed, combining input-output analysis, structural path analysis and process analysis techniques**.**

### Table 2.2 Types of uncertainty in input-output analysis

| Type of Uncertainty | Summary |
|---|---|
| **1. Allocation uncertainty** | Input-output data are aggregated over different products supplied by one industry (Lenzen, 2001b). For example, the meat products industry, producing all types of meat, contains a large percentage of beef in its output. A high land disturbance intensity is associated with beef production, therefore also making the meat products industry land disturbance intensive.<br>Consider a restaurant specialising in chicken dishes only. To attribute the chicken meat expenditure to the meat products industry would result in an unrealistically high land disturbance footprint due to the contribution of the beef cattle production within that industry. |
| **2. Aggregation uncertainty** | Input-output analysis results only give the average factor intensities of an industry's output. Accuracy is limited by the level of aggregation, as input-output and factor data are generally aggregated over a number of producers within one industry (Bullard, 1975; Lenzen, 2001b).<br>For example, consider a beef steak, and the land disturbance required to produce it. Land intensities vary with each producer, depending on stocking rates and sustainable practices. Because producers are aggregated within the beef cattle industry, input-output results only give the average land intensity for that industry. |
| **3. Price level changes** | Due to inflation over time, price levels must be corrected to the input-output table base year via price indices. However, price indices may be inaccurate due to the aggregation error (price level indices for products are aggregated into industries). |
| **4. Basic values versus purchasers prices** | Data used within input-output tables are collected from firms rather than consumers, so they are based on the firm's value of the product, or the basic value. However, consumers pay not only this basic value, but also the wholesale and retail margins, transportation costs, insurance etc. |
| **5. Technology changes since the base year** | The technology for the production of goods and services can change over time. Errors can occur if there is a large difference between the base year and the current study period. |
| **6. Source data uncertainty** | Most input-output tables (including Australia) are compiled from data collected in industry surveys, and as such, uncertainties exist due to potential errors during reporting, collection and processing (Lenzen, 2001b) |
| **7. Estimation uncertainty for capital flow** | Capital flow tables are not compiled in Australia, so they have to be constructed from industry totals of gross fixed capital expenditure (Lenzen, 2001b). The lower limit standard error involved with this process is estimated to be approximately 50% (Lenzen, 2001b). Perhaps an even greater limitation is that by including capital flow, anomalies are created, which in annual ecological footprint assessments creates unrealistically high results. |
| **8. Identical factor imports for imported commodities** | Foreign production factors are assumed to be equal to Australian production factors (Lenzen, 2001b). However, commodities produced by foreign industries can possess factor inputs that differ significantly from domestically produced commodities. |
| **9. Proportion-ality error** | There is an assumption that the physical flow of commodities between industries can be represented by the monetary values of the corresponding inter-industrial transactions (Lenzen, 2001b). |
| **10. Gate to grave truncation error** | Input-output analysis only considers factor requirements for the production of commodities (the 'cradle to gate' period), but not for the downstream components of the full life cycle, including use, maintenance, decomissioning, demolition, disposal or recycling (the 'cradle to grave' period) (Lenzen, 2001b). |

### 2.3.3 Hybrid methodology

In order for ecological footprint results to be useful for decision-makers, a disaggregation of the total ecological footprint is required (van Vuuren and Smeets, 2000). In input-output analysis-based ecological footprint assessments, the highest level of disaggregation possible is a breakdown of the total footprint (in hectares) into each supplying industry (for example, beef cattle, electricity supply or communication services; see Section 4.4). However, this does not indicate the type of impact (dependant on ecological footprint method, for example type of land disturbance) or the types of paths within each commodity grouping and their subsequent production layer order (that is, PL1, PL2, PL2… etc). This level of detail can only be achieved via the use of structural path analysis, and can be useful for making managerial decisions about key operational processes that hold the potential to decrease the size of the ecological footprint. Structural path analysis was first introduced to economics and regional science by Defourny and Thorbecke (1984), and it has since been applied in life-cycle assessments by Treloar and Lenzen (see Treloar, 1997; Treloar et al., 2000; Lenzen, 2001) and ecological footprints (see Lenzen et al., 2003b; Wood and Lenzen, 2003).

In order to achieve a higher level of disaggregation, a hybrid methodology has been developed which combines input-output analysis, structural path analysis and process analysis (see Lenzen et al., 2003b; Wood and Lenzen, 2003). Once input-output analysis has been conducted and the ecological footprint calculated, the decomposition technique structural path analysis is performed. This involves running an extraction algorithm that decomposes the input-output analysis using the Leontief inverse formula, and allows the total ecological footprint to be decomposed and ranked into detailed contributing paths. While the values of the paths are only indicative, the ranking of the paths allows for the identification and prioritization of targets for action on improving environmental sustainability (Lenzen, 2001a).

Once the key contributing paths to the ecological footprint have been identified, the process analysis approach can be used to manually trace the key contributing paths through their subsequent production layers. This allows for a sensitivity analysis of the ecological footprint to correct for the allocation uncertainty, and for path refinement via the correction of potential errors that are typically associated with input-output analysis (refer to Table 2.2).

### 2.3.4 Units of expression for the ecological footprint

To date, the size of the ecological footprint has generally been expressed in one of three ways: land appropriation in world average productivity (or 'global hectares'), land appropriation by actual land use (or 'actual land use hectares') and hectares of land disturbance (refer to Figure 2.3, Phase 2). Each unit of expression has strengths and weaknesses, and these are summarised in Table 2.3.

#### (a) Land appropriation in world-average productivity

In conventional ecological footprints (typically compound footprints), the appropriation of land is expressed in units of hectares per capita at world-average productivity (Figure 2.3, Phase 2.1, Approach 1.1). This standardisation procedure is achieved by using average national consumption data and world-average land yields to calculate agricultural land use, in order to facilitate 'general case' comparisons among regions and countries (see Wackernagel et al., 1997). This means that the areas of forest, pasture and crop land do not represent real land, but hypothetical areas that would be needed to support the consumption of the population, if local farming and forestry was conducted at 'world average productivity' (Lenzen and Murray, 2003).

Lenzen and Murray (2001) argue that much regional detail is lost through these averaging procedures. The ecological footprint is claimed to be "… a tool for weighing the merits of potential policies and developing effective strategies and scenarios for a sustainable future" (Wackernagel, 2002, p6). However, methods with a focus on regional problems are more useful for policy design, as most policies are designed and implemented at the regional level (Lenzen and Murray, 2001). Utilising this method, the ecological footprint is unsuitable for policy design, as it is unrelated to regional impacts on land and the sustainability of regional land use. Moreover, in expressing land appropriation in hectares per capita at world-average productivity, the potential for countries, regions or institutions (for example) to reduce their ecological footprint through improved ecological management is lost (van Vuuren and Smeets, 2000).

Another significant disadvantage of this method is that the ecological footprint is based only on how much *ecologically productive* land a population must appropriate to provide for its consumption needs indefinately (Simpson et al., 2000). However, even unproductive land can be useful for human purposes, and should not be disregarded (Lenzen et al., 2003b). For example, in Australia, large areas of arid and semi arid land is used for grazing – areas that would be excluded in this method, thereby underestimating the ecological footprint. Simpson et al. (2000) accounted for this limitation in their assessment of Australia's ecological footprint by including semi-arid and arid areas of land. Table 2.3 describes other weaknesses associated with this particular method.

### (b) Land appropriation by actual land use

A new method evolved in response to these weaknesses described above, incorporating actual land areas used by sectors and their corresponding land yields. These improvements are more commonly found in component-based footprint studies. By using actual land areas, the calculated area is equal to the real, touchable area used for the consumption of a specific region. As aforementioned, this regional focus is much more useful for policy design. For example, land use based on local land yields is much more relevant as these can be influenced by increasing productivity – which may result in unsustainable land use practices (van Vuuren and Smeets, 2000). The land appropriation by actual land use method generally improves on the original method by including all areas of land in most ecological footprint calculations.

### (c) Land disturbance model

Despite these improvements, conceptual problems still remain in both of the above-mentioned methods (refer to Table 2.3). Some of the more critical limitations are discussed below.

The ecological footprint is a one-dimensional indicator, calculated by summing up all consumption-related direct and indirect ecological impacts (of a region, activity) in terms of land use. In both of the aformentioned methods, this requires different consumption categories to be translated into the related land-use area. However, no account is taken of the local features of land types and land use (for example land cover) in this translation (van den Bergh and Verbruggen, 1999). The methodology employs a fixed weighting scheme, which applies a fixed rate of substitution between different categories of environmental disturbance. For example, residential land has the same weight as agricultural land, despite the fact that residential land is clearly more environmentally destructive than land for pasture. Thus the land condition, or the deviation from a pristine state (Lenzen and Murray, 2003) is not established in the land appropriation ecological footprint approach.

In addition, because the land types used in consumption-land use matrices do not reflect land condition, no distinction is made between the sustainable and unsustainable use of land (van Vuuren and Smeets, 2000). This lack of distinction may lead to the paradoxical situation that unsustainable agricultural production methods (contributing to soil degradation) actually decrease the ecological footprint due to higher productivities, despite the fact that in the long-term, it would be more unsustainable (van den Bergh and Verbruggen, 1999). For example, the ecological footprint for beef consumption by a specified population simply involves a measurement of the land area required for the corresponding amount of cattle (Lenzen and Murray, 2003), dependant on the land yield factor (either world-average productivity or actual land yield, see Section 2.3.4a,b). Therefore, farmers that had extensively cleared large tracts of native vegetation causing subsequent soil salinity and erosion problems, would not be distinguished from those farmers who had adopted environmentally-responsible management practices.

**Table 2.3 Strengths and weaknesses of 'world average productivity', 'land use' and 'land disturbance' ecological footprint approaches***

| ***World Average Productivity*** <br> ***('global hectares')*** <br> ***see Wackernagel and Rees (1996)*** | ***Land use*** <br> ***('local land hectares')*** <br> ***see Bicknell et al. (1998)*** | | ***Land Disturbance*** <br> ***('hectares of land disturbed')*** <br> ***see Lenzen and Murray (2001)*** | |
|---|---|---|---|---|
| **WEAKNESSES** | **IMPROVEMENTS** | **WEAKNESSES** | **IMPROVEMENTS** | **WEAKNESSES** |
| 1. Does not indicate the sustainability of regional land use (Lenzen and Murray, 2001), thereby making it unsuitable for policy design (See Section 4.3.1) | 1. Uses local land yields, thus providing a better interpretation of regional land use. | | 1. By revealing the land (cover) disturbance of all (including regional) areas, this approach can be useful for policy design. | |
| 2. Only examines bioproductive areas. Unproductive land that may be useful directly or indirectly for human purposes is excluded. For example, in Australia, large tracts of arid or semi arid land is used for grazing – areas that would be excluded in this approach, thereby underestimating the ecological footprint (see Simpson et al., 2000). | 2. Generally includes all areas of land | | 2. All areas of land are considered | |
| 3. Considers only emissions of $CO_2$ from energy-use sources | | 3. Weakness in column one still applies | 3. Accounts for greenhouse gas emissions from both energy-use and non energy-use sources, including $CO_2$, $CH_4$, $N_2O$, $CF_4$ and $C_2F_6$. | |
| 4. Land types used in the consumption-land-use matrices do not reflect land condition, thus no distinction is made between the sustainable and unsustainable use of land (Vuuren and Smeets, 2000). | | 4. Weakness in column one still applies | 4. By using land disturbance, it focuses on a process that contributes to unsustainability (as opposed to land appropriation), as land cover disturbance can be an indicator of unsustainable farming or forestry practices by indicating for soil erosion etc (Graetz et al., 1995). | 4. However, the land disturbance approach still cannot address whether land use is practised sustainably (Lenzen and Murray, 2001). |
| 5. A fixed weighting scheme and a consequent fixed rate of substitution is supposed between different categories of pressure, even if it is clear that their environmental impacts are very different (Levett, 1998; van den Bergh and Verbruggen, 1999). | | 5. Weakness in column one still applies | 5. By utilising a land disturbance model, criticism 5 is not applicable. | |
| 6. Limited options for greenhouse gas assimilation (van den Bergh and Verbruggen, 1999; Lenzen and Murray, 2001). | | 6. Weakness in column one still applies | 6. Disturbance-based model negates criticism of limited greenhouse gas assimilation options, as it looks at the projected disturbance from emissions (see Lenzen and Murray, 2001). | |
| 7. Limited scope. Omission of some important environmental aspects, such as chemical use and water consumption (Vuuren and Smeets, 2000). | | 7. Weakness in column one still applies | | 7. Still does not consider all aspects of environmental sustainability |

* **Note**: This table displays three methods, the first (on the left) is improved on by the second (land use), and then the third (land disturbance).

It is evident therefore that problems lie within the actual ecological footprint concept of ‘land appropriation’ – that is, simply the area of land required to support a specified level of resource and waste flows. van den Bergh and Verbruggen (1999) argue that in order to measure sustainability, there is a need to focus on processes that contribute to unsustainability. As a result, Lenzen and Murray (2001) have attempted to more closely describe regional ecosystem degradation, rather than land appropriation, by developing a new approach to ecological footprinting.

There is a host of literature available on the use of biological indicators as a means of gauging environmental impacts. According to Bell and Morse (1999), the two most common approaches are to:

(a) identify the composition of ‘indicator’ species that are sensitive to environmental changes such as temperature or pollutants (for example, fish distribution near the point of discharge of industrial waste; see Learner et al., 1976), and
(b) measure biodiversity (for example, the Shannon-Wiener index of biodiversity; see Southwood, 1978).

However, an indicator applicable on a broader scale is required when using the ecological footprint index, as the system boundary often extends nation or even world-wide. As a result, Lenzen and Murray (2001) proposed that a method based on land condition, which uses actual areas of land used by the respective population, would be more useful in terms of indicating for sustainability (Lenzen and Murray, 2001).

Lenzen and Murray (2001) put forward that the degree of land cover disturbance is a useful proxy for ecosystem degradation in Australia at a very broad scale. They argue that a disturbance-based approach “..would better reflect the image of a footprint on land, because it describes the effects of human land use on all ecosystems and species, independent of their productivity, or the services they may provide to humans” (Lenzen and Murray, 2001, p231). Additionally, Graetz et al. (1995) argue that land cover disturbance is the best surrogate available for measuring large-scale biodiversity, an indicator of ecosystem health (or degradation).

In formulating the land-disturbance model, Lenzen and Murray (2001) used results from a comprehensive survey conducted by Graetz et al. (1995) of land cover disturbance over the entire Australian continent. The study used 1990-1992 satellite imagery to map the severity of land cover disturbance by tenure and class, via comparing the current coverage of 34 vegetation classes with the 'natural' vegetation state (Graetz et al., 1995). The vegetation state at the time of European invasion of Australia (1788) was selected to represent the 'natural' state, as the most significant habitat destruction is considered to have occurred post European settlement (Glanznig, 1995).

Lenzen and Murray (2001) developed a weighting system to reflect the degree of alteration of land from its natural state, based on the disturbance categories developed by Graetz et al. (1995) and new land use types (refer to Table 2.4)

**Table 2.4 Basic weighting factors for land use reflecting land condition in Australia**

| Disturbance Category (from Graetz et al., 1995) | Land use type | Land condition weighting factor |
|---|---|---|
| 1. Consumed | Built | 1.0 |
| 2. Degraded | Degraded pasture or crop land<br>Mined land | 0.8 |
| 3. Replaced | Cleared pasture and crop land<br>Non-native plantations | 0.6 |
| 4. Significantly Disturbed | Thinned pasture<br>Urban parks and gardens<br>Native plantations | 0.4 |
| 5. Partially Disturbed | Partially disturbed grazing land | 0.2 |
| 6. Slightly Disturbed | Reserves and unused crown land<br>Slightly disturbed grazing land | 0.0 |

Adapted from Lenzen and Murray (2003).

In order to obtain the ecological footprint, this disturbance-based approach multiplies each area of land by its land condition factor, so that each part of the land receives a value that reflects both its area and its condition (Lenzen and Murray, 2003). Therefore disturbance (D) = affected area (A) x land condition (C).

In addition to the six land condition types included in the disturbance-based ecological footprint assessment (Table 2.4), hypothetical energy and emissions land categories are incorporated. An 'energy land' category accounts for those greenhouse gases generated from energy-use sources, and an 'emissions land' category accounts for those greenhouse gases generated from non energy-use sources (such as land clearing, enteric fermentation in livestock, industrial processes, waste, coal seams, venting and leakage of natural gas; Lenzen and Murray, 2003). This represents an refinement on the aforementioned ecological footprint methods, as they fail to account for greenhouse gas emissions released from non energy-use sources. This is an important improvement particularly for Australian-based ecological footprint assessments, as non energy-use greenhouse gas emissions have been found to be particularly significant in Australia (Lenzen and Murray, 2001).

In complying with the disturbance-based approach, Lenzen and Murray (2001) examine the projected disturbance of terrestrial and aquatic ecosystems (due to climate change and sea level rise under doubled $CO_2$ equilibrium conditions; Darwin et al., 1996) for the incorporation of the hypothetical energy and emissions land, based on an emissions to land conversion factor of 68.5 ha/kt of carbon dioxide (weighted) equivalents. Due to the substantial uncertainty in predicting impacts of climate change on land, these figures should be taken as a crude approximation (Lenzen and Murray, 2001). In keeping with the disturbance-based model, a contentious issue of significant debate among ESD researchers and practitioners, that of the energy use scenario, is avoided. The accuracy and realism of the energy footprint is a critical component of the ecological footprint method because in most cases, the estimated energy footprint amounts to approximately one half of the total calculated ecological footprint (Ferng, 2002). Therefore, the size of the energy footprint would change almost simultaneously if alternative energy scenarios were to be implemented (van den Bergh and Verbruggen, 1999).

The conventional ecological footprint method offers limited options for converting fossil energy consumption into a corresponding land area:

(a) The amount of biologically productive land required (ie. forest ) to assimilate the carbon dioxide produced by burning fossil fuel. This option has been the most popular; see for example, Simpson et al. (2000), Bicknell et al. (1998), and Chambers and Lewis (2001).
(b) The land area required to grow a biological substitute for fossil fuel (for example sugar cane for ethanol)
(c) The land area required to "rebuild natural capital at the same rate as fossil fuel is being consumed" (Wackernagel and Rees, 1996, p73).

Conceptually, van den Bergh and Verbruggen (1999) argue that more sustainable energy-use scenarios should be allowed for. They believe that the disregard for other economically rational solutions is not consistent with marginal cost thinking of economics, and therefore unnecessarily realistic from an economics perspective (van den Bergh and Verbruggen, 1999). Dependant on a region's geographical, climatic, and technological characteristics, there may be better options for greenhouse gas assimilation, such as increases in energy efficiency, fuel mix and renewable energy sources (Lenzen and Murray, 2001). Consequently, in using a disturbance-based approach for the incorporation of energy-use greenhouse gas emissions, the debate pertaining to methods of greenhouse gas assimilation is negated.

In summary, Lenzen and Murray's (2001) disturbance-based ecological footprint is the sum of disturbances across the eight land types, combining present and potential future land disturbance (six land condition types plus the hypothetical energy and emissions land). Whilst the disturbance-based approach is an improvement over conventional methods, it still fails to distinguish whether land is being utilised sustainably. The sustainability of land use requires the measurement of disturbance caused to an ecosystem, and a knowledge of an ecosystem's ability to withstand and/or recover from potential impacts (also known as ecosystem resilience; Lenzen and Murray, 2003). Many potential ecosystem disturbances and consequent impacts are not considered in the land disturbance approach (refer to Table 2.5)

**Table 2.5 'Disturbances' the land disturbance model fails to consider**

| Examples of 'disturbances' the land disturbance approach fails to consider | Potential Impacts |
|---|---|
| Fertiliser and pesticide use<br>Unsustainable freshwater consumption<br>Fisheries<br>Aquaculture<br>Sediment run-off<br>Habitat fragmentation<br>Alteration of fire regimes<br>Irrigation | Water Pollution<br>Toxicity<br>Loss of biodiversity<br>Salinity<br>Acid sulphate soils<br>Soil and wind erosion<br>Wind erosion<br>Loss of soil fertility<br>Hydrological changes<br>Air pollution |

However, until more detailed information becomes available on these factors, Lenzen and Murray (2001) propose that land (cover) disturbance is the best proxy available.

## 2.4 Applications of the ecological footprint

The ecological footprint concept has been applied to populations at numerous scales, including product, individual, household, institutional, regional, country-wide and world-wide (refer to Table 2.6). Studies have focused primarily on national and regional scales, though in recent times, studies have been conducted on institutional scales (Chambers and Lewis, 2001; Flint, 2001; Venetoulis, 2001; Lenzen et al., 2003b; Wood and Lenzen, 2003).

**Table 2.6 Ecological footprint applications**

| Date | Author/s | Ecological footprint unit of analysis |
|---|---|---|
| 1994 | Larsson, et al. | A semi-intensive shrimp farm on the Bay of Barbacoas, South America |
| 1997 | Wackernagel et al. | Footprint of Nations report |
| 1997 | Folke, et al. | Cities in Baltic Europe (29 cities in total) |
| 1998 | Bicknell et al. | New Zealand, with a specific focus on the New Zealand economy |
| 1999 | Jansson et al. | Baltic Sea Drainage Basin |
| 2000 | Simpson et al. | Australia, with a focus on the South East Queensland Region |
| 2000 | van Vuuren and Smeets | Benin, Bhutan, Costa Rica and the Netherlands |
| 2000 | Lewis et al. | Comparative study of packaging systems |
| 2001 | Chambers and Lewis | Anglican Water Services and Best Foot Forward (environmental consultancy firm) |
| 2001 | Lenzen and Murray | Australia |
| 2001 | Barret, J. | Guernsey (Channel Islands) |
| 2001 | Flint, K | University of Newcastle, Australia |
| 2001 | Venetoulis, J | University of Redlands |
| 2002 | Maltin and Starke | The Los Alamos National Laboratory |
| 2002 | Cole and Sinclair | Himalayan Tourist Region |
| 2002 | World Wildlife Fund | The ecological footprint of two summer package holidays to Majorca and Cyprus |
| unpublished | Charlton, K | Western Australia |
| 2002 | Loh (ed) | Footprint of Nations (146 countries in total) |
| 2003 | Lenzen et al | Sydney Water Corporation |
| 2003 | Wood and Lenzen | Comparative institutional study of the School of Physics (University of Sydney) and the Sustainable Ecosystems Department of the Commonwealth Scientific and Industrial Research Organisation |

This shift in scale has been in response to criticisms that national calculations simply reiterate already established inequities between the consumption of the developed and the developing world (van den Bergh and Verbruggen, 1999). Studies applied on a more localised level, on the other hand, provide practical information for managers, especially for commercial and public organisations that have the ability to control and direct their own purchasing (Lenzen et al., 2003b).

### 2.4.1 The ecological footprint and eco-tourism

Eco-tourism is a growing niche market within the Australian tourism industry (Preece et al., 2003). The definition of eco-tourism adopted by Eco-tourism Australia is:

"Eco-tourism is ecologically sustainable tourism with a primary focus on experiencing natural areas that fosters environmental and cultural understanding, appreciation and conservation" (Ecotourism Australia, 2000)

Typically located in pristine, fragile ecosystems, eco-tourism resorts must respect the environmental assets that they are dependent on (Wood, 2002). The projected growth of eco-tourism in Australia (both domestic and inbound) will place increasing demands on the existing infrastructure, and energy and resource consumption (Department of Industry, Tourism and Resources, 2002). Adequate planning and innovative strategies are required to ensure that eco-tourism is able to grow sustainably within the environmental and social carrying capacity of eco-tourism destinations.

The ecological footprint is a planning tool that holds significant potential in guiding the sustainable operation of eco-tourism destinations. By highlighting and assigning ecological impacts to resource consumption and waste assimilation patterns (both on-site and off-site in upstream production layers), actions can be taken (for example in purchasing policies) to decrease the amount of ecological impact caused by eco-tourism operations. This also has the potential to identify cost savings.

Not only could the ecological footprint assist in achieving best practice for environmentally sustainable tourism, it could also provide an opportunity for guest-based environmental education and interpretation, as demonstrated by the availability of 'online' ecological footprint calculators (see Redefining Progress, 2003). Environmental education and interpretation are important components of eco-tourism, through the acknowledgment of environmental issues such as resource management and influencing tourist behaviour to be more environmentally sustainable. Both environmental education and interpretation and environmental best practice represent some of the requirements needed to achieve eco-tourism accreditation (see the Nature and Eco-tourism Accreditation Program, Ecotourism Australia, 2000). Therefore, the ecological footprint holds the potential be particularly useful within the eco-tourism industry by assisting tourist destinations to (a) be more environmentally responsible and make progress towards ESD, and (b) strengthen marketing strategies by helping to achieve eco-tourism accreditation and eco-tourism awards.

### 2.4.2 Where are the gaps in the literature?

To date, only two ecological footprint assessments in the world appear to be based on the tourism industry. These include:

(1) A study on a Himalayan tourist region, investigating the direct tourist impact on the size of the footprint (Cole and Sinclair, 2002); and
(2) The ecological footprint caused by of two summer package holidays to Majorca and Cyprus, including airfares and two weeks duration spent at a specified resort in each city (World Wildlife Fund, 2002).

Thus far, no institution-based ecological footprint assessment has been conducted for the operation of a tourism or eco-tourism resort, either nationally or internationally. Given the projected growth expected within the industry and the fragile ecosystems in which eco-tourism resorts are typically located, there is a clear need for eco-tourism resorts to assess their operational ecological impacts. The ecological footprint has been utilised in other scenarios to provide detailed information on these factors (see Lenzen et al., 2003b; Wood and Lenzen, 2003). An ecological footprint on an eco-tourism resort would thus provide useful information to assist decision-makers in developing an action plan for sustainability and in achieving progress towards the goal of ESD.

# CHAPTER 3: THE PRESENT ANALYSIS

The preceding chapter provided an overview of the theoretical development of the ecological footprint method along with a broader overview of related research. This chapter presents the detail on how this methodology was applied to the case study area of Kingfisher Bay Resort and Village in order to address the specific research objectives.

## 3.1 Overall aim and research strategy

To date, no institutionally-based ecological footprint has been calculated for a tourism or eco-tourism resort, either nationally or internationally. The aim of this research was to evaluate the ecological footprint as an indicator for ESD for an eco-tourism resort. Consequently, the case study approach was adopted and steps were taken to identify a suitable resort and organisational partner. A successful ecological footprint analysis was dependent on gaining access to the required data and being able to liaise closely with the resort's managers. These criteria made Kingfisher Bay Resort and Village (KBRV), located on Fraser Island, Queensland, an ideal candidate, in addition to the following reasons:

(a) KBRV is a fully accredited large-scale eco-tourism resort (the resort and all tours have been awarded Advanced National Eco-tourism Accreditation),
(b) the resort is located in a World Heritage listed area,
(c) KBRV places emphasis on achieving eco-tourism based awards (thereby making the results of this study distinctly useful), and finally
(d) KBRV is generally regarded as one of Australia's most successful examples of eco-tourism accommodation, and serves as a case study for the eco-tourism industry (Eco-tourism Australia, 1999).

In addition, KBRV is in close proximity to the University of the Sunshine Coast (USC), and the Memorandum of Understanding established between the two institutions facilitated a high level of cooperation.

## 3.2 Specific objectives

As mentioned in the introduction, the specific objectives of this study were to:

(a) Calculate the ecological footprint of the eco-tourism resort, KBRV, and examine the sensitivity of the ecological footprint to alternative calculation methods.
(b) Identify the key contributing factors to the ecological footprint for KBRV.
(c) Evaluate the potential of using the ecological footprint as an indicator of progress towards ESD.

## 3.3 Selection of ecological footprint method

As discussed in Section 2.3 and represented in Figure 2.3, there is a range of methods that can be used to calculate the ecological footprint. For this analysis, the hybrid ecological footprint method in conjunction with the land disturbance model was chosen above all other footprinting methods for the following reasons. First, the hybrid method has a superior ability to capture the contributing factors to the ecological footprint within the study's system boundary, including the ability to conduct an outlier analysis to correct for potential errors. Second, the land disturbance model was chosen because it represents aspects of regional ecosystem degradation, and hence unsustainable practices more so than other methods. Refer to Section 2.3 for a detailed account of the concepts involved with the land disturbance model and hybrid ecological footprint approach.

The uncertainties and limitations that are characteristic of the selected methods are also summarised in Section 2.3. The input-output analysis technique, in particular, has several inherent uncertainties. Some of these can be attended to methodologically, while others remain as intrinsic limitations and will be discussed further in Chapter 4. Those uncertainties that were able to be addressed are presented in methodological sequence in the forthcoming sections.

## 3.4 Gaining access to required information

To conduct an ecological footprint analysis of KBRV, complete access to KBRV's sensitive and confidential financial data was needed. This involved building upon the existing Memorandum of Understanding between KBRV and the USC. Discussions were held with the general manager of KBRV, with an objective to outline the key concepts of the ecological footprint, establish the need for KBRV to conduct such an assessment, and acquire permission for full access to KBRV financial data and relevant staff members. Once this access to data was secured, both on-site and in the central office (off-site), arrangements were made to secure rights to use the land disturbance model and hybrid ecological footprint approach.

Negotiations were conducted with Dr Manfred Lenzen, a Research Fellow from the University of Sydney and co-inventor of the land disturbance model and hybrid ecological footprint approach[1]. Permission was acquired to utilise and evaluate the methods, and an intellectual property agreement was established between the University of Sydney and USC regarding the incorporation of the land disturbance model input-output 'multipliers' (developed by Dr Lenzen) in the present analysis.

## 3.5 Phase One: On-site assessment

An on-site assessment for KBRV was the first phase[2]of this five-phase analysis (see Figure 3.1). This involved the compilation of an on-site land and emissions inventory through the measurement of the on-site land and emission requirements via an operational auditing process. Those items of the inventory with no associated dollar value (namely the results from the land use and cover disturbance assessment) were added as an f x 1 vector of direct land and emission requirements to the indirect land and emission requirements. This is presented in Phase four of Figure 3.1 and represents the compilation of KBRV's total ecological footprint. The items that did have an associated dollar value, namely emissions associated with fuel use, were included

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[1] See Lenzen and Murray (2001) for an application of the land disturbance model-based Ecological Footprint to Australia, and Lenzen et al. (2003b) for the application of the hybrid Ecological Footprint approach to the Sydney Water Corporation.

[2] Figure 3.1 summarises the five methodological phases undertaken in this analysis, and will be frequently referred to throughout the current chapter.

into commodity vector y, the outcome of Phase two, Figure 3.1. The methods employed to gather information for the KBRV on-site assessment are described in the following sections.

### 3.5.1 Land use and land cover disturbance assessment

The land use and subsequent land cover disturbance of the KBRV property was assessed according to the disturbance category classification developed by Lenzen and Murray (2001; refer to Section 2.3.4). Firstly, areas of the 65.5 ha KBRV property were classified into the 6 categories for actual land disturbance (see Table 2.4 for actual land disturbance categories). Cleared land in this study refers to a reduction in overstorey cover to less than five per cent, while thinned land refers to an intermediate class of tree cover, between cleared and uncleared. These were chosen for comparability with the study conducted by Graetz et al. (1995) on the assessment of land cover disturbance Australia-wide. It must be noted that KBRV has a number of bush-walking tracks located on the property, however only those tracks with a width greater than or equal to two metres were included, classified as cleared areas[1]. A measurement of these classified areas was then calculated from the scale 1:2000 master site plan developed by Kimber and Associates (1998), and weighted according to the relevant disturbance category land condition-weighting factor. Results are presented in Section 4.1.

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[1] Most bushwalking tracks located on the resort had an average diameter of approximately 1.5 metres.

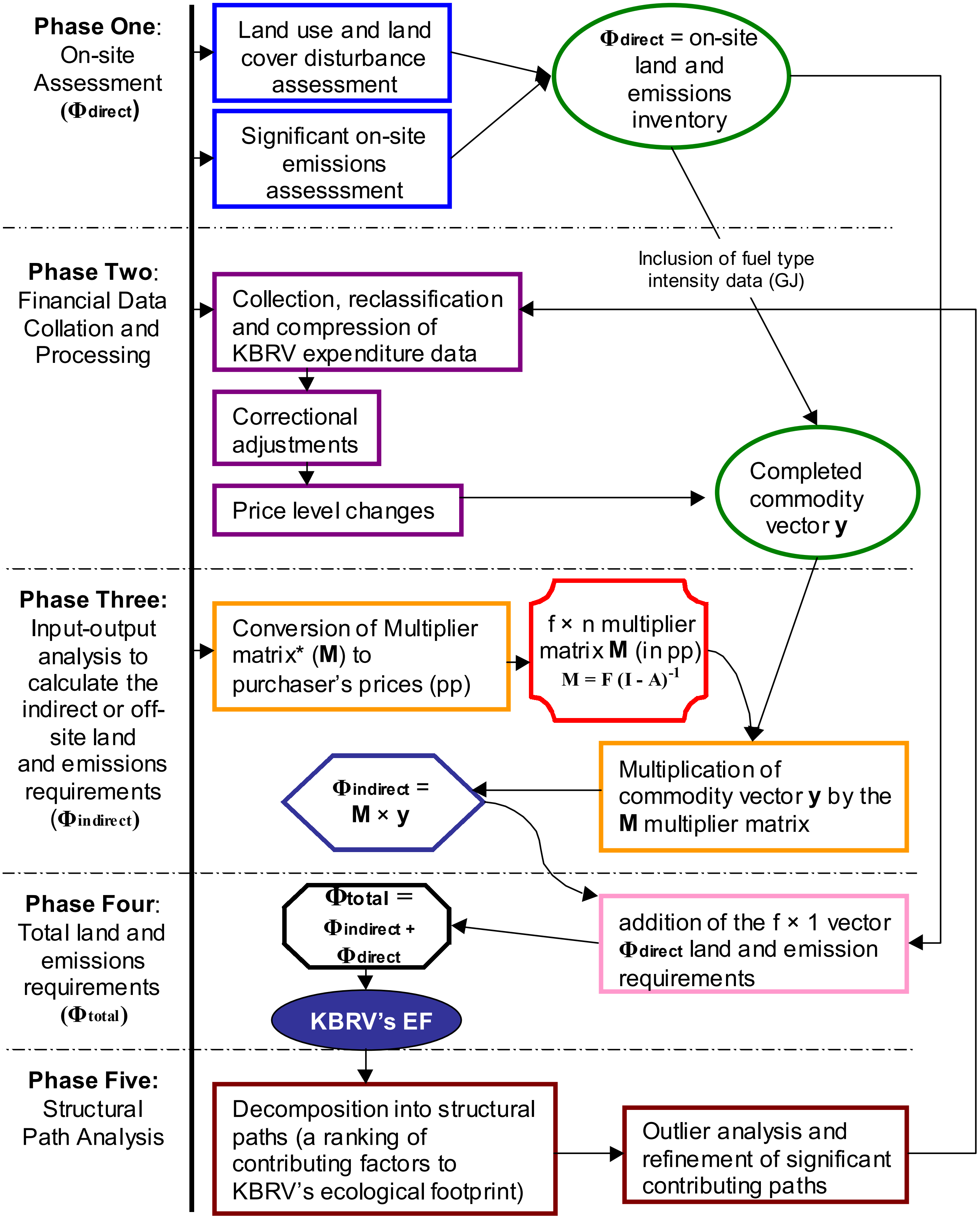


**Figure 3.1 Methodological phases involved in the calculation of an ecological footprint for KBRV.**

* Note: The Multiplier matrix used in this analysis was developed by Lenzen and Murray (2001).

### 3.5.2 Significant on-site emissions assessment

On-site emission sources identified in the audit of resort operations included:

- vehicle use (including buses and cars),
- barge and ferry use,
- liquid petroleum gas (LPG) usage (predominantly used for heating and cooking),
- the on-site waste-water treatment plant (WWTP).

A notable omission from the identified sources was the emissions associated with power generation. KBRV utilises underground power from the mainland, thus these emissions are classified as off-site and not included in the on-site emissions assessment. The back-up power generator was identified as a potential emission source, however discussions with the KBRV Maintenance Manager determined that emissions generated from this source were negligible during the 2002 period (Thers, pers. comm., 2003).

The on-site WWTP was identified as a potential source of significant emissions. However, because the WWTP features aerobic processes for the treatment of waste, carbon dioxide emissions feature as the principal by-product. The Intergovernmental Panel for Climate Change (IPCC) and Australian Greenhouse Office (AGO) guidelines specify that emissions of carbon dioxide generated from biomass sources should not be counted in greenhouse gas inventories (NGGIC, 1998a). This is due to the assumption that, over time, regrowth of biomass (for example, crops and forests) equals consumption. As a result, emissions of carbon dioxide from KBRV's on-site WWTP were not included in this analysis.

The emissions generated from fuel-usage sources were calculated by determining an energy intensity factor (GJ/$) for each fuel type. Therefore, by multiplying with KBRV fuel expenditure data, the contribution of energy (GJ) can be calculated for each dollar spent. Greenhouse gas emissions may then be calculated from the total energy consumption values for each fuel type via an emission factor. Emission factors are used to indicate the quantity of greenhouse gases emitted due to the combustion of a unit of fuel and are measured in energy terms (NGGIC, 1998b).

In establishing the intensity factors for each fuel type (LPG, unleaded petrol and diesel), averaged price values for each fuel type during the 2002 period were determined (in cents per litre) via communications with the KBRV maintenance manager. These price values were then:

- adjusted for inflation that had occurred since 1994 (refer to Section 3.6.3), and
- divided by energy content conversion factors (gross energy content values, or in other words, the total amount of heat released during combustion; Bush et al., 1999)

Refer to Appendix 4 and Section 4.1 for calculations and results, respectively, of the LPG, unleaded petrol and diesel fuel intensities. These intensities (i) were then incorporated into commodity vector y by multiplying by the relevant (price adjusted) KBRV expenditure data (k), to obtain the total energy intensity (GJ) for each fuel type (Total GJ = i × k), as represented in Phases one and two of Figure 3.1. The amount of greenhouse emissions for each fuel type (in tonnes) was calculated in a latter phase of the analysis (refer to Phase three, Figure 3.1).

## 3.6 Phase Two: Financial data collation and processing

The outcome of Phase two (Figure 3.1) was the formation of a commodity vector y, which was utilised in latter stages of the analysis. This involved:
(a) the collection, reclassification and compression of KBRV financial data,
(b) amendments, and
(c) price level changes.
These are described in turn.

### 3.6.1 The collection, reclassification and compression of KBRV financial data

Phase two of this study required the examination of the KBRV Resort Operations Pty Ltd Executive Report for 2002. Each expenditure item during the twelve-month period ending January 2, 2003 was examined, reclassified and compressed into a commodity vector y, according to the Australian input-output product classification (refer to Figure 3.2). The Australian input-output product classification (IOPC) is an ‘industry-of-origin’ product classification that has been specifically developed for the compilation and application of Australian input-output tables (ABS, 1999). Each product item in the classification is shown according to the industry in which it is primarily produced. Therefore, the structure of the IOPC consists of industry-of-origin headings with detailed product items shown under each heading (refer to Appendix 5 for a list of the IOPC industries used in this study).

The reclassification and compression of the KBRV's financial data consequently involves matching and reclassifying each item into the industries specified by the IOPC. This process proved to be a difficult task, involving discussions with the KBRV financial controller and other area managers in order to achieve an adequate understanding of what many of the expenditure items specifically included.

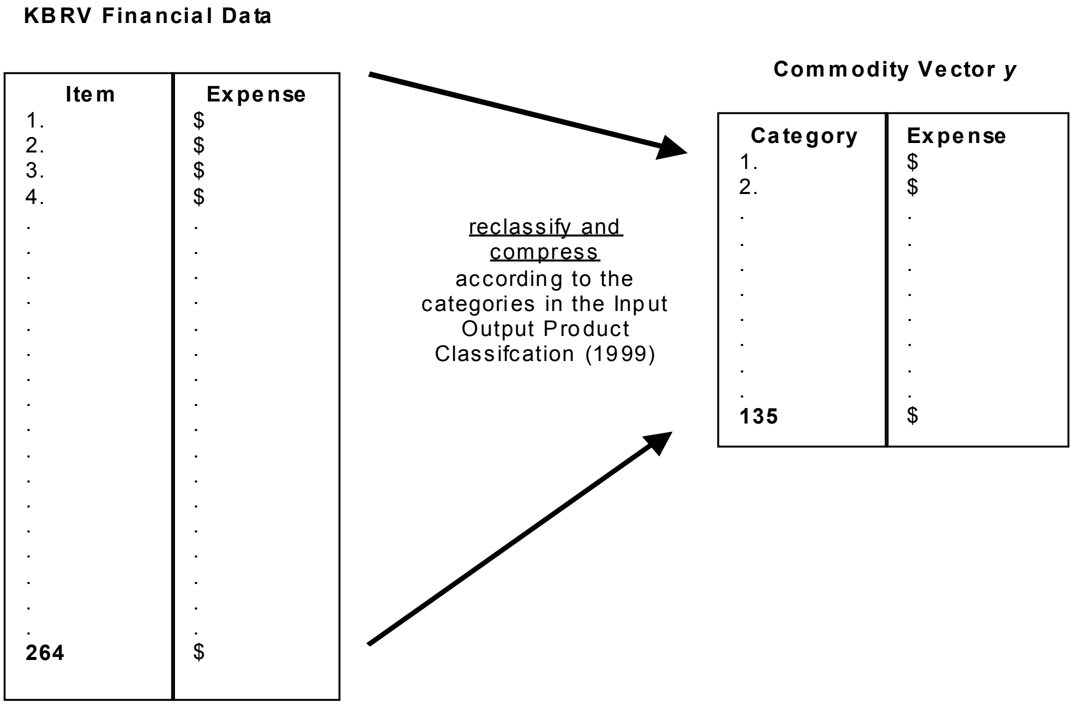


Figure 3.2 The reclassification and compression of KBRV financial data

Salary expenses were excluded from commodity vector y, as salary expenditure is commonly assumed to be exogenous to the production system, thereby benefiting the household and not the producers (Herendeen, 1998). If salary expenditure were to be included, the double-counting of some costs would occur. For instance, for a factory manufacturing computers, the energy cost of payroll includes the energy costs of employees' computers (Lough, 1996). Merchandise sold at the souvenir shop was also excluded for the following reasons. First, the ecological footprint in this analysis was used to reflect resort operations (in their control) and it could be argued that sold merchandise is extrinsic to this. Second, much of the merchandise is imported, and imported goods have been excluded from this analysis (refer to Section 3.7.4b). Third, some aspects of the shop were included in the present analysis by default – namely food, beverage and non-consumable grocery items and the electricity required for operations.

### 3.6.2 Amendments to the KBRV financial data

A breakdown of inputs to a company's operational cost that is as detailed as possible has been identified as important for minimising the relative standard error of the land disturbance footprint (Lenzen et al., 2003b). Therefore, upon completion of the reclassification of the KBRV financial data, further itemisation of some categories was required. These categories included: food, beverage, operational supplies, guest supplies, replacements, KBRV vehicle fuel and oil and repair and maintenance.

A Supplier Purchase Report for the 12 months ending January 2, 2003 was obtained which provided a detailed inventory and the corresponding expense for items purchased which provided for the beverage, operational and guest supplies categories. Thus this information was used to further itemise and reclassify the aforementioned expense categories, corresponding to the Australian IOPC. For the further breakdown of the total 'food' or 'replacement' expenditure for 2002, discussions were held with the KBRV purchasing management team (for 'food') and the KBRV financial controller (for 'replacements').

The fuel and oil expenditures for KBRV vehicle use (for example ferries, buses and cars) were aggregated into one category – vehicle fuel and oil. In order to breakdown this category into more detailed inputs, information from the KBRV Maintenance Manager was utilised regarding (a) the types of fuel used by each vehicle (ie, ferry, bus, car, tractor etc), and (b) the ratio of fuel to oil for each vehicle and fuel type. This level of detail was sufficient for use within the relevant IOPC industries.

No adequate breakdown of inputs was available for the materials used in the repair and maintenance of KBRV buildings and other constructions. As a result, these expenses were allocated to the IOPC industry 4102, entailing the repair and maintenance of building and construction, including labour costs. However, the KBRV repair and maintenance expenditure includes repair and maintenance materials only, excluding labour costs. As a result, adjustments were made to counter the labour expense included in IOPC industry 4102. It was determined that labour costs accounted for approximately half of the total expenditure for IOPC industry 4102 (ABS, 1999), therefore materials used within this category also accounted for half the expenditure. As such, the KBRV expenditure on materials for repair and maintenance was doubled to counter the labour component of the IOPC industry 4102.

On completion of amendments to the KBRV financial data, the number of entries into commodity vector y (that is, the number of entries in the IOPC classifications) totalled 73. The number of entries is particularly important, as it has been shown that the higher the number of entries, the lower the total error associated with ecological footprint calculations (Lenzen, 2001). A similar study of the Sydney Water Corporation contained 42 entries in the IOPC, which was deemed adequate to guarantee sufficiently small errors in the indirect land and emission requirements (Lenzen et al., 2003). Therefore it is reasonable to assume that an adequate breakdown of the financial data in this study was achieved.

In terms of upstream production layers, this also means that 73 paths represent the immediate suppliers to KBRV (1st order, or PL1). Because 135 industries were included in the input-output analysis of this study, the 2nd order (PL2) potentially contains 73 × 135 paths, totalling 9855 paths. Thus the 3rd order (PL3) potentially contains 73 × 135 × 135 paths, or 1330425 paths, and so on through the production chain (refer to Sections 2.3.2 and 2.3.1c for more information).

### 3.6.3 KBRV financial data price level changes

This study used land and emission requirement multipliers, which were developed from the 1994-95 input-output tables – the most current available at the commencement of this analysis (refer to Appendix 6). As the study period for this analysis was the calendar year 2002, expenditure needed to be adjusted for the price inflation that had occurred since 1994-95. This is a standard procedure in input-output analysis, as input-output tables are often published four years after the study period. For example, the 1994-95 input-output tables produced by the Australian Bureau of Statistics were published in March, 1999.

Adjusted prices (to be used within the land and emission requirement multiplier matrix) were determined by multiplying commodity vector y (the reclassified and compressed KBRV financial data) by:

(1) the product of the 1994 price index (PI) and the 135 IOPC industries (i), and
(2) dividing the result by the product of the 2001 price index (PI) by the 135 IOPC industries (i).

Therefore, the adjusted prices = y × (PI [1994] × i) / (PI [2001] × i). The failure to adjust for inflated price level changes would have resulted in an over-estimation of the ecological footprint.

## 3.7 Phase Three: Input-output analysis

Input-output analysis was conducted in the third phase of this study (refer to Figure 3.1). The aim was to calculate the higher-order requirements, or more specifically the indirect land used and emissions generated in upstream production layers for materials extraction, manufacturing and services. An example of a higher-order requirement is the fugitive methane emissions released from the mining of black coal, which is used for the generation of electricity that is supplied to KBRV. The higher-order requirements of KBRV were calculated via a Multiplier matrix (M), which contained off-site or indirect land and emission requirements. The higher order requirements of KBRV were used in a latter phase of this analysis to calculate KBRV's offsite ecological footprint. Lenzen and Murray (2001) developed the Multiplier matrix in a number of steps, which are briefly summarised in the forthcoming section. A more comprehensive explanation can be found in Appendix 6. The detailed mathematical formulation of the input-output analysis model used in this study is described in Lenzen's (2001a) paper entitled 'A generalised input-output multiplier calculus for Australia'. Due to the constraints of an intellectual property agreement between USC and the University of Sydney, the production and land requirements and subsequent land disturbance multipliers used within this study cannot be shown.

### 3.7.1 Formation of the Multiplier matrix

The first step in constructing the Multiplier matrix, developed by Lenzen and Murray (2001), was to use the Australian input-output tables (ABS, 1999), to determine the Direct Requirements matrix (A). This matrix describes the intermediate demand of each industry for other industry commodities per unit of industry output. This was achieved through the division of all industry entries in any industry's column of the input-output tables (representing inter-industry transactions) by the total value of sales (output) for that industry.

An F matrix (Figure 3.3) was then developed from the Direct Requirements matrix. It represented an $f \times n$ matrix of intensity factors, where row $i$ =, 1, .... $f$, represented the land (that is, the land use and land cover disturbance) and emission requirements (tonnes of greenhouse gas emissions) and column $j$ = 1, ...., $n$, represented the unit of output for each IOPC industry, which was derived from the Direct Requirements matrix. It is therefore assumed that the beef cattle industry, for example, has a fixed relationship between the amount of carbon dioxide produced and the dollar output of the beef cattle industry.

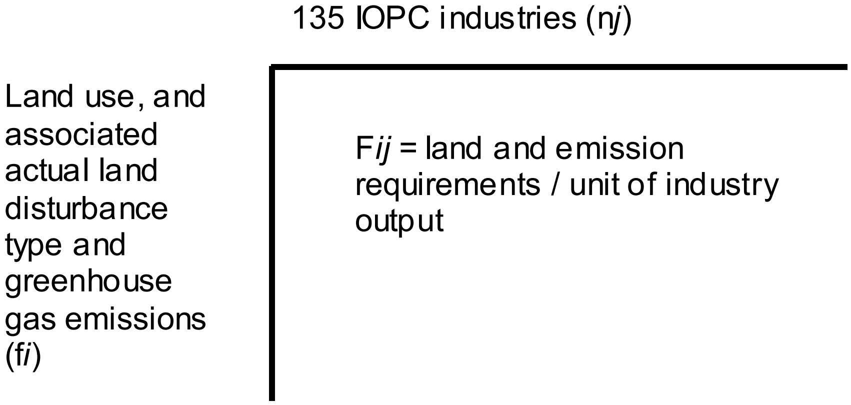
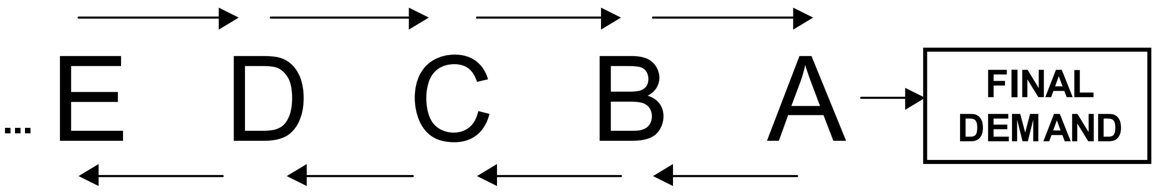


**Figure 3.3 A representation of the F matrix used in the input-output analysis phase**

An element of the F matrix, $F_{ij}$, can therefore be seen as a direct multiplier for the amount of production factors *i* (land and emissions) required by industry *j*. In other words, only direct production factor requirements, and not indirect requirements, are included. For example, consider an increase in the final demand for products of industry A. This will result in direct increases in purchases from industries B, C, D and so on. However, in addition, when industry B sells more of its output to industry A, industry B's demand for the products of industries C, D (etc.) will likewise increase, with these effects spreading throughout the production chain (refer to Figure 3.4). This 'backward purchasing' is known as the indirect requirements (Bullard et al., 1978).

***Forward purchasing – the direct requirements***



***Backward purchasing – the indirect requirements***

**Figure 3.4 A representation of the direct and indirect requirements of inter-industrial transactions**

This representation clearly demonstrates how all industries are linked, both directly and indirectly, with each other. Therefore, to assess the total production factor requirements of the production chain comprehensively, indirect relationships must be included. This is achieved via the multiplier matrix (M), which incorporates final demand via the Total Requirements matrix, or the Leontief Inverse.

The Leontief Inverse was calculated via the matrix inversion of the Direct Requirements matrix (A), which included the F matrix assembled in rows beneath the Direct Requirements matrix, and the incorporation of final demand from IOPC industries, where $M = F(I - A)^{-1}$. I represents the identity matrix used during matrix inversion – a procedure performed in all input-output analysis studies. Please refer to Appendix 6 for more detail on the calculation of the Leontief Inverse.

In contrast to the F matrix (which includes the Direct Requirements matrix), the Multiplier matrix (including the Leontief Inverse) contained total multipliers, that is the amount of production factors *i* (land and emissions) directly and indirectly required in all industries to produce a unit of final demand from industry *j*.

As previously mentioned, the Multiplier matrix was used within this analysis to calculate the off-site production factor requirements (that is, land and emissions) embodied in all purchased inputs to KBRV's operation (refer to Figure 3.1, Phase three).

### 3.7.2 Conversion of multipliers to purchaser's prices

The Multiplier matrix developed from the 1994-95 input-output tables are in basic values (bv), that is, 'farm' or 'factory gate' prices. Transactions recorded in the tables are valued at the prices received by the producer, rather than those paid by the buyers. As a result, the commodity flows are recorded at the value at which they leave the producers, before commodity taxes and other margins are added. This is on account of basic values being more reliable and constant, as commodity taxes and other margins may vary over time (Bullard et al., 1978).

Conversely, the KBRV financial data are recorded at purchasers' prices (pp). As a result, the multipliers (M) formulated from the input-output tables were converted to purchasers' prices ($M_{bv} \rightarrow M_{pp}$). Therefore, the intermediate (that is, indirect or off-site) land and emissions inventory = $y_{pp} \times M_{pp}$ ($^{\text{production factors}}/_{\$pp}$).

### 3.7.3 Multiplication of commodity vector y by the Multiplier matrix

In order to calculate the off-site land and emission requirements ($\Phi_{indirect}$), KBRV's annual operation cost (represented by the n × 1 commodity vector y; refer to Section 3.7 and Figure 3.1, Phase two) was multiplied with the Multiplier matrix. Therefore,
$\Phi_{indirect} = M \times y$, where $M \times y$ represents the land and emission requirements embodied in all inputs into KBRV's operation (Figure 3.1, Phase three).

### 3.7.4 Exclusions from the Multiplier matrix

Within this study, only domestic current demand was examined. Therefore, on-site and upstream expenditure on imported (i.e imported current demand) and capital (i.e domestic capital demand and capital imports) commodities was excluded. The justifications for these exclusions are described below.

#### (a) Capital expenditure exclusion

The ABS does not compile capital flow tables, as it is economic convention that purchases of capital goods are counted as net outputs of the economic system, rather than inputs to production processes (Bullard et al., 1978). In the context of this study, it means that the multipliers within the multiplier matrix (M) do not include, for instance, the land and emission requirements to build machinery used by each industry in each sector. To include a capital assessment, capital flow tables need to be constructed from industry totals of gross fixed capital expenditure from disparate sources. However, significant errors exist when creating a capital flow table constructed purely from expenditure totals (Lenzen, 2001a). The lower limit of standard error for capital flow estimates based on Australian data has been calculated at approximately 50% (Lenzen, 2001a).

Also, additional problems arise when including capital investments in the context of ecological footprint studies. For example, if KBRV purchases a piece of machinery that has a lifespan of 30 years, the result will be a ‘spike’ or anomaly in KBRV operational expenditure, creating an unrealistically high ecological footprint for that year.

Therefore, capital investment expenditure, both on-site and off-site (i.e upstream production layers) were excluded from calculating KBRV’s overall ecological footprint. This has also been the procedure followed in other ecological footprint studies of the same method (see Lenzen and Murray, 2001; Lenzen et al., 2003a; Wood and Lenzen, 2003). However, for comparative purposes, capital commodities were included via the use of industry total capital flow tables, in a separate analysis of KBRV’s ecological footprint; the results of which are presented in Section 4.7.

### (b) Exclusion of imported commodities

Commodities produced by foreign industries can possess very different land and emission requirements from those commodities produced in Australia (Lenzen, 2001). For instance, consider the production of beef cattle. Within Australia, and in particular Queensland, the land requirements for sustaining cattle are highly intensive. However, in other countries, the climate may support a higher carrying capacity for cattle grazing, thereby making beef production less land intensive.

If imports were to be included within this study, foreign industries would receive identical land and emission requirements as to those industries in Australia, and significant errors would exist with the assumption of homogeneity of land and emission requirements between foreign and domestic production. Consequently, it has been the standard procedure of other ecological footprint studies with similar methods to exclude imports (see Lenzen et al., 2003b; Wood and Lenzen, 2003). Therefore, for comparative purposes, imported commodities have been excluded in calculating KBRV's overall ecological footprint. However, it must be noted that the net effect of this exclusion is that KBRV's ecological footprint is underestimated, even if overseas production requirements are lesser than Australian production requirements. As a result, imported commodities were included in a separate analysis of KBRV's ecological footprint and will be presented, for comparative value, in Section 4.7.

## 3.8 Phase Four: Total land and emission requirements

To obtain the total land and emission requirements of KBRV, the direct or on-site requirements, a $f \times 1$ vector $\Phi_{\text{direct}}$, are simply added to the $\Phi_{\text{indirect}}$ land and emissions requirements.

Therefore, $\Phi_{\text{TOTAL}} = \Phi_{\text{indirect}} + \Phi_{\text{direct}}$

KBRV's total ecological footprint was then calculated from the $\Phi_{\text{TOTAL}}$ by using the requirements to satisfy the eight land disturbance types (six actual and two projected (energy and emissions) land disturbance types). The result was KBRV's total ecological footprint expressed in hectares of weighted land disturbance (refer to Section 2.3.4c).

## 3.9 Phase Five: Structural path analysis

As previously mentioned (Section 2.3.3), structural path analysis involves running an extraction algorithm that decomposes the Leontief inverse formula. This allows for KBRV's total ecological footprint to be decomposed and ranked into detailed contributing paths (Figure 3.1, Phase five).

### 3.9.1 Conversion of commodity vector y to basic values

In order for structural path analysis to be performed, the KBRV commodity vector y (in purchaser's prices: $y_{pp}$) was converted to basic prices ($y_{bp}$). This is because structural path analysis decomposes the Leontief inverse, which as previously mentioned was compiled from the Direct Requirements Matrix (A) that contains basic value units. Structural path analysis uses basic value coefficients within the A matrix because it allows for distinction within the purchaser's price margins, taxes and the production of the commodity.

For example, consider that KBRV purchases of $100.00 of beef. Hypothetically, the actual production cost of the meat and wholesale margin may only total $65.00. The remaining expense is attributable to taxes and other margins, such as retail, freight and insurance. Therefore, in the conversion of KBRV's commodity vector y to basic prices, taxes were subtracted (as they do not contribute to KBRV's ecological footprint) and other margin expenses (such as retail, freight and insurance) were re-allocated to the relevant industries.

### 3.9.2 Application of the decomposition algorithm

The total production factor multipliers resulting from the multiplier matrix, $M = F(I-A)^{-1}$, can be decomposed into contributions from 'structural paths' via unravelling the Leontief Inverse using its series expansion (Lenzen et al., 2003b):

$$F(I-A)^{-1} = F + FA + FA^2 + FA^3 + \ldots FA^{n-1} \tag{1}$$

Equation 1 can be further expanded to include the off-site land and emission requirements $M_i \times y_i$ caused by KBRV expenditure:

$$M_i y_i = y_i \sum_{j=1}^{n} F_j \left(\delta_{ji} + A_{ji} + (\mathbf{A}^2)_{ji} + (\mathbf{A}^3)_{ji} + \mathbf{\ldots}\right) \tag{2}$$

This equation can be further decomposed so that $Mi\ yi$ is the sum of a direct factor input $F_i\, y_i$, occurring in industry i itself, and subsequent higher-order input paths (see Lenzen et al., 2003b).

This decomposition resulted in a ranked list of detailed contributing structural paths for KBRV (refer to Section 4.6).

### 3.9.3 Sensitivity analysis: refinement of key contributing paths

Upon completion of structural path analysis, key contributing paths to the total KBRV ecological footprint were examined as part of a sensitivity analysis, to correct for potential input-output analysis allocation errors. As previously mentioned (Section 2.3.2), an allocation uncertainty exists within input-output analysis, as the intermediate usage data between IOPC industries are Australian averages. As a result, some atypical inputs to the KBRV commodity vector y were identified and corrected in order to reduce the allocation uncertainty error. These paths include KBRV expenditure on the commodities associated with the meat products and retail trade industries.

#### (a) Meat products expenditure refinement

The allocation of KBRV meat product expenditure (within commodity vector y) to the IOPC industry 2101, meat and meat products, was identified to be an allocation error, because the composition of meat types purchased by KBRV are atypical to the Australian averaged meat products sector. The meat and meat products industry contains a larger proportion of beef cattle product than that of KBRV. Beef cattle production has a large direct land disturbance impact due to the amount of land required to produce the cattle, and the degrading land practices adopted by some Australian beef cattle farmers. Hence, in allocating expenditure directly to the meat and meat products industry, an over-estimation was made in the total ecological footprint.

Therefore, instead of allocating KBRV expenditure on all meat products to the meat and meat products industry, this total expenditure was broken down according to the types of meat purchased (for example beef, sheep, pig, poultry) and then allocated to the relevant agricultural production industry. However, as the agricultural production industries for each meat type include intermediate costs as well as the cost of production (for example labour, road transportation, electricity etc), adjustments were made. It was determined that the agricultural production industries for beef, sheep, pigs, poultry and other agriculture attribute 80% of their expenditure to production costs only. Therefore, the KBRV meat expenditure was multiplied by a factor of 0.8 to negate the intermediate costs involved in the agricultural production industries, thus isolating the production cost only.

A problem arising from the re-allocation from the meat and meat products industry to the relevant primary agricultural production industries was that the intermediate costs associated with the meat and meat products industry, that would normally be included, were not considered. It was determined that the meat and meat products industry attributes 20% of their expenditure to intermediate costs. In particular, approximately 10% of the expenditure from the meat and meat products industry is attributable to road freight related costs. To include the road freight expenditure, 10% of KBRV total meat expenditure was multiplied by the fraction of road freight expenditure for the meat and meat products industry (10%). The result was added to the road freight industry within KBRV commodity vector y (Section 3.6.1) in order for the road freight costs of the meat and meat products industry to be included in the total ecological footprint. It must be noted that the remaining intermediate cost expenditure, representing 10% of the total meat and meat products expenditure, was not included due to the number of different types of costs (and subsequent industries) involved. Despite this outcome being an underestimate, it is still more accurate than the outcome that would have been achieved all KBRV meat expenditure were allocated to the meat and meat products industry.

### (b) Refinement of inputs from the retail trade industry

KBRV purchases commodities from the retail trade industry – namely food. The retail trade industry, in turn, uses commodities from different industries to operate, as does every other industry. Within the IOPC retail trade industry (5101), "takeaway food selling is treated as non margin output of retail trade" (ABS, 1999, p12). This means that the retail trade sector uses food commodities (from take-away based industries 2101 to 2111) which are classed as part of the operations (as opposed to the output).

Therefore, when examining the land disturbance resulting from the collective retail trade industry, the beef and sheep cattle component of meat and meat products used by the retail trade sector potentially hold significant impact to the overall land disturbance ecological footprint. This was evident when an initial structural path analysis was conducted. The retail trade ranked fourth in terms of land disturbance contributions to the footprint (retail trade, 0.814 ha). As KBRV does not purchase takeaway food from retail outlets for the operations of the resort, the take away selling contributions (industries 2101-2111) were set to zero within the Direct Requirements matrix to exclude the paths of takeaway selling within the retail trade sector when calculating the KBRV ecological footprint.

## 3.10 The calculation of KBRV's ecological footprint according to alternative methods

For comparative purposes, KBRV's ecological footprint was calculated according to three other methods:

(1) The method outlined in Wackernagel and Rees (1996)
(2) The method used by Simpson et al. (2000) for the calculation of the Australian ecological footprint
(3) The method used by Bicknell et al. (1998) for the calculation of the New Zealand ecological footprint.

The calculation of KBRV's ecological footprint according to the above-mentioned methods involved using the method used in the present analysis with modifications specific to each method. For example, Wackernagel and Rees (1996) and Simpson et al. (2000) both utilised process analysis-based techniques as the method of 'trace-back' through upstream production layers (see Sections 2.3.1, 2.3.1a and 2.3.1c). Unfortunately, the number of production layers included were not specified (Lenzen et al., 2003). It was therefore assumed that the system boundary of these approaches was up to and including the 2nd order of production. This boundary limit has been adopted in previous studies of ecological footprint method comparisons (see Lenzen and Murray, 2001; Lenzen et al., 2003b). This involved a calculation of ecological footprint impact up to and including the 2nd order only – in other words, the remaining production layers (determined in the present analysis method) were excluded from the results of these methods.

However, it is probable that the Wackernagel and Rees (1996) and Simpson et al. (2000) methods would not include all paths in the 1st and 2nd orders of production for the analysis of KBRV. This is because it would require achieving the complete coverage of the 9855 contributing paths potentially present up to and including the 2nd order of production (identified in the present analysis; refer to Section 3.6.2). Therefore, the KBRV ecological footprint results produced according to the Wackernagel and Rees (1996) and Simpson et al. (2000) methods may be overestimates in comparison to what the methods, in reality, would actually achieve. It must be noted that for the method utilised by Simpson et al. (2000), the total upstream production requirements were calculated for carbon dioxide emissions (only), as a form of input-output analysis was utilised for the calculation of carbon dioxide intensities.

Conversely, Bicknell et al. (1998) utilised input-output analysis for the method of ‘trace-back’ in their ecological footprint analysis of New Zealand. As a result, upstream production requirements were included for the calculation of the KBRV ecological footprint according to the Bicknell et al. (1998) method.

The methodological differences between the units of expression are described in Section 2.3.4, but are briefly repeated here for clarity. The units of expression differed from the land disturbance approach used in the present analysis. Wackernagel and Rees (1996) and Simpson et al. (2000) express the ecological footprint through land appropriation by world-average productivity or global hectares, while Bicknell et al. (1998) express the ecological footprint through land appropriation by actual land use hectares. Note that Simpson et al. (2000) also utilised an actual land use appropriation method in their analysis of the Australian ecological footprint. The land appropriation through actual land use was calculated from the land use requirements included in the Multiplier matrix used in the present analysis. The land appropriation by world productivity was calculated through the land use requirements (in the Multiplier matrix) which were adjusted for world average productivities via yield factors.

## 3.11 In summary..

This chapter highlighted the methodological procedures and associated decisions that had to be made in order for an ecological footprint to be calculated for KBRV. The following chapter presents the results of this analysis.

# CHAPTER 4: RESULTS

The final result of an ecological footprint assessment is just one number – in this case the ecological footprint (in hectares of land disturbance) of KBRV. However, as previously mentioned (Section 2.3.3) ecological footprint results are more useful for decision-makers when dis-aggregated into more meaningful components. First, the results of the on-site assessment are presented in Table 4.1. The subsequent results of the KBRV ecological footprint calculations will be presented in order of increasing detail. Aggregate results are presented first, followed by a breakdown into land types and greenhouse gas emissions, with a further breakdown into commodities supplied to KBRV and finally, a decomposition into structural paths. A summary of KBRV's ecological footprint according to various approaches will then be presented, in addition to a sensitivity analysis of KBRV's ecological footprint under various inclusion criteria.

## 4.1 On-site assessment results

Table 4.1 displays the categories of actual land disturbance used in the on-site land cover assessment of KBRV, and the corresponding actual (un-weighted) areas of land. The 'degraded' and 'partially disturbed' categories were not applicable in this case, and the slightly disturbed category with a land condition-weighting factor of 0.0 was ignored as it represents no impact. Figure 4.1 presents examples of each category of actual land disturbance caused on-site at KBRV.

**Table 4.1 KBRV areas of un-weighted land cover disturbance**

| Actual land disturbance category | Land type example | Land area (ha) |
|---|---|---|
| **Consumed** | Buildings, roads | 8.2 |
| **Replaced** | Cleared areas of land, non-native vegetation | 0.18 |
| **Significantly Disturbed** | Thinned areas of vegetation | 15.4 |

**Figure 4.1 Examples of the types of actual land disturbance on-site at KBRV**

**Top**: Resort accommodation and boarded paths such as these were classified as consumed land, while most of the surrounding vegetation was classified as significantly disturbed (thinned) land.
**Left**: A portion of a cleared walking track area that was classified as replaced (cleared) land.
**Right**: The KBRV shop and access road was classified as consumed land.

For the on-site emissions assessment, intensities (GJ/$) were calculated for the use of liquid petroleum gas (LPG), unleaded petroleum and diesel on-site, totalling 0.107 GJ/$, 0.059 GJ/$, and 0.071 GJ/$ respectively. These were calculated (via the Multiplier matrix) to equal 537.23 tonnes (t) , 465.7 t, and 823.36 t of carbon dioxide respectively.

## 4.2 The ecological footprint

Figure 4.2 displays the aggregate ecological footprint results for KBRV. In 2002, the total ecological footprint for KBRV operations was 3329 ha. The on-site ecological footprint totalled approximately 140 ha, contributing 4% to KBRV's total ecological footprint. Whilst this is a small contribution, the on-site footprint was approximately 40% larger than the 75.5 ha of (non-weighted) actual land occupied by KBRV. Greenhouse gas emissions generated on-site by KBRV operations resulted in a projected land disturbance of 125 ha, accounting for approximately 90% of the on-site footprint. Therefore, despite the large on-site footprint, the actual land disturbance component only contributed 10%.

Off-site upstream production was responsible for 96% of KBRV's total ecological footprint, contributing 3189 ha, with over three-quarters attributable to actual land disturbance related impacts.

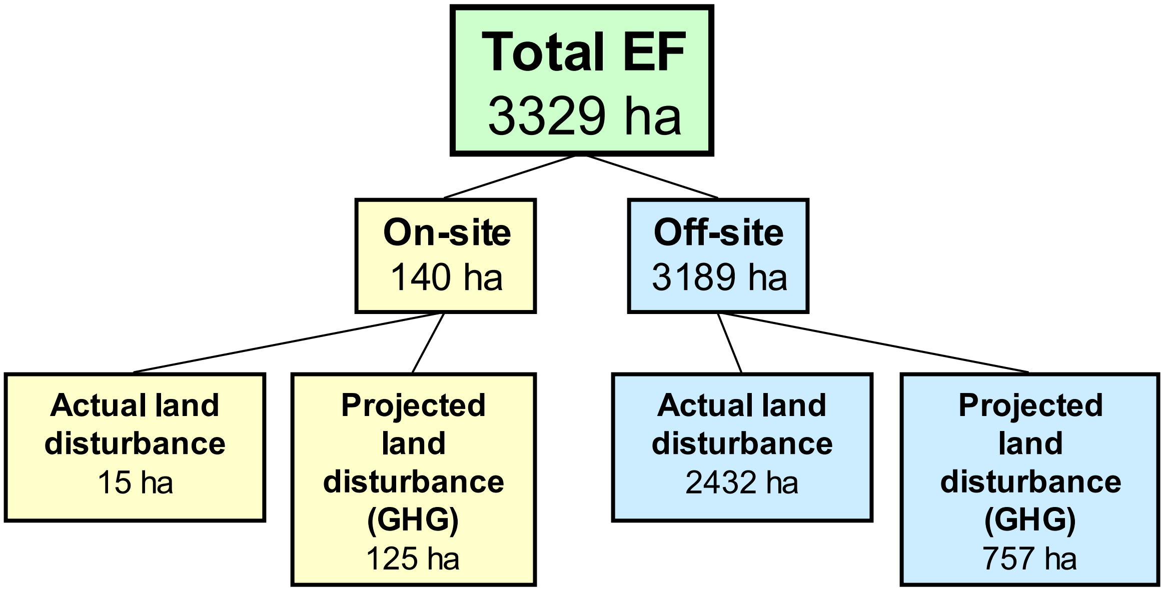


**Figure 4.2 Aggregate ecological footprint results for KBRV.**

Whilst there are numerous sources of estimation error in the calculation of the ecological footprint, it can be shown that the total error associated with input-output analysis is still relatively low (12%[1]). This error calculation is sensitive to the number of IOPC classification entries in the KBRV account breakdown used to construct commodity vector y (see sections 3.6.1, 3.6.2). The relatively low error of 12% reflects the large number of IOPC classification entries - in this case 73. Whilst this result assumes the use of accurate financial data and on-site impacts, it is a relatively safe assumption in the case of KBRV, as most of these component quantities were well known.

For communication purposes only, KBRV ecological footprint results have also been presented on a per capital basis (Table 4.2). During 2002, KBRV had an average of 229 full-time equivalent employees; thus the per-employee ecological footprint equalled 14.54 ha. In terms of tourist impacts, approximately 35 654 tourists stayed at KBRV at some point during 2002. Therefore, the per-tourist ecological footprint is approximately 0.1 ha.

**Table 4.2 KBRV's per capita ecological footprint**

| KBRV's footprint per tourist and employee | KBRV |
|---|---|
| Number of employees[2] | 229 |
| Ecological footprint per employee | 14.54 ha |
| Number of tourists[3] | 35 654 |
| Ecological footprint per tourist | 0.1 ha |

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[1] This is based on the common relationship for the propagation of stochastic errors $\Delta(EF) \approx 100\% / \sqrt{n}$ , where 100% represents a conservative value for the relative errors of the multipliers used to develop KBRV's ecological footprint (elements of the Multiplier matrix, see section 3.7.1) and n equals the number of IOPC classification entries in the KBRV account breakdown used to construct commodity vector y (Wood and Lenzen, 2003).

[2] Full time equivalent

[3] Averaged number of tourists that stayed at KBRV (total number of nights/average nights stay/average density)

## 4.3 The breakdown of the ecological footprint into land types and greenhouse gas emissions

The results presented in Figure 4.2 can be broken down further into the types of actual weighted land disturbance, and tonnes of greenhouse gas emissions (carbon dioxide equivalents), summarised in Table 4.3. The different sources of impacts are distinguished in the columns, including on-site and off-site impacts, and KBRV's total ecological footprint for each disturbance type.

**Table 4.3 Weighted land disturbance types associated with KBRV operations**

| Disturbance Type | On-site | Industrial (off-site) | Total |
|---|---|---|---|
| **ACTUAL LAND DISTURBANCE (ha)** | 14.5 | 2433 | 2447 |
| Consumed land (ha) (*C*[1]=1) | 8.2 | 24 | 32 |
| Degraded land (ha) (*C*=0.8) | 0 | 192 | 192 |
| Replaced land (ha) (*C*=0.6) | 0.12 | 931 | 931 |
| Significantly disturbed land (ha) (*C*=0.4) | 6.16 | 977 | 983 |
| Partially disturbed land (ha) (*C*=0.2) | 0 | 309 | 309 |
| **PROJECTED LAND DISTURBANCE (GHG) (ha)** | 125 | 757 | 882 |
| Greenhouse gas emissions (t) ($CO_2$-e) | 1827 | 11052 | 12879 |

[1] C represents the actual land disturbance category land condition-weighting factor.

In terms of on-site actual land disturbance, most impacts were the result of land occupied by resort infrastructure (C=1, 8.2 ha) including accommodation, restaurants, roads and other resort facilities, followed by the thinning of some areas of the natural vegetation surrounding resort infrastructure (C=0.4, 6.16 ha). As mentioned previously, on-site land impacts were insignificant in comparison to the land disturbance associated with off-site, upstream industrial production (99.4% of total actual land disturbance footprint).

Within the off-site upstream production land impacts, the disturbance types that contributed most to KBRV's total ecological footprint (approximately 90%) were replaced land (C=0.6, 931 ha), significantly disturbed land (C=0.4, 977 ha) and partially disturbed land (C=0.2, 309 ha). This was attributable to higher order inputs from agricultural industries, which are associated with extensive land uses, thereby contributing more land-associated impacts than greenhouse gas emission-related impacts. This is expressed quantitatively in the results from the structural path analysis in Section 4.6.

As mentioned previously, the projected land disturbance resulting from greenhouse gas emissions was the main contributor to the on-site footprint. The main source of on-site greenhouse gas emissions was the carbon dioxide emissions associated with fuel combustion (1827 t $CO_2$-e). Off-site, the most significant greenhouse gas emissions resulting from higher-order production were electricity supply (3560 t $CO_2$-e) and beef cattle (1715 t $CO_2$-e). Once again, this is shown clearly in the path ranking of the structural path analysis results, presented in Section 4.6.

## 4.4 Ranking of supply industries to KBRV according to ecological footprint contribution

The upstream ecological footprint contribution is illustrated in the ranking of supply industries presented in Table 4.4 at the IOPC-classified industry level. This represents the standard output from the input-output analysis method, in contrast to the consumption-land-use matrix produced in process analysis-based methods (Appendix 2). The purchase of beef products from the beef cattle industry was by far the single most important commodity, contributing over one-third to KBRV's total ecological footprint. The purchase of lamb products from the sheep industry was the second largest input, contributing 21% to the KBRV's total ecological footprint. As a result, the top 2 IOPC industries combined contributed approximately 60% to KBRV's total ecological footprint.

Within the top 30 IOPC industries presented in Table 4.4, 16 supplied food and beverage related commodities to KBRV in 2002 – a combined contribution of over 70% to KBRV's total ecological footprint. Electricity supply, ranked third, was another significant input to the total ecological footprint, contributing 7% to KBRV's total ecological footprint.

**Table 4.4 Ranking of industries according to their KBRV ecological footprint contribution**

| Rank | IOPC industry group | Commodity supplied to KBRV | EF (ha) |
|---|---|---|---|
| 1 | Beef cattle | Beef meat products | 1319.13 |
| 2 | Sheep cattle | Lamb meat products | 688.80 |
| 3 | Electricity supply | Electricity | 251.16 |
| 4 | Other food products | Eg sugar, coffee, spices | 89.51 |
| 5 | Textile fibres, yarns, woven fabrics | Eg linen and towel replacements | 82.32 |
| 6 | Dairy products | Dairy products | 81.10 |
| 7 | Water transport | Charter expense for barges | 76.97 |
| 8 | Bakery products | Bakery products | 73.10 |
| 9 | Gas oil, fuel oil | Diesel | 61.37 |
| 10 | Poultry and eggs | Poultry products and eggs | 54.88 |
| 11 | Petroleum and coal products | LPG | 44.63 |
| 12 | Sanitary and garbage disposal services | On-site waste-water treatment and garbage | 38.33 |
| 13 | Automotive petrol | Unleaded petrol | 36.34 |
| 14 | Business management services | Marketing expenses | 29.57 |
| 15 | Flour mill products | Flour mill products | 29.32 |
| 16 | Fruit and vegetable products | Fruit and vegetable products | 25.37 |
| 17 | Pigs | Pork meat products | 24.95 |
| 18 | Accommodation, cafes and restaurants | Meals and Accommodation off-site | 24.63 |
| 19 | Commercial fishing | Seafood products | 20.68 |
| 20 | Beer and malt | Beer and malt beverages | 20.21 |
| 21 | Soft drinks, cordials and syrups | Soft drinks, cordials and syrups | 17.37 |
| 22 | Wine and spirits | Wine and spirit beverages | 15.35 |
| 23 | Other construction | Maintenance and repairs of resort facilities | 14.02 |
| 24 | Personal services | Laundry and linen services | 13.81 |
| 25 | Clothing | Staff uniforms | 11.60 |
| 26 | Oils and fats | Oils and fats | 10.76 |
| 27 | Communication services | Postal, telephone and Internet services | 10.42 |
| 28 | Confectionary | Confectionary | 10.41 |
| 29 | Ownership of dwellings | Ownership of dwellings expenses | 10.12 |
| 30 | Property services | Eg. rent, vehicle hire, office costs | 9.75 |

## 4.5 Decomposition into production layers

Figure 4.3 (a) represents the decomposition of KBRV's total ecological footprint into upstream production layers via the series expansion of the Leontief inverse (see Appendix 6, equation 2). Figure 4.3 (b) and (c) represent a further breakdown of the total ecological footprint into 'actual' and 'projected' land disturbance types, respectively. Within the production layers, order 0 represents on-site effects, order 1 immediate suppliers of KBRV, order 2 the suppliers of immediate suppliers, etc. A notable difference between Figure 4.3 (b) and (c) is the higher starting position at the 0th order for KBRV's projected land disturbance from greenhouse gas emissions. This is attributable to the on-site emissions associated with KBRV's on-site fuel use (see Section 4.3).

In all three graphs, most impact occurs in the first order of production. For instance, the first order represents 77% of KBRV's total ecological footprint, 77% of the actual land disturbance footprint and 76% of the projected land disturbance footprint. In other words, the first order of all three figures represents approximately 76-77% system completeness. However, this is misleading due to adjustments made to KBRV meat product expenditure in commodity vector y (see Section 3.9.3a). For instance, the normal scenario for meat products supplied to KBRV is as follows: the beef, sheep, pigs, poultry, commercial fishing and other agriculture primary industries are 2nd order production industries, which supply the 1st order meat and meat products industry, which is the immediate supplier to KBRV (order 0). However, due to the refinements that had to be made to the meat products (Section 3.9.3a), the 1st order meat and meat products industry has been excluded, so that the beef, sheep (etc) primary industries are seen to be the immediate (or 1st order) suppliers to KBRV. Given the impact of these particular industries to KBRV's total ecological footprint (see Table 4.4), it is reasonable to assume that the significant impact shown at the first order of each figure (76-77%) is unrealistically high. In other words, the 76-77% system completeness should most likely occur at the second order.

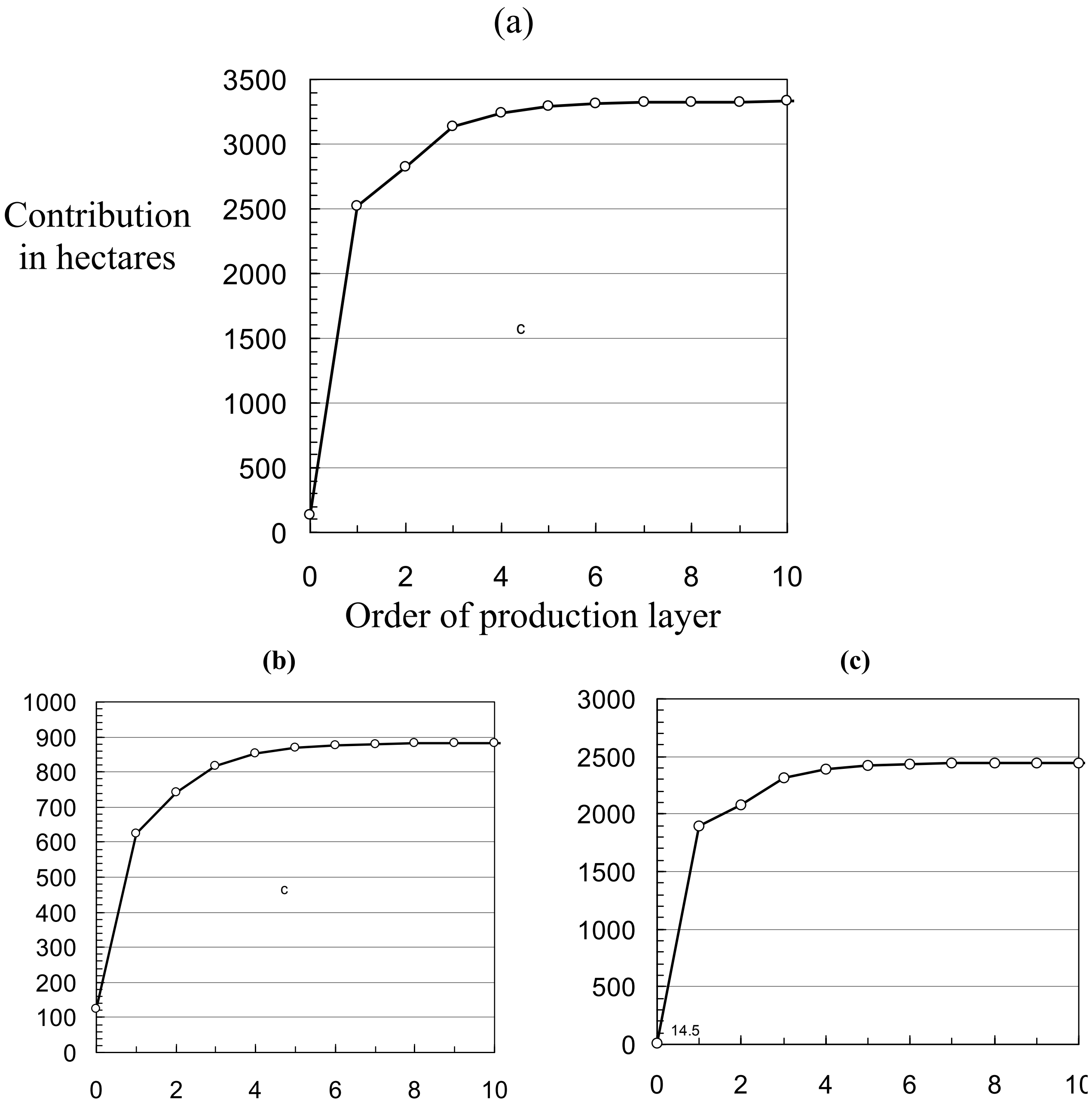

**Figure 4.3 Decomposition into production layers**

**(a)** KBRV's total ecological footprint
**(b)** Projected land disturbance by greenhouse gas emissions
**(c)** Actual land disturbance footprint

*N.B All graphs share identical X and Y-axes.*

## 4.6 Ranking of structural paths according to their ecological footprint contribution

As previously mentioned, the decomposition of the land and emission inputs into structural paths was obtained via an extraction algorithm (Section 3.9.2). The sorted paths according to their ecological footprint contribution are presented in Table 4.5. These ranking's are indicative only and are designed to be used for the identification and prioritization of targets for action. The largest path represents the 'significant disturbance' of land caused by the beef cattle industry contributing 529.6 ha, or 15.9% of KBRV's total ecological footprint[1]. The second largest path represents the beef cattle industry once again. However, in this case it represents the area of land 'replaced' due to beef production (434.6 ha). Given that third most significant path is associated with the sheep industry (289.5 ha of 'significant disturbance') it can be seen that the paths contributed by the beef and sheep industries combined, make up more than a third (37%) of KBRV's total ecological footprint.

Ranked fourth is the path of emissions generated from the electricity supplied to KBRV (213.2 ha, 6.4% of total). The five subsequent paths represent inputs for a range of land disturbance types from the beef and sheep industries, contributing a combined footprint of approximately 657 ha, or 19.8%. Vehicle barge transport to and from the resort (a contracted service thereby representing a 1st order input) ranked 10th and contributed 64.3 ha, or 1.9% to the footprint. Emissions from on-site fuel combustion, including vehicle and passenger ferry use, ranked 12th, 14th and 15th for diesel, LPG and unleaded petrol respectively, contributing a combined footprint of approximately 125 ha, or 3.8%. Emissions from the off-site landfill used by KBRV represented 28 ha (0.8% of the footprint). The remaining paths of the top 35 listed in Table 4.5 represent mostly meat and other food product inputs at the 2nd and 3rd order path level, and contributed less than 0.5% each to KBRV's total ecological footprint.

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[1] Whilst the path presents the beef cattle industry as a first order path, it is really a second order path based on the argument from the preceding section.

**Table 4.5 Results of structural path analysis for KBRV's ecological footprint**

| RANK | PATH* | AREA (ha) | % EF |
|---|---|---|---|
| 1 | Significantly disturbed > Beef cattle (1; 54%) | 529.6 | 15.9 |
| 2 | Replaced > Beef cattle (1; 47%) | 434.6 | 13.1 |
| 3 | Significantly disturbed > Sheep (1; 29%) | 289.5 | 8.7 |
| 4 | Emissions > Electricity supply (1; 24%) | 213.2 | 6.4 |
| 5 | Replaced > Sheep and shorn wool (1; 21%) | 196.3 | 5.9 |
| 6 | Partially disturbed > Beef cattle (1; 54%) | 167.9 | 5.0 |
| 7 | Emissions > Beef Cattle (1; 13%) | 112.7 | 3.4 |
| 8 | Partially disturbed > Sheep (1; 30%) | 91.8 | 2.8 |
| 9 | Degraded > Sheep and shorn wool (1;46%) | 88.5 | 2.7 |
| 10 | Emissions > Water transport (1; 7.3%) | 64.3 | 1.9 |
| 11 | Degraded > Beef cattle (1; 33%) | 63.5 | 1.9 |
| 12 | Emissions > Gas oil, fuel oil (0; 6.4%) | 56.4 | 1.7 |
| 13 | Replaced > Dairy cattle & milk > Dairy products (2; 4.1%) | 38.5 | 1.2 |
| 14 | Emissions > Other petroleum and coal products (0; 4.2%) | 36.8 | 1.1 |
| 15 | Emissions > Automotive petrol (0; 3.6%) | 31.9 | 1.0 |
| 16 | Emissions > Sanitary and garbage disposal (1; 3.2%) | 28 | 0.8 |
| 17 | Significantly disturbed > sheep > fibres, yarns, fabrics (2; 2.8%) | 28 | 0.8 |
| 18 | Emissions > Sheep (1; 2.2%) | 19 | 0.6 |
| 19 | Replaced > Sheep > fibres, yarns and fabrics (2; 2%) | 19 | 0.6 |
| 20 | Replaced > Wheat & other grains > Flour and cereal foods (2; 1.7%) | 16.3 | 0.5 |
| 21 | Significantly disturbed > Beef cattle > Meat products > Bakery products (3; 1.7%) | 16.2 | 0.5 |
| 22 | Significantly disturbed > Beef cattle > Meat products > Poultry and eggs (3; 1.5) | 14.7 | 0.4 |
| 23 | Significantly disturbed > Beef cattle > Meat products > Other food products (3; 1.4%) | 13.8 | 0.4 |
| 24 | Replaced > Beef cattle > Meat products > Bakery products (3; 1.4%) | 13.3 | 0.4 |
| 25 | Emissions > Dairy cattle and milk > Dairy products (2; 1.5%) | 13.1 | 0.4 |
| 26 | Replaced > Wheat & other grains > Other food products (2; 1.4%) | 12.8 | 0.4 |
| 27 | Replaced > Beef cattle > Meat products > Poultry and eggs (3; 1.3%) | 12.1 | 0.4 |
| 28 | Replaced > Beef cattle > Meat products > Other food products (3; 1.2%) | 11.3 | 0.3 |
| 29 | Replaced > Barley > Beer & malt (2; 1.2%) | 11 | 0.3 |
| 30 | Emissions > Other food products (1; 1.1%) | 9.8 | 0.3 |
| 31 | Partially disturbed > Sheep > Fibres, yarns and fabrics (2; 2.9%) | 8.9 | 0.3 |
| 32 | Degraded > Sheep > Fibres, yarns and fabrics (2; 4.4%) | 8.6 | 0.3 |
| 33 | Consumed > Accommodation, cafes and restaurants (0; 25%) | 8.2 | 0.2 |
| 34 | Emissions > Pigs (1; 0.78%) | 6.9 | 0.2 |
| 35 | Significantly Disturbed > Beef cattle > Meat products > Accommodation, cafes and restaurants (3; 0.67%) | 6.6 | 0.2 |

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[*] Components of the path include: (1) the type of land disturbance, (2) the industries, and in brackets, (3) the path order, where 0 = onsite, 1 = suppliers, 2 = suppliers of suppliers etc., and (4) the contribution of the path to the land disturbance type.

## 4.7 Sensitivity analysis: different models of inclusion criteria

As mentioned in Section 3.7.4, the ecological footprint calculation does not take into account imported or capital commodities. Similarly, it does not account for regional variations in production requirements. However, the sensitivity of the model to these factors is shown in Table 4.6, which displays variations to KBRV's total ecological footprint according to these three factors.

KBRV's total ecological footprint calculated with domestic production data only was 3329 ha. The inclusion of expenditure on imported commodities utilised through the production chain increased KBRV's total footprint by approximately 8% (3593 ha). However, as mentioned previously in Section 3.7.4, this assumes that the production requirements of imported commodities are consistent with those of equivalent domestic products. Similarly, if upstream production layer expenditure on capital commodities were included, the total footprint would increase by 13.5%, to 3779 ha. Combined, these two additions would amount to approximately a 28% increase of the total ecological footprint (Table 4.6).

**Table 4.6 KBRV's ecological footprint according to different inclusion criteria**

| Model type | KBRV's total ecological footprint (ha) |
|---|---|
| Class of commodities included | |
| (Australian) Domestic production only | 3329 |
| Domestic production including imported commodities | 3593 |
| Domestic production including capital commodities | 3779 |
| Domestic production including imported and capital commodities, and imported capital commodities | 4264 |
| Regional variation | |
| Australian domestic production (only) | 3329 |
| Australian domestic production with Victorian regional corrections | 1488 |

By comparison, the assumption about regional production requirement uniformity has a much greater potential impact. KBRV's total ecological footprint of 3329 ha was calculated with Australian average production factors, thus ignoring regional production requirement variations. However if, for example, KBRV's footprint was assessed with regional correction factors for the Victorian beef, sheep and dairy cattle industries, the total ecological footprint would decrease significantly by approximately 45%. This is further discussed in Section 5.1.2.

## 4.8 KBRV's ecological footprint according to various approaches

For comparative purposes, the results for KBRV were also calculated according to the methods of Wackernagel and Rees (1996), Simpson et al. (2000), and Bicknell et al. (1998) (Table 4.7). It must be noted, however, that direct comparisons cannot be made between all methods, due to significant methodological differences (see Section 3.10). The rows in Table 4.7 distinguish between study method, the ecological footprint contributions for on-site activities, 1st and 2nd order industrial requirements, total industrial requirements, and the total ecological footprint in terms of greenhouse gases and land use or disturbance.

KBRV's ecological footprint, when assessed using the original method by Wackernagel and Rees (1996), yields an area of 2659 ha. 18% of the footprint was attributable to on-site impacts (that is, the land occupied and carbon dioxide emissions generated on KBRV), and the remaining 82% was attributable offsite, upstream production in the form of appropriated bioproductive land and carbon dioxide emissions. Of the total ecological footprint, 40% was caused by land use, and 60% was needed to sequester carbon dioxide emissions.

Table 4.7 Summary: KBRV's ecological footprints according to various approaches (ha)

| | Method of 'trace-back' | Unit of expression | Emissions to land conversion factor[1] | Total on-site | Total 1st and 2nd order | Total industrial | Total | Land | Emissions[2] |
|---|---|---|---|---|---|---|---|---|---|
| **Wackernagel and Rees (1996)** | Process analysis | Land appropriation by world-average productivity | 0.01 global ha/Gj *(area needed for carbon sequestration)* | 479 | 2180 | | 2659 | 1075 | 1584 |
| **Simpson et al. (2000)[3]** | Process analysis, with input-output analysis for $CO_2$ emissions | Land appropriation by world-average productivity[4] | 0.01 global ha/Gj *(area needed for carbon sequestration)* | 479 | 1376[a] | 1274[b] | 3129 | 1415 | 1714 |
| **Bicknell et al. (1998);** | Input-output analysis | | 0.01 ha/Gj *(area needed for carbon sequestration)* | 294 | | 8086 | 8380 | 6881 | 1123 |
| **The present study (methods of Lenzen and Murray, 2001)** | Input-output analysis | Land disturbance | 68.5 ha/kt $CO_2$-e *(projected land disturbance)* | 140 | | 3189 | 3329 | 2447 | 882 |

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[1] For more information see section 2.3.4(c)

[2] The methods of Wackernagel and Rees (1996), Simpson et al. (2000) and Bicknell et al. (1998) only include energy-use $CO_2$ emissions; the Lenzen and Murray (2001) method accounts for greenhouse gases from both energy-use and non energy-use sources, including $CO_2$, $CH_4$, $N_2O$, $CF_4$ and $C_2F_6$; see section 2.3.4(c)

[3] [a] refers to bioproductive land only, and [b] refers to carbon dioxide emissions only

[4] Simpson et al. (2000) used several variations to the conventional EF method, including that of local productivity or actual land use, in contrast to the world average productivity method which has been shown here.

By comparison, KBRV's ecological footprint according to the method used by Simpson et al.(2000), was larger at 3129 ha. This 14% increase from the footprint calculated by the Wackernagel and Rees (1996) method can be attributed to a larger land use component of 340 ha, and a larger carbon dioxide emission footprint of 130 ha. KBRV's ecological footprint calculated by the Bicknell et al. (1998) method totalled 8380 ha, by far the largest ecological footprint out of the four methods. This was due to a large land use component of 6881 ha. Of the total footprint, 85% was attributable to actual land appropriation, and the remaining 15% to carbon sequestration. In contrast, the present study which followed methods presented in Lenzen and Murray (2001) calculated the total footprint to be 3329 ha, 74% due to actual land disturbance (2447 ha), and 26% attributable to projected land disturbance resulting from greenhouse gas emissions (882 ha). An interpretation of these differences is presented in Section 5.3.

# CHAPTER 5: DISCUSSION

A complete ecological footprint analysis is a complex process. Consequently, there are numerous and contrasting dimensions of the results that warrant discussion. In order to cover all of these, this chapter is structured in the following way. First, the actual footprint results are discussed in light of key methodological and analytical shortcomings, together with possible avenues for improvement (Section 5.1). Second, the results of input-output analysis and structural path analysis are discussed with respect to the value that is added by the latter (Section 5.2) . Third, the sensitivity of the ecological footprint to methodological differences is examined (Section 5.3), and this is followed by the comparison of KBRV's ecological footprint results with other studies utilising the same method (Section 5.4). Next, the implications of the structural path analysis results for KBRV management are discussed (Section 5.5), as well as the overall utility of ecological footprint analysis to KBRV (Section 5.6). The chapter concludes with an evaluation of the ecological footprint as an ESD indicator (Section 5.7).

## 5.1 Methodological and analytical shortcomings, and avenues for improvement

Several shortcomings were identified during the methodological and analytical phases of this analysis. These can be grouped into (a) uncertainties with on-site data, (b) limitations of input-output analysis, and (c) shortcomings in the land disturbance model. These will be discussed in turn.

### 5.1.1 Uncertainties with on-site data

A potential avenue for improvement relates to the data format of KBRV's financial records. If the ecological footprint method were to be adopted as a monitoring tool for environmental performance, it would be advantageous to be able to align KBRV financial data with IOPC industry categories as closely as possible. This would require routine records to provide the further breakdown of certain categories, particularly the food products, which were found to be important in terms of contribution to KBRV's ecological footprint. This would reduce the amount of time spent in matching disparate categories, and would reduce the possibility of assigning KBRV expenditure data to incorrect IOPC categories. Another recommendation, in light of ecological footprint being used as a future monitoring tool, would be for KBRV to provide source details on the main expenditure paths highlighted in present study's structural path analysis results. This would be relatively straightforward to implement, and would assist in the identification of atypical paths (to Australian average production paths, Section 3.9.3) that have a significant contribution to the overall ecological footprint.

### 5.1.2 Limitations of input-output analysis

Several noteworthy limitations exist in the input-output analysis method, providing a source of potential error in the results (see Table 2.2). These include the errors associated with imported and capital commodities, the aggregation uncertainty, the proportionality error and the allocation uncertainty. In part, this was the reason for the exclusion of on-site and upstream expenditure on imported and capital commodities from KBRV's total ecological footprint (see Section 3.7.4). The sensitivity analysis, which measured the impact of excluding these two sources of expenditure, revealed an underestimation in the total footprint by 8 and 14% by excluding imports and capital goods respectively; see Table 4.5). This was to be expected, as the net effect of excluding any factor such as this would inevitably result in an underestimation of the ecological footprint. However, it could be argued that including these factors would result in the introduction of another set of errors which could be even higher, and less predictable in their effect. Either way, it is important to be aware that the ecological footprint results will contain errors, independent of whether imported and capital commodities are included or excluded from an ecological footprint analysis.

One solution would be to gather more accurate information pertaining to both imported and capital commodities, which would allow for more accurate results. For imported commodities, this would require the development of an input-output framework that incorporated each of Australia's key trading partners. This would facilitate the examination of the same production requirements (ie land use/disturbance and greenhouse gas emissions) as done in Australia. In turn, this would allow the actual production requirements of a particular imported commodity to be traced and included. This would represent a significant improvement on the current method of assuming homogeneity between overseas and domestic production requirements whenever imports are included.

To include capital investments, on the other hand, would require capital flow tables (and a subsequent matrix) to be constructed from industry totals of gross fixed capital expenditure from disparate sources (Section 3.7.4a). However, such an inclusion of capital investments would result in anomalies in upstream and on-site expenditure, creating unrealistically high ecological footprint results (Section 3.7.4a). It would therefore be more appropriate to introduce the concept of depreciation to the capital flow matrix. This would involve examining variability and then depreciating the capital over a certain number of years (Lenzen pers. comm., 2003). This would also require an on-site capital assessment and depreciation.

A potential source of error in input-output analysis that is of greater significance in this study is the aggregation uncertainty. As mentioned in Section 2.3.2, the aggregation uncertainty is the result of aggregating a number of producers within one industry. For example, consider a beef steak, and the land disturbance associated with its production. Land intensities would actually vary with each producer, depending on factors such as stocking rates (which vary with location) and other practices. Because all producers are aggregated within the beef cattle industry, input-output results only give the average land intensity for that industry as a whole. The sensitivity analysis conducted in this study (Table 4.7) highlighted the importance of this aggregation uncertainty, in particular with respect to regional differences. Results showed that by simply adding regional (production requirement) correction factors for the beef, sheep and dairy industries which assumed them to be based in Victoria instead of Australia as a whole, the footprint was reduced by almost half (Section 4.7). This substantial reduction was attributable to the beef and sheep industries being the top two ranked supply industries in terms of ecological footprint contribution. In fact, these two industries combined contributed to more than one half of KBRV's total ecological footprint, thus making any refinement worthwhile (Section 4.4).

Given the significance of this aggregation uncertainty, there is a clear need for more information that allows different production regions to be distinguished. This can be achieved by forming a multi-regional input-output framework. This would require input-output tables to be produced state by state, or even statistical division, in contrast to the national input-output tables currently available in Australia. Such work is currently being undertaken in New Zealand, with the production of an input-output based ecological footprint for the Waikato region, which uses regional input-output tables (Environment Waikato Regional Council, 2003).

Another limitation of input-output analysis is the proportionality error. This error arises from the inherent assumption of proportionality between physical and monetary units in monetary input-output tables (see Table 2.2). For example, the energy content of \$100 of electricity supplied to smelters is assumed to be equal to the energy content in \$100 of electricity supplied to travel agencies, despite the variability in electricity prices (Lenzen, 2001b). In theory, this could be overcome by replacing all monetary entries in input output tables with physical units. However, this cannot be achieved for most IOPC industries in Australia, as much of the physical data are unavailable, and some IOPC industries are too heterogenous to allow the assignment of a variety of physical units (Lenzen, 2001b). Nonetheless, this limitation could be overcome through the development of comprehensive mixed table units where possible (Lenzen pers. comm., 2003). For example, a study conducted by Lenzen (2001b) replaced monetary entries in the input-output tables with physical units for the coal, oil, gas mining, petroleum refining, electricity, gas and water supply industries. This resulted in mixed-table units, where A\$ entries represented monetary flow, MJ entries represented energy industries, and L represented water supply industries.

One further limitation of input-output analysis was referred to earlier as the allocation uncertainty (Section 2.3.2). This is the result of aggregating different products supplied by one industry (refer to Table 2.2 for more information). With regards to this study, some structural paths, particularly those of higher order, may describe average Australian supply chains, but not KBRV-specific supply chains. This is because some of the products purchased by KBRV from a particular industry may be atypical in comparison to the products of the respective IOPC industry, in terms of their land use (land actual land disturbance) and emissions (for example, meat products industry refinement in Section 3.9.3a). This error was substantially reduced in Phase five when selected, highly-ranked paths were further refined by the manual auditing of suppliers in a more detailed process analysis technique (Figure 3.1). However, some aggregation uncertainty is likely to remain in the KBRV ecological footprint results, particularly in those structural paths involving the beef and water transport industries. This will be discussed in Section 5.5.

### 5.1.3 Shortcomings of the land disturbance model

The land disturbance model represents an improvement over conventional ecological footprint methods through its incorporation of one aspect of regional ecosystem degradation – land (cover) disturbance (see Section 2.3.4c). However, as mentioned previously, there are many types of ecosystem disturbance and consequent impacts not considered in the land disturbance model (refer to Table 2.5). For instance, the impacts of pollution, soil erosion, salinity, species loss and habitat fragmentation, both on-site and through each production layer, are not included. A particularly important exclusion from the land disturbance model in light of the unique location of KBRV (World Heritage listed Fraser Island) is the use and potential disturbance of marine and freshwater resources. For instance, what are the impacts of the barges and passenger ferries that operate between KBRV and the mainland in terms of water pollution? Is KBRV's consumption of freshwater from the Fraser Island aquifer sustainable? Are any of the resort operations resulting in contamination of the underground freshwater aquifer and surrounding ocean environment?

The example of water resources can also be examined in terms of off-site (upstream) production. For instance, what water pollution impacts are occurring from the black coal mining operation that supplies coal for the generation of KBRV's electricity? Is the water use on the cotton farms that supply cotton to the fibres, yarns and fabrics IOPC industry (which supplies KBRV their staff uniforms) sustainable?

It is clear from the above that an ecological footprint analysis using the land disturbance model markedly overlooks many processes and impacts associated with regional ecosystem degradation, thus significantly underestimating the true ‘ecological footprint’. Furthermore, the strong focus on land cover disturbance as a proxy for ecosystem degradation can overlook and thus misrepresent the true environmental impact/s of many industries. For example, in comparison to production industries, the land disturbance model rates the beef cattle industry as a significantly large contributor to ecological footprints (see Sections 4.4 and 4.6). This is attributable to the land-intensive nature of the beef cattle industry, disturbing, on average, a larger area of land than other production industries (Wood and Lenzen, 2003). However, it could be argued that other less land-intensive industries (which under the land disturbance model contribute less) should generate larger ecological footprints. For instance, whilst crop-producing industries require less land than grazing industries, they are typically associated with the more intensive use of pesticides and higher water consumption patterns, which could, for example, lead to reduced environmental flows in streams, reduced water availability, water pollution, toxic effects on aquatic organisms and even pesticide residues in food destined for human consumption. Because the land disturbance model incorporates land cover disturbance only, these impacts are not included. Therefore, the beef industry contributions will typically rank higher than contributions from say the cotton industry. In other words, even if the cotton industry were more ‘ecosystem-intensive’, the beef industry would always contribute more to the ecological footprint in this analysis because it is more land-intensive.

Another important shortcoming of the land disturbance model is that it does not distinguish whether or not land is being used sustainably (Section 2.3.4c). A measure of land use sustainability requires not only the measurement of disturbance caused to an ecosystem, but also some measure of an ecosystem’s ability to withstand and/or recover from potential impacts (Lenzen and Murray, 2003). This concept has been referred to as ‘ecosystem resilience’ or ‘ecological integrity’ in ecological literature (Westman, 1978; Pimental et al., 2000).

To date, the development and incorporation of measures that adequately reflect ecosystem resilience has been considered an impossible task due to the complexity of ecological systems (Klomp and Green, 1996; Lenzen and Murray, 2003). This complexity stems not only from the vast numbers of species involved, but also from the richness and variety of interactions that organisms have, both with their environment and with each other (Klomp and Green, 1996). Perhaps with advances in the fields of modelling, geographical information systems and satellite technologies, combined with more extensive environmental databases, ecologists will come up with suitable measures of ecosystem resilience. Research in the emerging field of ecosystem health shows more promise (Pimental et al., 2000). However, until more detailed information becomes available on these factors, land cover disturbance is the best indication currently available (Lenzen and Murray, 2001), particularly in light of the vast numbers of ecosystems that become incorporated in ecological footprint assessments. For instance, the ecological footprint conducted in this study examined the production requirements (ie actual and projected land disturbance) for upstream industries that are located Australia-wide. To date, no land disturbance indicator, let alone ecosystem resilience indicator, exists that would be applicable on such a scale. Furthermore, if imported commodities are to be included in future studies via an international input-output framework (Section 5.1.2), the production requirements of industries and hence ecosystems located in other countries must also be included. The use of the land (cover) disturbance model thus represents the best, feasible indicator to date, despite its associated limitations.

Given the range and significance of the shortcomings discussed in this section, it could be argued that the ecological footprint is of no value without more complete information – that it uses inadequate and inaccurate data to produce inaccurate results. This view represents a philosophical stance that pervades commentaries on sustainability research. However, it could be argued that assessments such as the ecological footprint, which do underestimate true ecological impact, should nevertheless be conducted and reported with statements of qualifications whilst more accurate reporting techniques are being developed. This view is supported by the values underpinning the precautionary principle, which play an integral role in both the strong view of sustainability and the ecological footprint (refer to Section 2.1). Accepting the limitations and sources of uncertainty in ecological footprint analysis is not equivalent to ignoring them, and it is imperative that they be made explicit. In a practical sense, this includes the clear acknowledgment and separate presentation of results that are typically associated with high uncertainties.

In the same way that the ecological footprint does not account for a range of negative ecological impacts, it does not assign any value to strategies that mitigate environmental impact incorporated into organisational operations. For example, the ecological footprint does not allow credits to be obtained from eco-friendly processes such as the recycling of effluent from KBRV operations through its worm farm.

## 5.2 The added value of structural path analysis in ecological footprint assessments

The ranking of industries (that supply commodities to KBRV) according to their ecological footprint contribution provided useful information. However, the industry level information alone was insufficient to enable the identification of potential avenues for environmental impact abatement. For example, the industry level contributions to KBRV's ecological footprint revealed that the dairy products industry was the 6th largest contributor (81.10 ha). However, from this information it is impossible to determine the cause for the majority of the impact. Structural path analysis was able to show that the largest proportion of the impact within the dairy products industry was due to the 'replaced' disturbance of land that was required for the dairy cattle, which in turn provided the milk used to produce the dairy products supplied to KBRV – a second order path contributing 38.5 ha.

Another problem with simply ranking the industries is that it completely omits those on-site impacts which are not production-based. For example, structural path analysis identified carbon dioxide emissions arising from KBRV's on-site fuel use as a significant contributor (125ha; refer to Table 4.5), an impact overlooked in the KBRV ecological footprint industry level results. Therefore, structural path analysis represents a critical phase to this analysis.

## 5.3 The sensitivity of the ecological footprint to methodological differences

Without doubt, ecological footprint estimates are sensitive to the methods employed (Table 4.7). Although KBRV's ecological footprint calculated according to the different methods could not be compared directly, variations could be explained by examining the different methodological procedures and assumptions therein. This highlights the importance of each methodological decision made during ecological footprint calculations. This is not to say that previous methods are incorrect – rather it is intended to highlight the ecological footprint as a field that is continually developing and improving. The following discusses some of the differences noted in Table 4.7.

The ecological footprints calculated according to the Wackernagel and Rees (1996) and Simpson et al. (2000) methods both used process analysis as the method of 'trace-back' (refer to Section 3.10) and, in this analysis, were expressed in land appropriation units by world-average productivity (or global hectares). However, Simpson et al.'s (2000) total ecological footprint value was larger than that of Wackernagel and Rees (1996) by 470 ha. As previously mentioned (Section 4.8) this increase was attributable to larger land use and carbon dioxide emission components. This is because Simpson et al. (2000) captured higher order production carbon dioxide emissions via input-output analysis, and included arid and semi arid types of land as opposed to only the bio-productive areas land included in the Wackernagel and Rees (1996) method. The inclusion of arid and semi-arid land types had a particularly significant effect (an increase of 340 ha) because KBRV purchases a large number of commodities that originate from agricultural industries, which are predominantly arid land-intensive. However, if Simpson and colleagues were to have used input-output analysis for the calculation of land requirements (in addition to the carbon dioxide requirements), the land requirements necessary for higher order production would have been included making their total ecological footprint estimate even larger.

When all upstream requirements of land were considered by Bicknell et al.'s (1998) method, KBRV required 6881 ha of land (excluding carbon dioxide emissions). This represents more than a four-fold increase on the Simpson et al. (2000) land appropriation estimate. This is because the input-output analysis method employed by Bicknell et al.(1998) allowed for the complete capture of all upstream requirements, or the full production life-cycle of the commodities purchased by KBRV.

In contrast, KBRV's ecological footprint according to the Lenzen and Murray (2001) method, which utilises the same method of 'trace-back' as the Bicknell et al. (1998) method (input-output analysis, but with weightings of land and emission impacts) yielded a significantly smaller result of 3329 ha. This lower figure is likely to be more accurate as these weighting factors more closely describe regional land disturbance (see Section 2.3.4c).

An important insight from this analysis was that the 'weight' of KBRV's ecological footprint occurred in upstream production layers. Decomposition into production layers (Section 4.5) revealed that most impact occurred at the 2nd order of production[1] (the suppliers of suppliers) and above. Therefore a large truncation error would have resulted if the manual process analysis-based method were used for 'trace-back'. This constitutes a strong case for the use of input-output analysis for the 'trace-back' through upstream production layers, as it automatically covers the infinite paths of industrial transactions (Section 2.3.2).

## 5.4 Comparison of KBRV ecological footprint results with other studies using the same method

The input-output and land disturbance approach used in this analysis has been utilised in a range of settings. Whilst these settings are distinctly different to KBRV and no in-depth comparisons (such as those in the previous section) can be made, it is nonetheless interesting to compare certain features. Table 5.1 presents the ecological footprints of KBRV, the University of Sydney School of Physics (SOP) (Wood and Lenzen, 2003), the

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[1] Most impact occurred at the 2nd order if the meat products industry is included as the supplier to KBRV, thereby making the primary meat industry contributions occur at the 2nd order of production (see Section 4.5).

CSIRO Sustainable Ecosystems Department (CSE) (Wood and Lenzen, 2003) and the Sydney Water Corporation (SWC) (Lenzen et al., 2003b).

**Table 5.1 A comparison of institutional ecological footprints**

| **Footprint and components (ha)** | **KBRV** | **SOP** (Wood and Lenzen, 2003) | **CSE** (Wood and Lenzen, 2003b) | **SWC** (Lenzen et al., 2003) |
|---|---|---|---|---|
| **Total ecological footprint** | **3329** | **794** | **1420** | **73100** |
| On-site | 140 | 4.2 | 76.6 | 9500 |
| Off-site | 3189 | 789 | 1343 | 63600 |
| Actual land disturbance | 2447 | 371 | 620 | 19100 |
| Projected land disturbance | 882 | 423 | 800 | 54000 |

One interesting feature is that the on-site impacts of SWC are orders of magnitude higher than KBRV, SOP and CSE. This reflects the combined effect of large methane emissions released from on-site wastewater treatment plants and carbon dioxide emissions associated from on-site fuel use.

It is also interesting to note that, within the off-site component, the relative contribution of the meat industry to the actual land disturbance category was shown to be significant for KBRV, SOP and CSE. This is representative of the large actual land disturbance component displayed in Table 5.1. KBRV, with its five food outlets, has a strong focus on hospitality, whilst SOP and CSE had a small, but nevertheless significant contribution through their catering facilities (Wood and Lenzen, 2003). SWC, on the other hand, had off-site impacts orders of magnitude higher than KBRV, SOP and CSE, particularly with respect to the projected land disturbance component. This was partly due to the scale of the organisation, and the organisation’s heavy reliance on coal-fired power stations (Lenzen et al., 2003b).

## 5.5 Management implications of structural path analysis results

One of the principal aims of ecological footprint analysis is to guide management. As previously mentioned (Section 2.3.3) the detailed, decompositional nature of structural path analysis results is particularly useful for making managerial decisions about key operational processes, which hold the potential to decrease the size of the ecological footprint.

### 5.5.1 The significance of beef and lamb production impacts

The results from structural path analysis showed that, by far, the largest component of KBRV's ecological footprint was the 'significantly disturbed' and 'replaced' categories of land disturbance caused by the beef and sheep industries supplying beef and lamb products, respectively, to KBRV (see Section 4.5). These two industries represented the top three structural paths, being responsible for over one third of KBRV's overall impact. The beef and sheep industries were also identified as the top two IOPC industries in terms of ecological footprint contribution, representing over 56% to KBRV's total ecological footprint (Section 4.3).

However, whilst the beef industry represented the largest contribution, it must be acknowledged that these land disturbance impacts may be slightly inflated due to the aggregation of producers (known as the aggregation error, see Section 5.1.2) and the nature of the Australian beef cattle industry. Exported beef products are largely sourced from grazing pastures in Queensland, where cattle farming disturbs a larger area per head of cattle than in the southern parts of Australia, which, in general, supply the domestic beef industry (Wood and Lenzen, 2003). If regionalised input-output data were available, thereby eliminating the aggregation error, it would be possible to refine footprint estimates by identifying the region from which KBRV sourced its meat products.

Nonetheless, given the significance of the beef and sheep industry inputs to KBRV's ecological footprint, the consumption of beef and lamb products still remains as an area to target for ecological footprint reduction. If seen as a viable avenue for KBRV, one possible option is to influence the amount of beef and lamb products consumed at the five food outlets[1] located within the resort. Because KBRV is a tourist destination, it is unlikely that offering fewer beef and lamb products would be a preferred option. A more likely strategy could involve promoting the personal responsibility of informed food choice among tourists. KBRV have already made a positive step with respect to the provision of alternative meat options, such as crocodile, kangaroo and emu dishes. However, this positive action could be greatly enhanced through promoting greater awareness among tourists regarding the consequences of beef and lamb consumption. Information could be provided on menus and at the ranger eco-tourism interpretive centre, introducing the ecological footprint concept, and promoting the fact that personal food consumption choice can increase or decrease KBRV's ecological footprint. Such information also creates excellent opportunities for enhancing the interpretation experience provided at KBRV – a core principle and requirement of eco-tourism (Eco-tourism Australia, 2000; see Section 2.4.1).

### 5.5.2 Electricity supply impacts

Another significant impact highlighted in the structural path analysis was the greenhouse gas emissions emanating from the coal-fired power stations supplying electricity to KBRV (213.2 ha, or 3.6%). KBRV has already taken steps to minimise the impacts associated with energy use. These include energy monitoring and reporting measures that allow for the systematic identification of improvement opportunities in the organisation's use of energy. Therefore, to reduce the impact of this path, KBRV must shift from its current reliance on using electricity sourced from fossil fuels.

This could be achieved by purchasing 'green power' from the national electricity grid to supply KBRV's energy needs. Green power is the generic name given to electricity generated from clean, renewable energy sources such as solar and wind power, hydro, biomass, wave energy and landfill gas (Ergon Energy, 2003). Significant greenhouse gas emission savings can be made from using 'green power'. For example, if in the calendar

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[1] These include the Maheno and Seabelle specialty restaurants, the Sandbar bistro, the Wilderness Bar (provides staff and backpacker meals), and the Coffee Rock Café.

year 2002 KBRV sourced 100% of its electricity needs from ‘green power’, the organisation would have effectively prevented the generation of approximately 3112 tonnes of carbon dioxide – emissions which were generated in the above-mentioned higher order path of electricity supply.

A reduction in greenhouse gas emissions is not the only benefit that would accrue from this change. By sourcing energy needs from ‘green’ sources, KBRV could also fulfil key environmental objectives easily and efficiently. KBRV would also be eligible to use the green power customer logo[1] on its promotional materials to demonstrate its commitment to environmental leadership. This strategy has the potential to reap marketing benefits (Green Power, 2003a). For example, the Novotel and Hotel Ibis hotels located at Homebush, Sydney, have purchased 100% of their energy needs through green power. The general manager of both hotels regards the purchasing of green power as a smart business decision:

“Under the Green Power Accreditation Program, we’re able to exploit fully the marketing potential of the Green Power logo to gain extra competitive advantage. It’s a logo that people around Australia are starting to associate with environmental responsibility” (Green Power, 2003b).

### 5.5.3 Water transport impacts

Inputs from the water transport industry, like that of beef, may also suffer from the aggregation error. The projected land disturbance impacts of the water transport industry may be inflated due to the aggregation error and the nature of this particular path. Because this path represents relatively short transfers between KBRV and the mainland, the greenhouse gas emissions generated may be atypical to the averaged greenhouse gas emission requirements of the water transport industry. In order to determine whether the contribution from this path was inflated, process analysis-based research is required for the further disaggregation of the water transport industry.

### 5.5.4 On-site fuel use emission impacts

On-site fuel use impacts arising from greenhouse gas emissions were ranked 12th, 14th and 15th for diesel, LPG and unleaded petrol respectively, contributing a combined footprint of approximately 125 ha. As previously mentioned (Section 3.5.2), sources of fuel use on KBRV include vehicle use (diesel and unleaded petrol) and LPG for cooking and heating purposes. The most promising avenue for improvement within this category is with the KBRV vehicle fleet. KBRV has attempted to minimise the impacts associated with vehicle fuel use with the purchase of an electric 'car-train' to transfer tourists to and from the KBRV jetty to the resort. However, problems of insufficient power have meant that electric-powered vehicles are not a viable option for more widespread adoption at KBRV (Davies, pers. comm., 2003). In view of these considerations, fuel-efficient vehicles should be purchased as replacements, and the use of LPG[2] as an alternative fuel source should be considered where viable (Australian Greenhouse Office, 2002).

## 5.6 Utility of the ecological footprint to KBRV

Of what real value is ecological footprint analysis to KBRV? In light of the methodological and analytical shortcomings presented in Section 5.1, it is clear that the ecological footprint is not a tool for providing absolute and conclusive data, or realistic projections. Nonetheless, this ecological footprint analysis has provided information that is valuable for KBRV's environmental management decisions. It may also be particularly useful for KBRV management with respect to communicating their commitment to eco-tourism and interpretation.

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[1] Green Power is a national accreditation program that sets stringent environmental and reporting standards for renewable energy products offered by electricity suppliers to households and businesses across Australia. See www.greenpower.com.au

[2] LPG produces less carbon dioxide per litre than petrol. For every litre of petrol used, 2.3 kg of carbon dioxide is released in comparison to 1.5 kg for LPG (Australian Greenhouse Office, 2002).

### 5.6.1 Interpretation value

The National Eco-tourism Accreditation Program (NEAP), under which KBRV has been awarded advanced eco-tourism accreditation, defines interpretation as the key element in its definition of eco-tourism. Whilst environmentally sustainable practices are valuable initiatives, customers need to be sufficiently environmentally aware in order to seek them out and pay for them (Eco-tourism Australia, 2000). Perhaps Tilden (1977) summarised the importance of interpretation best:

> *Through interpretation, understanding.*
> *Through understanding, appreciation.*
> *Through appreciation, protection.*

The ecological footprint is thus particularly useful in light of the importance of interpretation to eco-tourism. An important advantage of the ecological footprint is the ability to communicate the significance of resource consumption effectively, an essential element of ESD (Section 2.1). This is attributable, primarily, to the ecological footprint's superior ability to aggregate a number of different aspects of environmental performance into a single, easily understood form – area of land (disturbance) (Section 2.2.4). As a result, the ecological footprint could be used effectively to communicate environmental performance to both corporate and tourist/visitor audiences.

In addition, the ecological footprint could be used to enhance the tourism experience at KBRV, by 'personalising' the significance of resource consumption in terms of KBRV's ecological footprint and environmental impact. For example, the results of this analysis could be communicated on a per tourist basis (see Section 4.2), engendering a sense of personal responsibility amongst tourists in their use of resources. Such information could provide an innovative and enjoyable source for interpretation, revealing the effects of tourist actions on KBRV's ecological footprint explicitly. Future work could include the use of interactive tourist ecological footprint calculators, enabling the tourist to calculate their own ecological footprint resulting from their stay. Furthermore, a program could be developed rewarding those tourists who choose to use less energy and resources during their KBRV experience. Such a program would greatly assist KBRV to maintain its award-winning track record of eco-tourism excellence, through the clear demonstration of innovative best practice. Therefore, by directly involving tourists and providing personal connections, the above-mentioned interpretation opportunities could enhance the interpretation resources available at KBRV significantly:

*"... interpretations, creatively packaged and powerfully delivered, lie at the heart of successful and genuine eco-tourism".* (Eco-tourism Australia, 2000, p133).

### 5.6.2 Decision-making value

There are several ways in which ecological footprint analysis can assist KBRV management. By allowing for greater transparency into some of KBRV's less observable off-site impacts, environmental impact abatement policies and strategies can be developed that consider upstream production impacts. This would complement the existing (on-site) environmental audits that are routinely conducted at KBRV (Davies, pers. comm., 2003).

Ecological footprint analysis also provides the opportunity for scenario analysis. Using the baseline results from this analysis, the relative impacts of counterfactual scenarios could be determined. For example, the net reductions in the ecological footprint resulting from a substitution of 20% of the beef dishes available in KBRV's restaurants with pork, or another type of meat, could be calculated. This could also be applied with regards to energy sources, etc., thus allowing for the targeting of top-ranked paths. Unfortunately, scenario calculations involving the sourcing of operational inputs from different locations is not currently possible, as this requires further work on regionalising Australian input-output data (see Section 5.1.2).

Finally, the ecological footprint lends itself for use as a valuable benchmarking tool. If calculated at regular intervals, the ecological footprint would allow KBRV to monitor and evaluate its progress towards 'environmental' sustainability (only). Therefore, through calculating the ecological footprint and implementing subsequent environmental impact abatement strategies, KBRV can actively demonstrate its commitment to environmental sustainability. This would enhance their capacity to stay in the forefront of eco-tourism, maintaining or improving their current share of the eco-tourism market.

## 5.7 The ecological footprint as an index for Ecologically Sustainable Development

The ecological footprint is one of only a few ESD indicators that considers the interrelationship between the social, economic and environmental dimensions of ESD. It does this by relating socio-economic material and energy flows to land disturbance impacts (Section 2.2.4). Nevertheless, because the ecological footprint was developed through the 'strong' ESD perspective (Section 2.1), indicators from the social and economic ESD dimensions are not considered. Examples of such indicators include measures of health and well being of a population, and measures of the economic sustainability of a sugar mill upon which a small community depends. Furthermore, the ecological footprint does not encompass many environmental aspects that should be considered when assessing for environmental sustainability (see Section 5.1.3).

Due to the complex, interconnected nature of the biophysical and socio-economic environments in which we live, it is not enough to simply measure the environmental impacts of consumption arising from our socio-economic environment (see Figure 2.1). Such information must be complemented with indicators that measure for social and economic impacts, in order to provide a more holistic view of ESD. For example, based solely on the ecological footprint, it may be less land-intensive to source certain food products from an area outside of the immediate local community of KBRV. However, such a policy shift should not be taken in isolation as it overlooks these other socio-economic dimensions of ESD. This 'trade-off'position is reinforced by the requirement of Eco-tourism Australia (2000) that eco-tourism should provide ongoing, constructive contributions to local communities, in order to counter any negative impacts on the local community.

Because the ecological footprint, on its own, does not incorporate other dimensions of ESD, it is often maligned as a poor ESD indicator (van Vuuren and Smeets, 2000; van

Kooten and Bulte, 2000; Moffatt, 2000). Rather than dismiss the utility of the ecological footprint in communicating aspects of ESD, it should be presented and communicated in context. Consequently, indicators from the economic and social dimensions of ESD, together with supplementary environmental indicators, should be used concurrently with the ecological footprint to provide a more holistic view of ESD performance.

Attempts to generate a single index for ESD from a wide range of indicators would be futile, as the 'information value' of the composite index would be lost and therefore of little use for decision-makers. Conversely, compiling a vast number of indicators (representing the social, economic and environmental dimensions of ESD) into a set can create confusion about achieving multiple goals, thereby decreasing practicability (Chambers et al., 2000). A potential solution to these problems lies in partnering the ecological footprint with the AMOEBA approach[1] to sustainability indicators proposed by Bell and Morse (1999). The AMOEBA approach keeps the richness of indicator results intact, whilst simultaneously providing a simple, easily understood output. It represents a systemic approach to ESD analysis that pools environmental, social and economic indicators together effectively in a visual manner aimed at non-scientists (Bell and Morse, 1999). In other words, the AMOEBA provides a visual cross-section of ESD, within a project context. The inclusion of the ecological footprint within the AMOEBA construct therefore offers an exciting opportunity for communicating complete ESD performance effectively. This kind of reporting is otherwise known as triple bottom line reporting (Suggett and Goodsir, 2002). Figure 5.1 displays a representation of a systemic ESD analysis via the AMOEBA approach.

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[1] The AMOEBA is an acronym that in Dutch stands for 'general method for ecosystem description and assessment' (Bell and Morse, 1999).

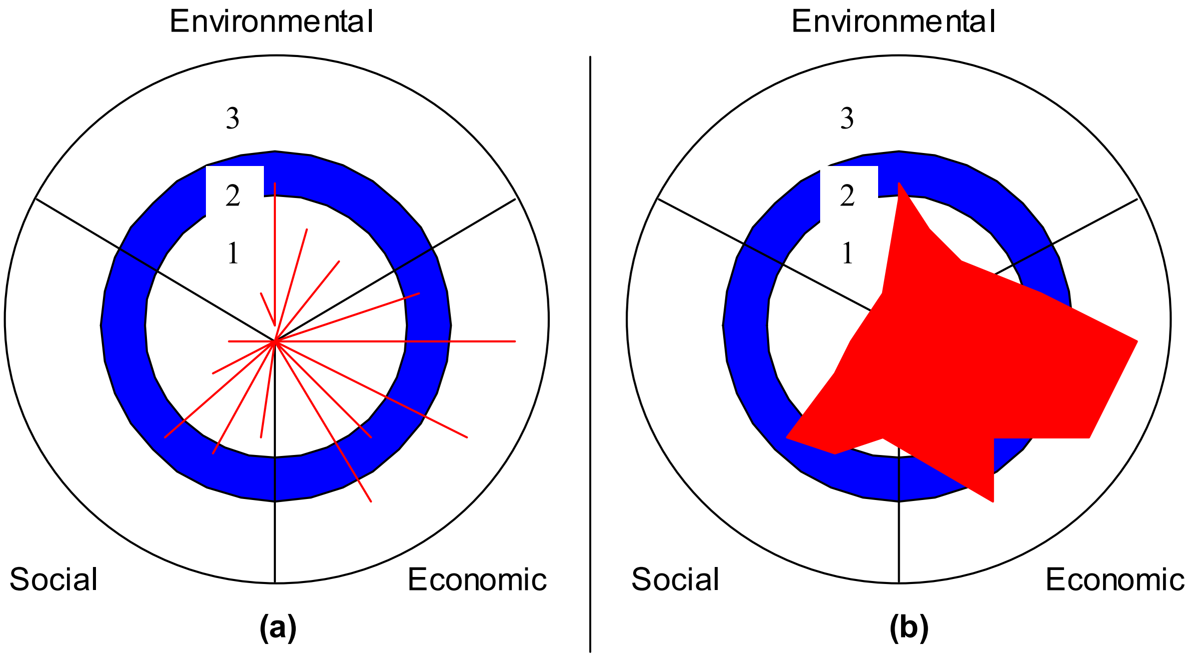

**Figure 5.1 An example of systemic ESD analysis via the AMOEBA approach**

(Adapted from Bell and Morse, 1999)
**(a)** The shaded area represents the equilibrium band or reference condition, whilst lines represent environmental, social and economic ESD indicators
**(b)** AMOEBA drawn from connecting the ESD indicators
**1** = not sustainable by deficit, **2** = state of equilibrium, and **3** = not sustainable by surfeit (Bell and Morse, 1999).

The AMOEBA approach involves, firstly, the identification of key ESD indicators that are representative of the three dimensions of ESD. Second, a band of equilibrium or reference position is developed, usually derived through a qualitative assessment of key stakeholders (Bell and Morse, 1999). The reference position typically refers to three concentric bands: (1) not sustainable by deficit, (2) state of equilibrium, and (3) not sustainable by surfeit (refer to Figure 5.1). Defining the limits of the band of equilibrium is very subjective, and this leads to a debate on its own (see Bell and Morse, 1999, for more information). For instance, what levels are agreed to be sustainable? What are the upper and lower limits of sustainability? Is there an upper limit to environmental sustainability?

Once the band of equilibrium is set for each ESD indicator, the measures for each indicators are drawn in according to their current state relative to the three bands, thus developing the AMOEBA itself (Figure 5.1, (b)). The ecological footprint could be applied within this framework by effectively representing one dimension within the AMOEBA, thus allowing the ecological footprint to be 'visualised' in context of other ESD indicators. Therefore, not only would this take into account the benefits of the ecological footprint mentioned previously, it would also allow for the holistic examination of an organisation's ESD performance and greatly assist corporate triple bottom line reporting.

One step further, the AMOEBA (containing the ecological footprint and other ESD indicators) could be used for determining avenues for impact abatement action (whether they be environmentally, socially or economically targeted). This is achieved through the unique visualisation of the AMOEBA, enabling the clear identification of those areas in need of most improvement (indicators that fall into the 'unsustainable by deficit' category).

Furthermore, by presenting ESD indicators in terms of their 'unsustainability by deficit or surfeit', the AMOEBA can identify those areas which are 'over-extended', thereby (theoretically) allowing for the re-allocation of resources to assist impact abatement strategies required to balance 'unsustainable by deficit' areas. This concept of re-allocation or 'trade-offs' is not intended to represent the substitution of natural capital, which is a fundamental principle of the 'weak' ESD perspective. Rather, it is intended to identify areas of surplus and attempt to trade these areas to places of deficit. However, in line with the 'strong' ESD approach that features in the precautionary principle (Section 2.1), 'surplus' of natural capital (in the unlikely event that a surplus of natural capital is identified) should not be substituted or traded off for human made forms of capital.

In light of the above, the AMOEBA lends itself for use in trialing counterfactual scenarios, in order to identify those options which would be most effective in achieving the balance that is ESD. Furthermore, the AMOEBA could also be used to monitor ESD performance over time, where the AMOEBA would change shape in response to actions taken (Bell and Morse, 1999). Theoretically, the more the AMOEBA imitates a perfect circle within the equilibrium band, the more an organisation tends toward ESD (Bell and Morse, 1999).

Therefore, by incorporating the utility of the ecological footprint within the AMOEBA framework, a holistic triple bottom line assessment of an organisation's performance can be achieved, featuring:

- multi-dimensional ESD performance and outcomes information,
- the systematic assessment of the impacts of organisation performance, and
- a basis for identifying benchmarks and assessing trends.

(Suggett and Goodsir, 2002)

## 5.8 Conclusion

It is useful at the end of this analysis to examine how well the aims and objectives of this research were realised. Starting with the first of the specific objectives, an ecological footprint was calculated for KBRV. In addition to this, it was calculated using a range of alternative methods and was shown to be highly sensitive to methodological differences including the 'trace-back' of upstream production requirements, and how the ecological footprint is expressed.

Through a detailed examination and assessment of KBRV's operational inputs, the key contributing factors to its ecological footprint were identified and ranked in order of their importance. The most significant inputs identified were beef and lamb inputs, on-site methane emissions arising from the wastewater treatment plant, electricity supply, water transport and on-site fuel use impacts. Some operational input impacts were shown to be amenable to management, whilst others revealed the need for further research.

The third objective of evaluating and using the ecological footprint as an indicator of progress towards ESD, required a more holistic analysis. It was this objective that embedded this research within the broader context of ESD research. The critical analysis of the ecological footprint's theoretical base, revealed that it is not sufficient as a stand-alone indicator for ESD. This was shown to be due, in part, to its inability to capture important aspects of ecological integrity. However, it was demonstrated that it could be used effectively in conjunction with other indicators of ESD, within a composite measure such as the AMOEBA.

In summary, the research aims of this study were realistic and were achieved. The results offer both practical outcomes for KBRV, in terms of how to progress towards more sustainable operations, as well as some contribution to the theoretical development of the method. Along with its ongoing methodological refinement, the most promising avenue for increasing the utility of the ecological footprint approach, is its incorporation within a composite systemic measure for ESD.

# REFERENCE LIST

***The following reference list follows the journal format outlined by the Journal of Applied Ecology.***

Australian Greenhouse Office (2002) Fuel consumption guide 2001-2002. Australian Greenhouse Office, available at: http://www.greenhouse.gov.au/fuelguide/pubs/2001-02.pdf

Australian Greenhouse Office (2003) AGO Factors and Methods Workbook, Version 3. Australian Greenhouse Office, Canberra.

Australian State of the Environment Committee (2001). Australia State of the Environment 2001. Independent Report to the Commonwealth Minister for the Environment and Heritage, CSIRO, Canberra.

Barret, J. (2001) Component ecological footprint: developing sustainable scenarios. Impact Assessment and Project Appraisal, 19, 107-118.

Bell, S., Morse, S. (1999) Sustainability Indicators: Measuring the Immeasurable? Earthscan Publications Ltd., London.

Bicknell, K.B., Ball, R.J., Cullen, R., Bigsby, H.R (1998) New methodology for the ecological footprint with an application to the New Zealand economy. Ecological Economics, 27, 149-160.

Bullard, C.W., Penner, P.S., Pilati, D.A (1978) Net Energy Analysis: Handbook for Combining Process and Input-Output Analysis. Resources and Energy, 1, 267-313.

Bush, S., Dickson, A., Harman, J., Anderson, J. (1999) Australian Energy: Market Developments and Projections to 2014-15, ABARE Research Report 99.4. Australian Bureau of Agricultural and Resource Economics, Canberra.

Chambers, N., Lewis, K. (2001) Ecological Footprint Analysis: Towards a Sustainability Indicator for Business. Certified Accountants Educational Trust, London.

Chambers, N., Simmons, C., Wackernagel, M. (2000) Sharing Nature's Interest: Ecological Footprints as an Indicator of Sustainability Earthscan Publications Ltd., London.

Charlton, K. (unpublished) An Ecological Footprint Analysis for Western Australia. Honours Thesis 2002, Curtin University of Technology, Perth.

Cole, B., Sinclair, A.J (2002) Measuring the Ecological Footprint of a Himalayan Tourist Center. Mountain and Research Development, 22, 132-144.

Costanza, R., Cumberland, J., Daly, H., Goodland, R., Norgaard, R. (1997) An Introduction to Ecological Economics St. Lucie Press, Boca Raton, Florida.

Daly, H.E., Cobb, J. (1989) For the Common Good: Redirecting the Economy Towards Community, the Environment and a Sustainable Future Beacon, Boston.

Darwin, R., Tsigas, M., Lewandrowski, J., Raneses, A. (1996) Land use and cover in ecological economics. Ecological Economics, 17, 157-181.

Defourny, J., Thorbecke, E (1984) Structural Path Analysis and Multiplier Decomposition within a Social Accounting Matrix Framework. The Economic Journal, 94, 111-136.

Department of Industry, Tourism and Resources (2002) The Ten Year Plan for Tourism: A Discussion Paper, Commonwealth of Australia, Canberra, available at: http://www.industry.gov.au/library/content_library/Tourism10plandiscussionpaper.pdf

Dixon, R. (1996) Inter-Industry Transactions and Input-Output Analysis. The Australian

Economic Review, 3, 327-336.

Ecologically Sustainable Development Steering Committee (1992) National Strategy for Ecologically Sustainable Development, Environment Australia, available at: http://www.ea.gov.au/esd/national/nsesd/strategy/index.html

Ecotourism Australia (1999). Australia—the World'sNatural Theme Park (ed S. McArthur, Dowling, R.) In: Proceedings of the Ecotourism Association of Australia National Conference 1999, Ecotourism Association of Australia, Kingfisher Bay Resort and Village, Fraser Island, Queensland.

Ecotourism Australia (2000) Nature and Ecotourism Accreditation Program (NEAP) 2nd ed. Ecotourism Association of Australia, Brisbane.

Ehrlich, P., Holdren, J. (1971) Impacts of Population Growth. Science, 171, 1212-17.

Ekins, P., Simon, S., Deutsch, L., Folke, C., de Groot, R. (2003) A framework for the practical application of the concepts of critical natural capital and strong sustainability. Ecological Economics, 44, 165-185.

Environment Australia (2002) Are We Sustainaing Australia? Report Against Headline Sustainability Indicators. Environment Australia, Canberra.

Environment Waikato Regional Council (2003) Regional ecological footprint. Waikato Regional Council, available at: http://www.ew.govt.nz/ourenvironment/indicators/community/sustainability/ecofoot/techinfo.htm#Bookmark_Bookmark1

Ergon Energy (2003) What is Ergon clean energy? Ergon Energy, available at: http://www.ergon.com.au/environment/clean_energy

Farrell, A., Hart, M. (1998) What does sustainability really mean? Environment, 40, 4-31.

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

Ferng, J.J. (2002) Toward a scenario analysis framework for energy footprints. Ecological Economics, 40, 53-69.

Fischer-Kowalski, M., Haberl, H. (1997) Tons, joules and money: modes of production and their sustainability problems. Society and Natural Resources, 10, 61-85.

Flint, K. (2001) Institutional ecological footprint analysis: a case study of the University of Newcastle, Australia. International Journal of Sustainability in Higher Education, 2, 48-62.

Folke, C., Jansson, A., Larsson, J., Costanza, R. (1997) Ecosystem Appropriation by Cities. Ambio, 26, 48-62.

Forsund, F.R., Strom, S. (1976) The Generation of Residual Flows in Norway: An Input-Output Approach. Journal of Environmental Economics and Management, 3, 129-141.

Gallopin, G.C. (1997) Indicators and their Use: Information for Decision-making. In SCOPE 58: Sustainability Indicators; Report of the project on Indicators of Sustainable Development (ed B. Moldan, Billharz, S., and Matravers, R.). John Wiley & Sons Ltd., West Sussex, England.

Getzner, M. (1999) Weak and strong sustainability indicators and regional environmental resources. Environmental Management and Health, 10, 170-176.

Glanznig, A. (1995) Native Vegetation Clearance, Habitat Loss and Biodiversity Decline, Rep. No. 6. Department of the Environment, Sport and Territories Biodiversity Unit, Canberra.

Goedkoop, M., Effting, S., Collignon, M. (2000) The Eco-indicator 99: A damage oriented method for Life Cycle Impact Assessment, Vol. 2003. Product Ecology Consultants.

Graetz, R.D., Wilson, M.A., Campbell, S.K. (1995). Landcover Disturbance over the Australian Continent: a contemporary assessment, Rep. No. 7. Department of the Environment, Sport and Territories, Canberra.

Green Power (2003a) What is green power? Green Power, available at: www.greenpower.com.au

Green Power (2003b) Novotel and Hotel Ibis Homebush Bay: Stylish and Green. Green Power, available at: http://www.greenpower.com.au/images/dl/GPCASE_NOVOTEL.pdf

Gutes, M.C. (1996) The concept of weak sustainability. Ecological Economics, 17, 147-156.

Haberl, H., Schandl, H. (1999) Indicators of sustainable land use: concepts for the analysis of society-nature interrelations and implications for sustainable development. Environmental Management, 10, 177-189.

Hardi, P., Zdan, T., ed. (1997) Assessing Sustainable Development: Principles in Practice. International Institute for Sustainable Development, Canada.

Harrison, P. (1992) The Third Revolution: Environment, Population and a Sustainable World I. B. Tauris, London.

Hendrickson, C., Horvath, A., Joshi, S., Lave, L (1998) Economic Input-Output Models for Environmental Life-Cycle Assessment. Environmental Science and Technology, 32, 184A-191A.

Herendeen, R.A. (1998) Net energy considerations. In Economic Analysis of Solar Thermal Energy Systems (ed R.E. West, Kreith, F.). The MIT Press, Cambridge.

Hille, J. (1998) The Concept of Environmental Space - Implications for policies, environmental reporting and assessments EEA.

Hubacek, K., Giljum, S. (2003) Applying physical input-output analysis to estimate land appropriation (ecological footprints) of international trade activities. Ecological Economics, 00, 1-15.

Jansson, A., Folke, C., Rockstrom, J., Gordon, C. (1999) Linking Freshwater Flows and Ecosystem Services appropriated by people: The case of the Baltic Sea Drainage System. Ecosystems, 2, 167-172.

Joshi, S. (2001) Product Environmental Life-Cycle Assessment Using Input-Output Techniques. Journal of Industrial Ecology, 3, 95-120.

Kimber, M.D and Associates (1998) KBRV Master Site Plan. Malcolm D. Kimber and Associates, Armidale.

Klomp, N.I., Green, D.G. (1996) Complexity and Connectivity in Ecosystems. Complexity International, 3, available at: http://journal-ci.csse.monash.edu.au/ci/vol03/klomp/klomp.html.

Lange, G.-M. (1998) Applying an integrated natural resource accounts and input-output model to development planning in Indonesia. Economic Systems Research, 10, 113-134.

Larsson, J., Folke, C., Kautsky, N. (1994) Ecological Limitations and Appropriation of Ecosystem Support by Shrimp Farming in Colombia. Environmental Management, 18, 665-675.

Lave, L.B., Cobas-Flores, E., Hendrickson, C.T., McMichael, F.C. (1995) Using input-output analysis to estimate economy-wide discharges. Environmental Science and Technology, 29, 420A-426A.

Learner, M.A., Williams, R., Harcup, M., Hughes, B.D. (1971) A survey of the macro-fauna of the River Cynon, a polluted tributary of the River Taff (South Wales). Freshwater Biology, 1, 339-367.

Lenzen, M. (2001a) A generalized Input-Output Multiplier Calculus for Australia. Economic Systems Research, 13, 65-92.

Lenzen, M. (2001b) Errors in Conventional and Input-Output-based Life-Cycle Inventories. Research and Analysis, 4, 127-148.

Lenzen, M., Lundie, S., Bransgrove, G., Charet, L., Sack, F. (2003b) Assessing the ecological footprint of a large metropolitan water supplier - lessons for water management and planning towards sustainability. Journal of Environmental Planning and Management, 46, 113-141.

Lenzen, M., Murrary, S.A (2001) A modified ecological footprint method and its application to Australia. Ecological Economics, 37, 229-255.

Lenzen, M., Murray, S. (2003) The Ecological Footprint: Issues and Trends, Rep. No. ISA Research Paper 01-03. The University of Sydney, Sydney.

Lenzen, M., Murray, S.A., Korte, B. and Dey, C.J (2003a) Environmental impact assessment including indirect effects - a case study using input-output analysis. Environmental Impact Assessment Review, 5294, 1-20.

Leontief, W. (1941) The Structure of the American Economy, 1919-1939 Oxford University Press, Oxford.

Leontief, W. (1970) Environmental Repurcussions and the Economic Structure: An Input-Output Approach. Review of Economics and Statistics, 52, 262-271.

Lewis, K., Simmons, C., Chambers, N. (2000) An Ecological Footprint Analysis of Different Packaging Systems. Best Foot Forward, Oxford.

Loh, J.(ed). (2002). Living Planet Report 2002. World Wide Fund for Nature, Cambridge.

Lough, T.S. (1996) Energy analysis of the structures of industrial organisations. Energy, 21, 131-139.

Maltin, M.K., Starke, T.P. (2002) The Laboratory's Footprint: Our Environmental Impacts, Rep. No. LA-UR- 02-1971. Los Alamos National Laboratory, California.

McGregor, I.M. (2003) Is Australia Progressing towards Ecologically Sustainable Development? Environmental Health, 3, 31-45.

Moffat, I. (2000) Ecological footprints and sustainable development. Ecological Economics, 32, 359-362.

National Greenhouse Gas Inventory Committee (NGGIC) (1997) National Greenhouse Gas Inventory 1995. Australian Greenhouse Office, Canberra.

National Greenhouse Gas Inventory Committee (NGGIC) (1998a) Workbook 8.1 for Waste, Rep. No. 8.1. Australian Greenhouse Office, Canberra.

National Greenhouse Gas Inventory Committee (NGGIC) (1998b) Energy Workbook 3.1 for Transport (Mobile Sources), Rep. No. 3.1. Australian Greenhouse Office, Canberra.

Pearce, D.W., Atkinson, G.D. (1993) Capital theory and the measurement of sustainable development: an indicator of 'weak' sustainability. Ecological Economics, 8, 103-08.

Pimental, D., Westra, L., Noss, R.F, ed. (2000) Ecological Integrity: Integrating Environment Conservation and Health. Island Press, Canada.

Preece, N., van Oosterzee, P., James, D. (2003) Two Way Track: Biodiversity Conservation and Ecotourism - an investigation of linkages, mutual benefits and opportunities, Vol. 2003. Biodiversity Unit, Environment Australia.

Promoting Action for Sustainability Through Indicators at the Local Level in Europe (PASTILLE) Consortium (2002). Indicators into Action: A practitioners guide for improving their use at the local level. European Union Fifth Framework Programme (FP5), London, available at: www.lse.ac.uk/depts/geography/Pastille/PGuide.pdf

Rapport, D., Costanza, R., Epstein, P., Gaudet, C., Levins, R. (1998) Ecosystem Health. Blackwell Science, London.

Rapport, D.J. (2000) A New Strategy for Public Health: Editorial. Ecosystem Health, 6.

Rapport, D.J. (2000) Ecological footprints and ecosystem health: complementary approaches to a sustainable future. Ecological Economics, 32, 367-370.

Redefining Progress (1995) Genuine Progress Indicator, Accessed 2003. Redefining Progress, available at: http://www.rprogress.org/projects/gpi

Redefining Progress (2003) Ecological Footprint Quiz, Accessed 2003. Redefining Progress, available at: http://www.earthday.net/footprint/index.asp

Rees, W.E. (1992) Ecological footprints and appropriated carrying capacity: What urban economics leaves out. Environment and Urbanization, 4, 121-130.

Rees, W.E. (2000) Eco-footprint analysis: merits and brickbats. Ecological Economics, 32, 371-374.

Shearman, D., Sauer-Thompson, G. (1997) Green or Gone: health, ecology, plagues, greed and our future Wakefield Press, Kent Town.

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

Simmons, C., Lewis, K., Barrett, J. (2000) Two feet - two approaches: a component-based model of ecological footprinting. Ecological Economics, 32, 375-380.

Simspson, R., Petroeschevsky, A., Lowe, I. (2000) An Ecological Footprint Analysis for Australia. Australian Journal of Environmental Management, 7, 11-18.

Solow, R. (1993) Sustainability: an economist's perspective. In Economics of the Environment (ed N.S. Dorfman), pp. 179-87. W.W. Norton, London.

Southwood, T.R.E. (1978) Ecological Methods Chapman and Hall, Cambridge.
Sustainable Energy Authority Victoria (2003) What is cogeneration? Sustainable Energy Authority, available at:
http://www.seav.vic.gov.au/advice/business/infosheets/cogeneration_CHP.html

Suggett, D., Goodsir, G. (2002) Triple bottom line measurement and reporting in Australia: making it tangible, The Allen Consulting Group, Document Printing Australia.

Tilden, F. (1977) Interpreting our heritage. University of North Carolina Press, Chapel Hill.

Treloar, G.J. (1997) Extracting embodied energy paths from input-output tables: Towards an input-output-based hybrid energy analysis method. Economic Systems Research, 9, 375-388.

Treloar, G.J., Love, P.E.D., Iyer-Raninga, U., Faniran, O.O. (2000) A hybrid life cycle assessment method for construction. Construction, Management and Economics, 18, 5-9.

Australian Bureau of Statistics (ABS) (1999) Australian National Accounts Input-Output Tables 1994-95, Rep. No. Catalogue No. 5209.0. Australian Bureau of Statistics, Canberra.

United Nations Conference on Environment and Development (UNCED) (1992) Agenda 21, Rio de Janeiro, Brazil.

United Nations Environment Programme (UNEP) (2002) Synthesis Global Environment Outlook 3: Past, present and future perspectives. United Nations Environment Programme, London.

United Nations Environment Programme (UNEP) Working Group for Cleaner Production in the Food Industry (1999) The Potential for Generating Energy from Wet Waste Streams in NSW, prepared for the NSW Sustainable Energy Development Authority (SEDA).

van den Bergh, J.C.J.M., Verbruggen, H. (1999) Spatial Sustainability, trade and indicators: an evaluation of the 'ecological footprint'. Ecological Economics, 29, 61-72.

van Kooten, G.C., Bulte, E.H. (2000) The ecological footprint: useful science or politics? Ecological Economics, 32, 385-389

van Vuuren, D.P., Smeets, E.M.W (2000) Ecological footprints of Benin, Bhutan, Costa Rica and the Netherlands. Ecological Economics, 34, 115-130.

vanLeeuwen, J.A., Waltner-Toews, D., Abernathy, T., Smit, B. (1999) Evolving Models of Human Health Toward an Ecosystem Context. Ecosystem Health, 5, 204-219.

Venetoulis, J. (2001) Assessing the ecological impact of a university - The ecological footprint for the University of Redlands. International Journal of Sustainability in Higher Education, 2, 180-196.

Viebahn, P. (2002) An environmental management model for universities: from environmental guidelines to staff involvement. Journal of Cleaner Production, 10, 3-12.

Wackernagel, M. (2002) What We Use and What We Have: Ecological Footprint and Ecological Capacity. Redefining Progress, Oakland, USA.

Wackernagel, M., Onisto, L., Linares, A.C., Falfan, I.S.L, Garcia, J.M., Guerrero, A.I.S., Guerrero, M.G.S. (1997) Ecological Footprints of nations: How Much Nature Do They Use? International Council for Local Environmental Initiatives, Toronto.

Wackernagel, M., Rees, W.E. (1996) Our Ecological Footprint: Reducing Human Impact on the Earth New Society Publishers, Canada.

Webb, A. (1998) Den Haag's 'Environmental Thermometer', Vol. 2003. Action Towards Local Sustainability, available at: http://www.sustainability.org.uk/info/casestudies/den_haag.htm

Westman, W.E. (1978) Measuring the inertia and resilience of ecosystems. Bioscience, 28, 705-710.

Wood, M.E. (2002) Ecotourism: Principles, practices and policies for sustainability. United Nations Publications.

Wood, R., Lenzen, M. (2003) An Application of a Modified Ecological Footprint Method and Structural Path Analysis in a Comparative Institutional Study. Local Environment, 8, 365-386.

World Commission on Environment and Development (WCED) (1987) Our Common Future Oxford University Press, Oxford.

World Wildlife Fund (WWF) (2002) Holiday Footprinting: A practical tool for responsible tourism. WWF-UK Business and Consumption Unit, London.

## PERSONAL COMMUNICATIONS

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Lenzen, M. (2003) University of Sydney, NSW.

Thers, G. (2003) KBRV, QLD.

# APPENDICES

# Appendix 1: The Bellagio Principles for Assessment

(Source: Hardi and Zdan, 1997)

## 1. GUIDING VISION AND GOALS

Assessment of progress toward sustainable development should:

- be guided by a clear vision of sustainable development and goals that define that vision

## 2. HOLISTIC PERSPECTIVE

Assessment of progress toward sustainable development should:

- include review of the whole system as well as its parts
- consider the well-being of social, ecological, and economic sub-systems, their state as well as the direction and rate of change of that state, of their component parts, and the interaction between parts
- consider both positive and negative consequences of human activity, in a way that reflects the costs and benefits for human and ecological systems, in monetary and non-monetary terms

## 3. ESSENTIAL ELEMENTS

Assessment of progress toward sustainable development should:

- consider equity and disparity within the current population and between present and future generations, dealing with such concerns as resource use, over-consumption and poverty, human rights, and access to services, as appropriate
- consider the ecological conditions on which life depends
- consider economic development and other, non-market activities that contribute to human/social well-being

## 4. ADEQUATE SCOPE

Assessment of progress toward sustainable development should:

- adopt a time horizon long enough to capture both human and ecosystem time scales thus responding to needs of future generations as well as those current to short term decision-making
- define the space of study large enough to include not only local but also long distance impacts on people and ecosystems
- build on historic and current conditions to anticipate future conditions
  - where we want to go, where we could go

## 5. PRACTICAL FOCUS

Assessment of progress toward sustainable development should be based on:

- an explicit set of categories or an organizing framework that links vision and goals to indicators and assessment criteria
- a limited number of key issues for analysis
- a limited number of indicators or indicator combinations to provide a clearer signal of progress
- standardizing measurement wherever possible to permit comparison
- comparing indicator values to targets, reference values, ranges, thresholds, or direction of trends, as appropriate

## 6. OPENNESS

Assessment of progress toward sustainable development should:

- make the methods and data that are used accessible to all
- make explicit all judgments, assumptions, and uncertainties in data and interpretations

## 7. EFFECTIVE COMMUNICATION

Assessment of progress toward sustainable development should:

- be designed to address the needs of the audience and set of users
- draw from indicators and other tools that are stimulating and serve to engage decision-makers
- aim, from the outset, for simplicity in structure and use of clear and plain language

## 8. BROAD PARTICIPATION

Assessment of progress toward sustainable development should:

- obtain broad representation of key grass-roots, professional, technical and social groups, including youth, women, and indigenous people - to ensure recognition of diverse and changing values
- ensure the participation of decision-makers to secure a firm link to adopted policies and resulting action

## 9. ONGOING ASSESSMENT

Assessment of progress toward sustainable development should:

- develop a capacity for repeated measurement to determine trends
- be iterative, adaptive, and responsive to change and uncertainty because systems are complex and change frequently
- adjust goals, frameworks, and indicators as new insights are gained
- promote development of collective learning and feedback to decision-making

## 10. INSTITUTIONAL CAPACITY

Continuity of assessing progress toward sustainable development should be assured by:

- clearly assigning responsibility and providing ongoing support in the decision-making process
- providing institutional capacity for data collection, maintenance, and documentation
- supporting development of local assessment capacity

# Appendix 2: The consumption-land-use matrix

| | **Land-Use Categories** | | | | | | |
|---|---|---|---|---|---|---|---|
| **Consumption Categories** | **A Energy** | **B Built up** | **C Garden** | **D Crop** | **E Pasture** | **F Forest** | **Total** |
| **10 Food**<br>11 Plant Products<br>12 Animal Products | A10 | B10 | C10 | D10 | E10 | F10 | |
| **20 Housing**<br>21 Construct./maint.<br>22 Operation | A20 | B20 | C20 | D20 | E20 | F20 | |
| **30 Transportation**<br>31 Motorised private<br>32 Motorised public<br>33 Transport of goods | A30 | B30 | C30 | D30 | E30 | F30 | |
| **40 Consumer goods**<br>41 Packaging<br>42 Clothing<br>43 Furniture/app.<br>44 Books/magazines<br>45 Tobacco/alcohol<br>46 Personal Care<br>47 Recreation equip.<br>48 Other goods | A40 | B40 | C40 | D40 | E40 | F40 | |
| **50 Resources in services received**<br>51 Defence<br>52 Education<br>53 Health care<br>54 Social services<br>55 Tourism<br>56 Entertainment<br>57 Bank/insurance<br>58 Other services | A50 | B50 | C50 | D50 | E50 | F50 | |
| **60 Total** | **A60** | **B60** | **C60** | **D60** | **E60** | **F60** | |

Source: Wackernagel and Rees, 1996.

# Appendix 3: Typical components involved in the component-based approach to ecological footprinting

The following presents a list of component impacts usually considered on an annual basis, when undertaking a component-based ecological footprint analysis of a region or organisation (source: Chambers et al., 2000, p75).

**COMPONENTS**

- Electricity – domestic
- Gas – domestic
- Electricity – other
- Gas – other
- Recycled waste glass
- Recycled waste paper and card
- Recycled waste metals
- Recycled waste compost
- Recycled – other domestic waste
- Waste – household
- Waste – commercial (paper, metal etc)
- Waste – inert (brick, concrete etc)
- Food
- Wood products
- Travel by car
- Travel by bus
- Travel by train
- Travel by air
- Road haulage
- Rail freight
- Sea freight
- Air freight
- Water

# Appendix 4: Calculations involved in determining KBRV's LPG, Unleaded and Diesel fuel intensities

LPG intensity (i) = GJ/\$

Price (p) = 0.37\$/L × Price Index (PI, 1994) / PI (2001) = 0.24\$/L

Energy content (e) = 25.7 MJ/L

i = e/p = (25.7 MJ/L) / (0.24 \$/L) = 107.08 MJ/\$ = 0.107GJ/\$

Unleaded intensity (i) = GJ/\$

p = 0.90\$/L × PI (1994) / PI (2001) = 0.58\$/L

e = 34.2 MJ/L

i = e/p = (34.2 MJ/L) / (0.58\$/L) = 58.97 MJ/\$ = 0.059GJ/\$

Diesel intensity (i) = GJ/\$

p = 0.84\$/L × PI (1994) / PI (2001) = 0.54\$/L

e = 38.6 MJ/L

i = e/p = (38.6MJ/L) / (0.54\$/L) = 71.48 MJ/\$ = 0.071 GJ/\$

# Appendix 5: Input-output classification (IOPC) industries used in the analysis for KBRV

(Rem. = remainder)

**Table 1: Input-output classification industries used in the analysis for KBRV**

| IOPC category number | Industry Description |
|---|---|
| 0101 | Sheep and shorn wool |
| 01210020 | Barley, unmilled |
| 01210040 | Rice, in the husk |
| Rem. 0102 | Wheat, legumes for grain, oilseeds, oats and other grains |
| 0103 | Beef cattle |
| 0104 | Dairy cattle and untreated whole milk |
| 0105 | Pigs |
| 0106 | Poultry and eggs |
| 01610010 | Sugar cane |
| 01620010 | Seed cotton |
| Rem. 0107 | Vegetable and fruit growing, hay, plant nurseries, flowers |
| 0200 | Services to agriculture, ginned cotton, shearing, hunting and trapping |
| 03020010 | Softwoods, conifers |
| 03020020 | Hardwoods, brushwoods, scrubwoods, hewn and other timber |
| Rem. 0300 | Forestry and services to forestry |
| 0400 | Commercial fishing |
| 11010010 | Black coal |
| 12001920 | |
| 12000011 | Crude oil |
| 12000024 | Natural gas |
| 12000027 | Liquefied natural gas, liquefied natural petrol |
| Rem. 1100 | Brown coal, lignite |
| 1301 | Iron ores |
| 13120010 | Bauxite |
| 13130010 | Copper |
| 13140010 | Gold and lead |
| 13170010 | |
| 13170020 | Silver and zinc ores |
| Rem. 1302 | Uranium, nickel, tin, manganese and other non-ferrous metal ores |
| 1400 | Sand, gravel and other construction materials; gemstones and other mining |
| 1500 | Exploration and services to mining |
| 2101 | Meat and meat products |
| 2102 | Dairy products |
| 2103 | Vegetables, fruit, juices, jams and other fruit and vegetable products |
| 2104 | Oils and fats |
| 2105 | Flour, cereal foods, rice, pasta and other flour mill products |
| 2106 | Bread, cakes, biscuits and other bakery products |
| 2107 | Confectionery |

**Table 1 continued**

| | |
|---|---|
| 2108 | Raw sugar, animal feeds, processed seafoods, coffee, spices and other food products |
| 2109 | Soft drinks, cordials and syrups |
| 2110 | Beer and malt |
| 2111 | Wine and spirits |
| 2112 | Tobacco products |
| 2201 | Processed wool, textile fibres, yarns and woven fabrics |
| 2202 | Carpets, curtains, tarpaulins, sails, tents, napkins, tampons and other textile products |
| 2203 | Knitting mill products |
| 2204 | Clothing |
| 2205 | Footwear |
| 2206 | Leather and leather products |
| 2301 | Sawn timer, woodchips and other sawmill products |
| 2302 | Plywood, wall and window frames, doors, boards and other wood products |
| 2303 | Pulp, paper and paperboard |
| 2304 | Paper containers and products |
| 2401 | Printing, stationery and services to printing |
| 2402 | Newspapers, books, periodicals, recorded media and other publishing |
| 25100010 | Automotive petrol |
| 25100020 | Kerosene and aviation jet fuel |
| 25100030 | Gas oil, fuel oil |
| Rem. 2501 | Petroleum bitumen, refinery LPG and other petroleum and coal products |
| 25310040 | Mixed fertilisers |
| Rem. 2502 | Basic chemicals |
| 2503 | Paints |
| 25430010 | Pharmaceutical goods for human use |
| Rem. 2504 | Insecticides, pesticides, veterinary products and other agricultural chemicals |
| 2505 | Soap and other detergents |
| 2506 | Cosmetics and toiletry preparations |
| 2507 | Adhesives, inks, polishes, explosives and other chemical products |
| 2508 | Rubber products |
| 2509 | Plastic products |
| 2601 | Glass and glass products |
| 2602 | Bricks and other ceramic products |
| 26310010<br>26331920 | Cement |
| 26310020 | Lime |
| Rem. 2603 | Concrete and mortar |
| 2604 | Plaster and other concrete products |
| 2605 | Mineral and glass wool, abrasives and other non-metallic mineral products |
| 2701 | Basic iron and steel, pipes, tubes, sheets, rods, bars, rails, fittings and castings |

**Table 1 continued**

| | |
|---|---|
| 27210010<br>27220010 | Alumina, aluminium alloys and aluminium recovery |
| Rem. 2702 | Copper, silver, lead, zinc, nickel and other non-ferrous metal recovery; all basic non-ferrous metal, pipe, tube, plate, sheet, bar, strip, wire and other products |
| 2703 | Frames, mesh and other structural metal products |
| 2704 | Sheet containers and other sheet metal products |
| 2705 | Nuts, bolts, nails, springs, non-ferrous fittings, plate containers, metal blinds, locks, tools, wire fabric, cutlery, munitions, boilers and other fabricated metal products |
| 2801 | Motor vehicles and parts, other transport equipment |
| 2802 | Ships and boats |
| 2803 | Railway equipment |
| 2804 | Aircraft |
| 2805 | Photographic, optical, medical, radio and scientific equipment, watches |
| 2806 | Electronic equipment, photocopying, vending and gaming machines |
| 2807 | Household appliances and hot water systems |
| 2808 | Cable, wire, batteries, lights, transformers, motors and other electrical equipment |
| 2809 | Agricultural, mining and construction machinery, material handling equipment |
| 2810 | Pumps, bearings, air conditioning, printing, wood and metal working, food processing and other machinery and equipment |
| 2901 | Prefabricated buildings |
| 2902 | Furniture |
| 2903 | Coins, jewellery, sporting goods, toys, signs, brushes and other manufacturing |
| 3601 | Electricity supply |
| 3602 | Gas production and distribution |
| 3701 | Water supply, sewerage and drainage services |
| 4101 | Residential building, construction, repair and maintenance |
| 4102 | Non-residential buildings, roads, bridges and other construction |
| 4501 | Wholesale trade |
| 5101 | Retail trade |
| 5401 | Repairs of motor vehicles, agricultural, construction and other machinery |
| 5402 | Repairs of household and business equipment, wholesale and retail repairing |
| 5701 | Accommodation, cafes and restaurants |
| 61200010 | Bus and tramway transport services |
| 61230010 | Taxi and hired car with driver |
| Rem. 6101 | Road freight transport services |
| 62000030 | Railway passenger transport services |
| 65000010 | Pipeline transport services |
| 65000020 | Cable car, chair lift, monorail and over-snow transport |
| Rem. 6201 | Railway freight transport services |
| 6301 | Water transport |
| 6401 | Air and space transport |

**Table 1 continued**

| | |
|---|---|
| 6601 | Travel agencies, forwarding, storage, parking and other services to transport |
| 7101 | Communication services |
| 7301 | Banking |
| 7302 | Money market corporation, credit union, building society and other non-bank finance |
| 7303 | Financial asset investors and holding company services |
| 7401 | Insurance |
| 7501 | Security broking and dealing and other services to finance, investment and insurance |
| 7701 | Ownership of dwellings |
| 7702 | Property developer, real estate, plant and vehicle hire and other property services |
| 7801 | Scientific research, technical and computer services |
| 7802 | Legal, accounting, marketing and business management services |
| 7803 | Typing, copying, mailing, cleaning, staff placement and other business services |
| 8101 | Government administration |
| 8201 | Defence |
| 8401 | Education |
| 8601 | Health services |
| 8701 | Childminding and other community care services |
| 9101 | Motion picture, radio and television services |
| 9201 | Libraries, parks, museums and the arts |
| 9301 | Sport, gambling and recreational services |
| 9501 | Hairdressing, goods hiring, film processing, laundry and other personal services |
| 96340010 | Sanitary and garbage disposal services |
| Rem. 9601 | Police, interest groups, fire brigade, corrective and other services |

# Appendix 6: Formulation of the Multiplier matrix

This study utilised information from a comprehensive assessment conducted by Lenzen and Murray (2001) of the land and emission requirements of the production chain to calculate the land disturbance (that is, the combined land disturbance of the 8 land types, refer to section 2.3.4c), of each industry classified in the IOPC. This involved:

- the allocation of land area estimates,
- the assessment of land cover to classify land areas into 1 of 6 (actual) land type categories – namely consumed, degraded, replaced, significantly disturbed, partially disturbed and slightly disturbed, and
- the assessment of emissions generated to satisfy the remaining energy and emissions land categories of projected land disturbance (due to climate change).

Due to the constraints of an intellectual property agreement between USC and the University of Sydney, the production land and emission requirements and subsequent land disturbance multipliers used within this study cannot be shown.

This information was used to develop the F matrix ($f \times n$) of intensity factors, representing the land and emission requirements ([row] $i= 1, ....f$), per unit of output for each IOPC industry ([column] $j=1, ....n$). In other words, it is assumed that industry j has a fixed relationship between the amount of carbon dioxide produced, for example, and the output that j produced. The industry output data was obtained from the direct requirements (A) matrix of coefficients, which will be described in the forthcoming sections.

## (a) The Australian input-output tables

The 1994-95 Australian input-output tables, the most current available at the commencement of this study, provided the base for the input-output analysis model. The tables were developed by the Australian Bureau of Statistics, as part of the Australian national accounts, and provide detailed information about the supply and disposition of products in the Australian economy and about the structure of and inter-relationships between Australian industries (ABS 5209.0, 1999).

The entries in the input-output tables can be named $x_{ij}$, where *i* is the industry from which the flow comes and *j* is the industry to where it goes. The row entries in the table describe the way in which the total sales of each industry are allocated over the remaining industries in the Australian economy, and the column entries describe the inputs (or purchases) of each industry in relation to all other industries (Dixon, 1996). As each value in any row is also a value in a column, the output of each industry is shown to be an input into some other industry – in other words an inter-industry exchange, as represented by the shaded portion in Table 1. The final demand column represents the sales to consumers, namely households, government and foreign trade.

**Table 1: A sample of the 1994-95 Australian input-output table ($ million)**

| **use (*j*)**<br>**supply (*i*)** | **2101** | **2102** | **2103** | **2104** | **2105** | **FINAL DEMAND** |
|---|---|---|---|---|---|---|
| **2101**: Meat and meat products | 171.1 | 0.8 | 12.7 | 41.1 | 1.5 | |
| **2102**: Dairy products | 2.5 | 807.4 | 19.1 | 3.4 | 44.5 | |
| **2103**: Fruit and vegetable products | 0.4 | 1.3 | 158.2 | - | 15.1 | |
| **2104**: Oils and fats | - | 0.1 | 15.1 | 176.3 | 16.7 | |
| **2105**: Flour and cereal foods | 22.3 | 3.0 | 69.9 | 1.4 | 337.8 | |
| **Total value of purchases** | | | | | | |

Therefore, each producing industry within the Australian economy has a certain amount of output that may be used (a) within the industry, (b) sold as inputs to other producing industries, or (c) sold for final demand to consumers. The direct requirement coefficients ($a_{ij}$ forming the A matrix) were calculated from the Australian 1994-95 input-output tables (ABS, 1999), which describes the intermediate demand of each industry for other industry commodities per unit of (industry) output.

This involves the division of all the industry entries (for inter-industry transactions) in any industry's column of the input-output table (for example 2101; meat and meat products) by the total value of sales for that industry. In other words, let $x_{ij}$ be the value of sales from the industry in row *i* to the industry in column *j*, and let $X_j$ be the total value of purchases by the industry in column *j*. The direct requirement coefficient ($a_{ij}$ ) therefore equals $x_{ij}/X_j$. Therefore, a direct requirement coefficient, $a_{ij}$, represents the amount of inputs *directly* required from one industry in order to produce 1 dollar's worth of output of another industry (Dixon, 1996).

As previously mentioned, the F matrix used data from the A matrix (n × n) to determine the unit of industry output (j = 1…..n). An element of the *F* matrix, $F_{ij}$, can therefore be seen as a direct multiplier for the amount of production factors (land and emissions) *i* required by industry *j*. In other words, only direct production factor requirements, and not indirect requirements, are included. For example, consider an increase in the final demand for products of industry A. This will result in direct increases in purchases from industries B, C, D and so on. However, in addition, when industry B sells more of its output to industry A, industry B's demand for the products of industries C, D (etc.) will likewise increase, with these effects spreading throughout the production chain. This 'backward purchasing' is known as the indirect requirements (Bullard et al., 1978).

Consequently industries are linked, both directly and indirectly, with each other. Therefore, to comprehensively assess the total production factor requirements of the production chain, indirect relationships must be included. This is achieved via the multiplier matrix (M), which incorporates final demand via the total requirements matrix, or the Leontief Inverse.

## (b) The construction of the multiplier matrix (M)

The overall output x ($n \times 1$) of all IOPC industries ($i = 1, \ldots, n$) can be described as the sum of intermediate demand (that is, the direct requirements detailed in the A matrix) and final demand (the indirect requirements):

$$x = Ax + y \tag{1}$$

where y is a vector (n × 1) of final demand from IOPC industries $i = 1, \ldots, n$ (Lenzen, 2001).

Technically solving for the overall output x produces:

$$x = (I - A)^{-1} y \tag{2}$$

where I represents the $n \times n$ identity matrix (a matrix with left to right diagonal elements equalling 1 and the remainder 0) and $(I - A)^{-1}$ is called the Leontief Inverse.

The Leontief Inverse elements measure the direct and indirect output levels from each producing industry of the Australian economy required to satisfy given levels of final demand (Lenzen, 2001). The equation is the result of an iterative process that reveals the progressive adjustments of output to (indirect) final demand and direct input requirements, meaning that it can be expanded to the infinite series of inter-industrial transactions:

$$x = (I + A + A^2 + A^3 + \ldots + A^{n-1})\, y \tag{3}$$

Therefore, to assess the indirect and direct production (land and emission) requirements, the Leontief Inverse must be applied. This was achieved by arranging the F matrix (f × n) in rows *underneath* the A matrix (n × n) and inverting both, as initially performed by Leontief (1970). This results in a multiplier matrix where:

$$M = F \times (I - A)^{-1} \tag{4}$$

In contrast to the F matrix, the multiplier matrix contains <u>total multipliers</u>, that is the amount of production factors (land and emissions) *i* directly and indirectly required in all industries to produce a unit of final demand from industry *j*. This multiplier matrix M was then used to calculate the off-site production factor requirements (that is, land and emissions) embodied in all inputs to KBRV's operation.