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Southern Red Meat Production – a Life Cycle Assessment

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Abstract

As a major land manager and source of significant greenhouse emissions, the red meat industry could have significant opportunities to enhance the environmental performance of the Australian economy. To achieve optimal environmental outcomes and target management interventions, managers and policy makers need performance information based on best practice data acquisition and analysis. Environmental life cycle assessment (LCA) is an information tool offering an holistic perspective of the environment and the technical system being assessed, and it is for this reason that it is becoming increasingly commonplace in industrial and agricultural management.

Detailed process analysis of farm resource use and productivity was complimented by input-output analysis of service inputs in a hybrid LCA. This report addresses environmental performance indicators including: energy use; global warming potential; solid waste production; eutrophication potential; soil acidification potential and nutrient balances (nitrogen, phosphorus and potassium). The energy and global warming results are comparable with previously published work while the other indicators are not routinely reported for red meat LCAs. While the underlying data for water use are consistent with published results, we demonstrate the influence of different accounting approaches on the results and suggest that approaches that uncritically include rainfall produce counter-intuitive results.

This project enhances the quality of information available to policy makers and others who want to know the answer to questions like: “What is the carbon footprint of red meat?”, “How much energy is used in making red meat?” and “Is much waste produced?” The project also tested an improved suite of agricultural performance indicators for assessing natural resource management issues in LCA.

Executive Summary

Meat and Livestock Australia (MLA) engaged the Centre for Water and Waste Technology (CWWT) in the School of Civil and Environmental Engineering at UNSW and FSA Consulting to produce an environmental life cycle assessment (LCA) of red meat production. The project investigated three supply chains:

1. a sheep meat supply chain in Western Australia;
2. a premium export beef supply chain in southern NSW; and
3. an organic beef producer in Victoria.

Data were collected for the 2002 and 2004 calendar years for each supply chain. Primary data were obtained on each chain via site visits and reviews of information systems used by the individual property managers. Environmental indicators were selected at a workshop of project stakeholders including MLA officers and red meat producers. This report presents the results of the LCA work undertaken using these data, and discusses associated methodological issues.

This study is the first detailed LCA of red meat production in Australia. It combines detailed process-based LCA with high level input-output analysis to present a more accurate and complete picture of the environmental profile of supply chains than is feasible using either process LCA or input-output analysis in isolation.

The global warming potential of the three supply chains ranged from 6.8 to 11 kg CO_2-e per kg HSCW. The highest value was for the organic beef supply chain and the lowest was for the sheep meat supply chain. The presence of a feedlot in the premium export beef supply chain reduced that supply chain's greenhouse emissions – the lower enteric methane emissions resulting from more efficient feed conversion outweighed the additional carbon dioxide emissions associated with feed production.

Energy use varied between 24 and 30 MJ per kg HSCW. The meat processing facility generally constituted most of the energy demand in all three supply chains. Diesel consumption for stock transport did not contribute significantly to the total figures.

Estimates of water use that include rain used to provide drinking water, grow fodder and other feedstuffs for red meat production range from 15,000 to 105,000 L/kg in the literature[1]. When we include rain our estimates range from 7,387 to 57,634 L/kg HSCW post processor depending on the supply system and production year. When rain is excluded but significant irrigation occurs, the amount of water use estimated in the literature drops to a value in the thousands of litres. Most Australian red meat production does not involve significant irrigation. Without significant irrigation or rainfall included in the calculus, average water use falls to the hundreds of litres per kilogram. Our estimates range from 18 to 540 L/kg (the higher figures reflecting the production of irrigated feedsstuffs in our NSW example) and are consistent with the literature data.

[1] Note that it is not always clear from the reports as to stage of the supply chain at which the masses are computed, nor whether it is expressed as boneless.

The eutrophication potential exhibited a large range from 0.13 to 1.2 kg O_2 depletion per kg HSCW. Low estimated soil erosion at the grazing property helped the sheep meat supply chain outperform the other two chains for this indicator.

Reliable data on solid waste generation were particularly hard to obtain. We produced some estimates using two bases – including and excluding the organic wastes produced at the meat processing works. The former estimates range from 0.042 to 0.065 kg/kg HSCW. If the organic wastes are excluded, the range contracts to 0.021 to 0.039 kg/kg HSCW.

This work advanced the methodological development of life cycle impact assessment (LCIA) by examining the feasibility of novel indicators for natural resource management issues relevant to agricultural LCA. Where existing methodologies were followed the results are consistent with other work in agricultural LCA. Where new indicators were developed, this project presents results that can be benchmarked against other production systems as the application of these indicators progresses. It also offers insights into the variability of the three case study supply chains across different regions of Australia.

The nutrient management indicators suggested that the nitrogen (N) account for the grazing properties varied from a 0.028 kg N per kg HSCW loss to a 0.17 kg per kg HSCW accumulation of N on farm. The main contributors to these changes are growth of N-fixing pastures (or lack thereof) and the application of fertilisers.

The sheep and premium export supply chains also accumulated between 0.0085 and 0.019 kg phosphorus (P) per kg HSCW. Losses of 0.0039-0.0051 kg P per kg HSCW in the organic beef supply chain reflect a strategic decision by the property manager. This manager also uses mineral additives to significantly increase potassium (K), resulting in an accumulation of 0.095 kg K per kg HSCW. This is compared with absolute values at least a factor of four lower for the other supply chains.

This management activity is also reflected in the soil acidification indicator, which in 2002 showed a farm surplus of 630 kg $CaCO_3$-equivalent per hectare and year, while the other supply chains all showed a deficit of less than 23 kg $CaCO_3$-e/ha.y. In this report we argue that soil acidification, and the soil erosion potential indicator, are best described on an area basis rather than by the kg HSCW produced, although both results are shown in the report. Soil erosion potential also varied across the three supply chains, with the NSW chain exhibiting the highest erosion potential due to the characteristics of the soils and topography.

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List of Abbreviations

a	annum
ABS	Australian Bureau of Statistics
AGO	Australian Greenhouse Office
CO_2-e	Carbon dioxide equivalents
DRDC	Dairy Research and Development Corporation
GWP	Global Warming Potential
HSCW	Hot Standard Carcase Weight
IOA	Input-Output Analysis
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NGGIC	National Greenhouse Gas Inventory Committee
NLWRA	National Land & Water Resources Audit
UNEP	United Nations Environment Programme

1 Introduction

1.1 Project Description

Meat and Livestock Australia (MLA) engaged the Centre for Water and Waste Technology and FSA Consulting to perform an environmental life cycle assessment (LCA) of red meat production in Australia. The aim was to obtain relatively detailed (process-based) life cycle inventory (LCI) data for several supply chains.

The first phase of the project was a literature review of LCA data and approaches relevant to red meat production. This review is briefly summarised in this report.

The second phase involved LCI compilation. The project team has successfully liaised with three supply chains representing different parts of southern Australia: a sheep meat supply chain in Western Australia; a sheep and cattle based supply chain in southern NSW and an organic beef producer in Victoria. Data were collected for the 2002 and 2004 calendar years for each of these three supply chains. We would like to extend this work by considering at least one northern supply chain.

The third phase was a dialogue with project stakeholders regarding priorities in life cycle indicator enhancement. This is summarised in Section 2.2 of this report.

The fourth phase was analysis of the LCA results using a combination of the GaBi software package and CWWT's proprietary input-output analytical model. This report provides detailed analysis of the model results and considers some of the methodological issues encountered at various points in the study. It will be the basis for scientific publication of the results.

1.2 Background

The red meat industry is one of Australia's largest agricultural industries, with a gross value of production in excess of $9.5 billion (2006/2007). Australia is the second largest beef exporter and second largest sheep meat exporter in the world (MLA 2007; MLA 2007). The Australian red meat industry, like many other Australian primary industries, is coming under increasing pressure from both the community and government to document and justify its impact on the environment. Environmental management will also be important at an enterprise level in the future as it is likely to play a major role in determining competitive advantage, especially in export markets.

MLA has commissioned many research projects over the last decade to improve the environmental performance of the red meat industry. The red meat processing sector, in particular, has been the subject of intensive environmental research aimed at improving factory wastewater treatment, benchmarking environmental performance and quantifying greenhouse gas emissions. Many of the research outcomes and recommendations have been adopted by the industry through programmes like the Environmental Management Systems Manual and Eco-Efficiency Manual (MLA 2002). Research in the grazing sector has focussed primarily on improving profitability, productivity and sustainability. The results from the highly successful Sustainable Grazing System (SGS) program have been widely disseminated throughout the industry (MLA 2003) and the scientific literature (e.g. *Aust. J. Exp. Ag.* (2003) 43). Testing the SGS in a national experiment showed it to be more profitable and sustainable than other grazing systems, with improved pasture composition and persistence, increased ground cover, lower acidification, salinity, erosion, better water quality and increased biodiversity (MLA 2003). SGS and its subsequent education programmes (e.g. PROGRAZE) form the basis of MLA's current EDGEnetwork workshops. These workshops aim to improve producers understanding of the management of grazing, fertiliser applications, soils, water resources, pastures, weeds and biodiversity. MLA has also funded a significant amount of environmental research for the lot feeding sector (e.g. FLOT.132 – 2020 Vision of the beef industry; FLOT.328; Environmental Sustainability Assessment of the Australian Feedlot Industry).

While both the livestock production and processing sectors are achieving environmental successes, there is an absence of data on the environmental impacts of the red meat industry as a whole. The red meat production and processing industry are only two processes in the supply chain for the delivery of red meat to domestic and export markets. Without quantification of the impacts of dependent industries – for example, feed supplement industries such as grain, hay, molasses and oilseed/protein meal; transportation; fertiliser; pesticides and herbicides; energy and packaging – the industry is not in a position to optimise the environmental impacts of the entire system. Sectors of the supply chain beyond livestock production and meat processing, like transportation, feed and energy could play a significant role in the overall environmental impact. A whole of life cycle view offers the potential to identify areas where gains will be possible and hence the opportunity to help bring about an overall improvement in industry environmental (and business) performance. For example, there may be opportunities for producers to collectively improve resources management through engagement with suppliers, e.g. feed, fertiliser and transportation. Also, the industry can avoid creating new environmental problems through a greater understanding of their whole system. This is particularly valuable since "solving" an environmental problem in one sector (e.g. grazing property) to the detriment of another sector (e.g. feed supplementation) may not be sustainable in the long term. There may be opportunities for processors to improve their environmental performance through product stewardship/supply chain management, i.e. red meat supply, energy, packaging, transport and distribution.

1.3 Meat and related LCAs

Consumers are beginning to make product selection choices on the basis of environmental considerations and the environment is an area of potential non-tariff trade barriers to the international market. MLA's marketing of Australian lamb and beef in the USA, Japan and the Middle East is based on a "clean, green and safe" image. With increasing competition for export markets, it is likely that the industry will be called on to quantitatively justify its green image at some time in the future. LCA is a useful environmental tool for this purpose as it can quantify the environmental impacts of an entire industry. LCA has already been used by governments in their decisions on the development of industry legislation and will continue to be used in the future. Examples are several European Directives on packaging material, chemicals, waste management sector and take back schemes for automotives.

The importance of LCA for meat products is recognised in Europe and Japan with LCAs having been conducted on pork (Basset-Mens and van der Werf 2005; Eriksson 2005), lamb (Schlich and Fleissner 2005) and beef (Cederberg and Mattsson 2000; Haas et al. 2001; Ogino et al. 2004; Chassot et al. 2005). Related LCAs on leather (Canals *et al*., 2002) and particularly milk and dairy products (Blonk and van Zeijts 1997; Cederberg and Mattsson 2000; Haas et al. 2001; Berlin 2002; Eide 2002; Svenskmjölk 2002; de Boer 2003; Hospido et al. 2003; Lundie et al. 2003; Casey and Holden 2005) have been the subject of intense investigation. Beef in northern Europe is primarily sourced from dairy cattle and many studies grapple with the complexity of allocating environmental impacts to milk, meat and other co-products such as leather. In all cases, feed choice and feed production systems are the major contributors to the environmental impact.

Grains are an important feed component in the lot feeding sector of the meat industry. While most grains are produced from dryland crops in Australia rather than using significant irrigation resources, there is a substantial potential ecotoxicity burden associated with the use of pesticides and herbicides during production and storage (Narayanaswamy et al. 2005). In the Australian Dairy LCA, feed supplementation with grains represented a primary source of ecotoxicity in milk and thus in grinding beef for export to the USA. A recent Swiss study by Chassot et al. (2005) compared pasture to lot feeding beef and concluded that the differences between the two systems were relatively minor except for the considerably greater ecotoxicity impacts for the feedlot system resulting from greater fertiliser use.

Oilseeds and protein meals are important feed supplements in the lot feeding sector, with whole cottonseed, cottonseed meal and other protein meals frequently included in feedlot cattle diets. These materials are also commonly used in drought feeding situations on farms. An LCA of rapeseed oil production for use as a chainsaw lubricant has been conducted in the UK (Wightman et al. 1999) and, more recently, Australian LCI data for canola oil production were compiled by Narayanaswamy *et al*. (2004).

Wood et al. (2007) examined organic and conventional farming practices in Australia using a hybrid input-output LCA methodology. Their examination of meat, grain, fruit and vegetable production showed that while the direct on-site use of energy and materials of the organic farms exceeded those of the conventional farms, organic farming performed better when the entire supply chain was considered, except in the case of sheep and wheat production.

As part of an MLA project FLOT.328 ("Environmental Sustainability Assessment of the Australian Feedlot Industry") conducted in parallel to this project, the research team undertook a detailed review of literature on water use in feedlot processes (FSA Consulting 2005). This study identified a number of information sources that can be used to enhance the LCI analysis of water use on cattle grazing properties, including research by Winchester & Morris (1956), Hicks *et al*. (1988), Sanders *et al*. (1994) and Parker *et al*. (2000).

A similar review was undertaken on energy use and greenhouse gas emissions from Australian feedlot operations (FSA Consulting 2005) also as part of the FLOT.328 project. This study identified information sources that can be used to enhance the LCI analysis of energy use and greenhouse gas emissions of cattle grazing properties, including research by Lipper *et al*. (1976), Sweeten & McDonald (1979), Schake *et al*. (1981), Sweeten *et al*. (1986), Casada & Safley (1990), Sweeten (1990), Safley *et al*. (1992), Johnson & Johnson (1995), Steed & Hashimoto (1995), IPPC (1997), Harper *et al*.

(1999), Hegarty (1999), Hao *et al*. (2001), Hegarty (2001), Woodbury *et al*. (2001), NGGIC (2002), Page (2003), Tedeschi *et al*. (2003), AGO (2004), NGGIC (2004), ABS (2005), McGrabb (2005) and QDPI&F (2005).

1.4 Australian Dairy LCA

In Australia, both Dairy Australia and the Grains Research and Development Corporation have made significant investment in life cycle analysis and are using the results to target environmental improvements in their respective industries (Nicol 2005). Small individual Australian dairy farm case studies have found that the environmental impacts associated with the provision of feed are substantial (Wegener 1999; Chen et al. 2005). A preliminary Australian meat LCA was conducted for the Cannon Hill meat processing facility (Gibson 2002; Renouf 2002). The work primarily quantified water use, energy use and greenhouse gases for the processing site. Sugar production and electricity generation from sugarcane bagasse was also studied using LCA (Renouf 2002; Renouf 2002).

The Australian Dairy LCA has direct relevance to MLA as it forms the primary LCI for the US export grinding beef market. The dairy farms located in southern Australia fall into three major groups (DRDC 2001):

- Murray Dairy: >90% irrigation, 1.4 t feed/cow/yr, 4,700 L milk/cow/yr.
- Gippsland Dairy: ~50% irrigation, 0.8 t feed/cow/yr, 4,600 L milk/cow/yr.
- Western Victoria: <20% irrigation, 1.1 t feed/cow/yr, 4,800 L milk/cow/yr.

While the milk productivity for each of the regions is similar, the environmental concerns for each of the regions is quite different from the high water use and salinity problems in the Murray, high eutrophication in Western Victoria and water scarcity and deteriorating waterway quality in the Gippsland region (DRDC 2001).

2 Life Cycle Assessment Methodology

2.1 Overview

Life Cycle Assessment (LCA) is a form of cradle-to-grave systems analysis developed for use in manufacturing and processing industries to assess the environmental impacts of products, processes and activities by quantifying their environmental effects throughout the entire life cycle. LCA can be used to compare alternative products, processes or services; compare alternative life cycles for a product or service; and identify those parts of the life cycle where the greatest improvements can be made. An international standard has now been developed to specify the general framework, principles and requirements for conducting and reporting LCA studies (Blamey et al. 1998). LCA differs from other environmental tools (e.g. risk assessment, environmental performance evaluation, environmental auditing, and environmental impact assessment) in a number of significant ways. In LCA, the environmental impact of a product or the function a product is designed to perform is assessed, the data obtained are independent of any ideology and it is much more complex than other environmental tools (UNEP 1996). As a system analysis, it surpasses the purely local effects of a decision and indicates the overall effects.

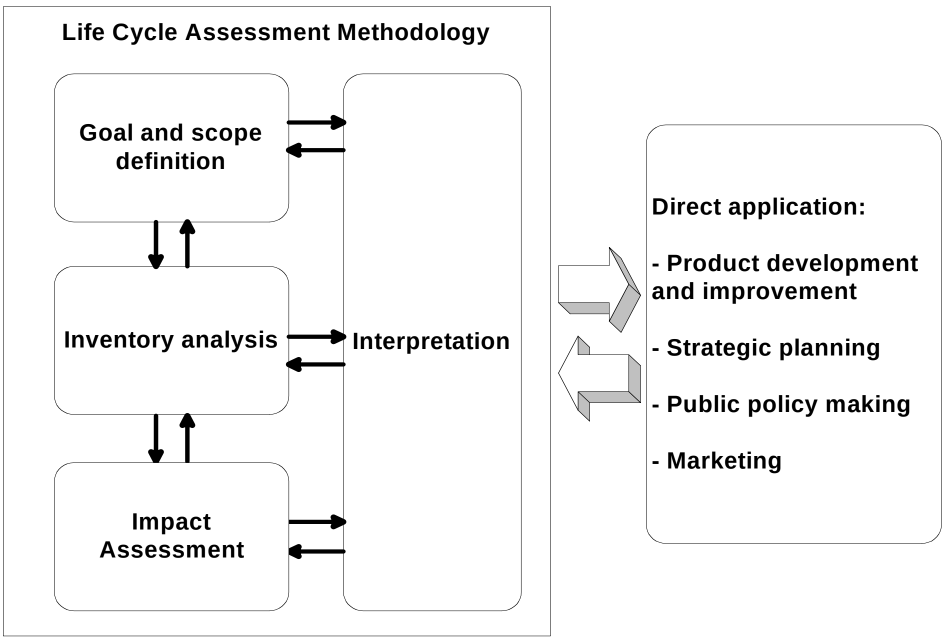

Figure 1: General framework for LCA and its application (ISO 14040, 1999)

There are four phases of LCA:

- *Goal and Scope Definition* defines the goal, functional unit and associated system to be studied.

- *Inventory Analysis* analyses all process inputs and outputs. It involves modelling unit processes in the system, considered as inputs from the environment (resources, energy) and outputs (product, emissions, waste) to the environment. Allocation of inputs and outputs needs to be clarified where processes have several functions (for example, one production plant produces several products). In this case, different process inputs and outputs are attributed to different goods and services produced. An extra simplification used by LCA is that processes are generally described without regard to their specific location and time of operation.

- *Impact Assessment* makes results from the inventory analysis more manageable and understandable in relation to natural environment, human health and resource availability.

- *Interpretation* involves evaluating inventory analysis and impact assessment outcomes against the study's goal.

An LCA is essentially a quantitative study. However, not all environmental impacts can be quantified due to a lack of data or inadequate impact assessment models. A guide to decisions can then be made through qualitative use of LCA and other tools for supply chain analysis. Quantitative analysis requires standardised databases of main processes (energy, transport) and software for managing the study's complexity.

2.2 Expanding the LCI using Input-Output Analysis

Input-output analysis (IOA) is a mathematical modelling technique based on a model of the national economy that can be used to 'fill in the gaps' of an LCA when detailed process-based engineering LCI data are unavailable.

The production systems in this LCA were studied in detail to include as much physical data as possible (as presented in previous sections). However, it is never possible to include the entire system. For example, how much water is consumed during the manufacturing of vehicle repair materials for the feedlot? Collecting such detailed data would be impractical and expensive. Therefore, LCA practitioners generally identify a system boundary based on experience in LCA and dialogue with the owners or managers of the system under study. Depending on the topic and purpose of the LCA, this may not be a problem, but in some cases it can lead to underestimation of the material or energy budget of a production system.

IOA has been proposed as an alternative to conventional LCA, because it overcomes these limitations. IOA involves constructing a mathematical model of the national economy and the environmental impacts of industries. The model can be used to estimate the environmental impacts of any producer based on that producer's expenditure patterns. However, IOA would not be as accurate as LCA in describing on-farm impacts.

Recent research in this area shows that the most accurate results can be achieved by combining the two techniques – using the precision of LCA to get a detailed picture of the main industry being examined, and using IOA to 'fill in the gaps' regarding some of the supporting industries. The research team at CWWT developed a sophisticated hybrid model to improve the accuracy of LCA by incorporating IOA results into it.

2.3 Life Cycle Impact Assessment – Suitability of Impact Models

At the start of this project, MLA identified a number of natural resource management issues of concern to the red meat industry, ranging from energy efficiency to feral animals (Table 1). Some of the natural resource management (NRM) issues can be modelled using the default list of LCA impact categories (de Haes et al. 1999; Guinee 2002). These include water quality, water use efficiency, eutrophication, energy use efficiency and greenhouse gas emissions and solid waste. However, conventional LCA impact models do not adequately cover the remaining NRM issues.

A workshop was held on the 18th of August 2006 to engage project stakeholders in a process of information sharing and prioritisation of NRM issues for this project. Considering the available models and the significance of the issues, the workshop prioritised the items in Table 1 marked with an asterisk.

Strategies for addressing these nonconforming NRM issues within a LCA framework are outlined below.

Table 1: Summary of environmental issues of concern for MLA (* denotes issues able to be modelled using conventional LCA input categories)

NRM Issues of concern
Water quality*
Water use efficiency*
Salinity
Soil erosion*
Nutrient management*
Soil acidification*
Weeds
Feral animals
Biodiversity
Vegetation management
Energy efficiency & greenhouse gas emissions*
Solid Waste*

2.4 Efficient Water Use

On livestock grazing properties and feedlots, water uses include irrigation, stock drinking, feed processing, cattle washing and trough cleaning. Clearing land for grazing may increase runoff from properties, while installing small agricultural dams may reduce it. In this work, water use is defined consistent with the definition used by the Australian Bureau of Statistics (ABS 2004):

> *"… water extracted directly from the environment for use, [which] includes water from rivers, lakes, farm dams, groundwater and other water bodies. Some of this water is then distributed via a water provider to other water users. The volume of water used from rainfall is not in scope of the water account, unless it was stored and/or delivered before use. For example, rainfall directly onto a crop is not in scope for the water account. However, if rainfall is collected in a farm dam and then applied onto the crop, it is in scope and is included in the self-extracted water use figures.'*

This is consistent with the work of various other strategic environmental assessments in Australia (e.g. Foran et al. 2005) and overseas (e.g. Beckett and Oltjen 1993). Water is considered "used" if it is either transferred from its natural watercourse or extracted from underground aquifers. By definition, dryland cropping does not "use" water. Similarly, rain that collects in a small agricultural dam within the property and consumed in situ is not "used" unless it is pumped to a location outside the catchment of that dam.

On-farm water use was estimated in this project using data supplied by individual producers. A farm hydrological water balance was constructed to account for all water inputs and outputs. In addition, water use by suppliers of goods and services to the grazing property, feedlot and meat processing works was estimated during life cycle modelling. Water use was reported on in the previous report which is included as Appendix E.

2.5 Energy / Greenhouse

Energy consumption was estimated in this project from data supplied by individual producers. Data from the Australian Greenhouse Office (AGO 2004) were used to convert raw energy data (e.g. litres of diesel) into primary energy consumption (e.g. megajoules of primary energy). Primary energy is also referred to as "full cycle" energy and means, for example, that electricity consumption is not only related back to the coal burnt to generate it, but to the energy involved in obtaining the coal. Primary energy consumption is then compared with the production of beef in kg HSCW.

Greenhouse gas emissions were estimated on the basis of the energy consumption data obtained in the LCI phase of the project. Emissions due to livestock transport, commodity delivery, water supply, administration and effluent irrigation sectors are included in the life cycle impact assessment (LCIA) and the total data are normalised against kg HSCW production. Emissions from agricultural livestock production are, in this study and generally, calculated by multiplying estimates of activity levels (such as cattle numbers, diet composition and manure production) by emission factors drawn from the National Greenhouse Gas Inventory Committee (NGGIC 2004).

Global warming potential (GWP) is usually evaluated on a 20, 100 or 500 year timescale. For this study, the most commonly used timescale was selected - 100 years. The relative contributions of each greenhouse gas to GWP were estimated by using equivalence factors set in the most recent publication by the Australian Government (DCC 2008) rather than the latest from the Intergovernmental Panel on Climate Change (IPCC).

2.6 Solid Waste

Solid wastes generated on livestock grazing properties include tyres; chemical containers and drums; end-of-life vehicles and equipment; and organic waste (e.g. carcases, spoiled feed). Solid wastes are often disposed of in on-farm tips. Waste production by suppliers of goods and services was also included in the overall analysis. Manure was not considered a waste at the feedlot, where it is reused as a matter of course and does not leave the LCA system boundary. The data for the meat processing works are presented in two ways: considering the paunch and yard manure as wastes, and excluding it from the definition of waste.

In this LCA, wastes were assessed primarily from a resource use perspective. Waste production was estimated from the data supplied by individual producers and feedlot operators and, for meat processing works, from MLA (2002) data. The resources used to produce the waste materials, and the environmental impacts of that production, were incorporated in the life-cycle modelling. Waste is presented as the mass of solid waste produced per kg HSCW produced.

2.7 Nutrient Management

The nutrient balance was calculated using mass balance principles to estimate the nitrogen (N), phosphorus (P) and potassium (K) in major system inputs (incoming livestock, fertiliser, feedstuffs and other nutrient inputs) and outputs (e.g. outgoing livestock, wool and harvested product (e.g. hay, grain)) on an annual basis. The mass of each input or output category was, where possible, calculated from the farm records kept for each property. In the case of inputs and outputs less readily quantified in situ (N fixation by legume pastures, N leaching through the soil profile) estimates from the literature were used to calculate the values used in the balance. The data for nutrient inputs and outputs were collected during the initial grazing property surveys and from the literature. The assumptions used to calculate the N, P and K for the nutrient balance are described below, and a summary of the data is provided in Table 3 and Table 6 at the end of each section.

2.7.1 Nutrient inputs

Livestock

The mass of livestock imported annually onto each property was calculated from farm records kept for the 2002 and 2004 calendar years. The chemical composition for beef entering and exiting the property was estimated using the Beef-bal program (DPI&F 2003). The use of a single number for the composition of livestock introduces the possibility of error for two reasons: 1) differences that occur in body composition for store animals (animals that have a low amount of body fat) compared to finished animals which are ready for sale and typically have a higher percentage of body fat, and 2) variations in body composition between animals of different sexes and ages. Considering the broad property scale nature of this research it was decided that a single figure for all classes of animal would be sufficient because the overall impact is likely to be relatively low compared to sources of error for other components in the nutrient balance.

For sheep production, data for live animal composition were sourced from Cornell University (CNMSP 2007). However these data showed less than 5% variation from the estimate used for beef cattle so it was assumed that sheep and cattle were equivalent in terms of nutrient removal from the system per kilogram of liveweight. Wool is a secondary (in terms of mass) output from the enterprise and was accounted for in the nutrient balance by assuming that clean wool weight (assumed at 70% of greasy wool weight) is 100% protein and therefore contains approximately 16% N, with negligible amounts of P and K.

Fertiliser

The mass of fertiliser applied on each supply chain property was collected from farm records for the calendar years 2002 and 2004. All values were calculated as property-scale averages. The composition (chemical analysis) of specific types of fertiliser can vary between manufacturers, but this is usually by less than 1% of N, P or K content. The chemical analysis for fertilisers applied were taken from Incitec (Incitec Pivot 2005; 2005; 2005). The chemical analysis for the organic fertilisers and soil amendments used on the Victorian property were collected from the relevant manufacturer (Nutri-tech 2006). The amount of nutrient used was calculated on an ‘as applied’ basis. Fertiliser usage for the cropping system was included in the nutrient budget so that impacts from grain production exported off-farm (separate to the red meat system) could be accounted for by an allocation factor applied in the final analysis.

Feed and feed supplements

Significant amounts of nutrients can be brought on farm in feed for livestock. The data supplied by producers in the survey for feed/feed supplement purchases were combined with standard figures for dry matter percentage and nutrient composition to estimate nutrient inputs. The nutrient composition for a wide range of commodities was collected for the related research project FLOT.328 and these data provided input for the current project.

Legumes - nitrogen fixation

N fixation is the single most significant nutrient addition not directly derived from grazing property inputs. It was not possible to directly assess the mass of N fixed by legumes on the supply chain properties so data were sourced from a wide breadth of literature for N fixation by legume pastures in Australia. The rate of N fixation reported in the literature varies from 11 - 12 kg N / ha / yr for white clover (8% of pasture biomass) in south western Victoria (Riffkin et al. 1999; McKenzie et al. 2003) to 162 kg N / ha / yr for subterranean clover in a mixed sward in Western Australia (Asseng et al. 1997). However, for mixed clover based pasture swards in southern Australia, the likely rate of N fixation is in the range 40 - 150 kg N / ha / yr (Asseng et al. 1997; Unkovich 1997; Dear et al. 1999; Riffkin et al. 1999). These references are summarised in Table 2.

N fixation is influenced by many factors, the primary drivers being legume species, pasture growth rate and the percentage of legume in the pasture sward. These factors were researched for each of the supply chains to allow a more accurate estimation of the likely rate of N fixation from the legume component. These were then matched as closely as possible to the available literature to determine a rate of N fixation at the property scale. Table 2 gives the N fixation rates that were used to estimate appropriate fixation rates for properties in each of the red meat supply chains.

Table 2: N fixation from legume pastures as cited in the literature

Species	Grazing conditions	Percentage of pasture sward	Region and rainfall	N fixed kg / ha / yr	Reference
White clover / ryegrass	Not known	12 – 23 %	South western VIC – 790mm	12 – 42	(McKenzie et al. 2003)
Sub clover	Intensive grazing	Not known	Southern Australia	92 (0 – 188)	(Unkovich 1997)
Sub clover / Phalaris	Intensive grazing	Not known	South western NSW – 575mm	48 – 59	(Dear et al. 1999)
White clover	Not known	8 %	Not known	11 – 18	(Riffkin et al. 1999)
Sub clover / ryegrasss	Intensive grazing	Not known	South western WA – 673mm in year of experiment	188	(Sanford et al. 1995)
Sub clover / ryegrasss	Intensive grazing	Not known	South western WA – 673mm in year of experiment	103	(Sanford et al. 1995)

An estimate of 46 or 92 kg N / ha / yr depending on rainfall in the survey year was assigned for the properties in Western Australia, New South Wales and Victoria that have clover based pastures after Unkovich et al. (1997). Considering all the references in Table 2, it is accepted that the actual N fixation could vary on a yearly basis from 10 - 190 kg N / ha / yr or more depending on the range of driving factors that are difficult to account for. Hence an intermediate figure was selected to try to represent a mean value.

Inputs of N from the atmosphere with rainfall and lightning were included in the mass balance using a single figure for the whole nation, though this may vary from one area to another. It was assumed that this difference is not likely to have a large effect on the mass balance considering the overall addition of N from this source is only around 5 kg N / ha / yr (Sharma and Campbell 2003). Other additions from the atmosphere can include calcium, magnesium and sodium from sea salts which are added at a rate dependent on the prevailing winds and distance from the ocean. There were insufficient data available for the properties involved to include a value for the deposition of these nutrients from the air and hence they have been ignored in this analysis.

Table 3 below shows the values used to calculate the nutrient budget for farms in the three supply chains. Data have been presented as a range covering the three properties and two years of data collection.

Table 3: Summary of nutrient input values and assumptions used for properties in the red meat supply chains

Nutrient inputs	Description	Value	Reference
Livestock	Sheep / Cattle	N = 2.4% of liveweight P = 0.7% of liveweight K = 0.2% of liveweight	QDPI&F (2005)
Fertiliser	urea, mono-ammonium phosphate, di-ammonium phosphate, sulfate of ammonia Pivot 15 Organic humates Seachange kelp mix single superphosphate muriate of potash K sulphate K humate	Dependant on fertiliser type – taken from manufacturers reported nutrient levels	Incitec Pivot (2005a,b,c)
Feed and feed supplements	Pasture hay Legume hay Lupins Canola meal Canola oil Minerals	N=1.3 %, P=0.4%, K=0.2% N=2.1 %, P=0.4%, K=1.0% N=4.6 %, P=0.3%, K=0.8% N=5.8 %, P=1.0%, K=1.2% N=0.0 %, P=0.3%, K=0.4% Dependant on type	QDPI&F (2005) and from manufacturers (mineral supplements).
Legumes - N fixation	Mixed clover / grass pastures	46 kg/ha or 92kg/ha Estimate dependant on density of legume within the pasture stand and the annual rainfall in the survey year	Unkovich et al. (1997) and references in Table 2

2.7.2 Nutrient outputs

Nutrient outputs have two main forms: export of produce and losses to the environment. The nutrient budget first assesses the nutrients added to the system less the nutrients exported in produce. The nutrient balance also defines the pool of nutrients that may be lost to the environment. This provides data to other indicators in the assessment including acidification and water quality.

Quantifying nutrient losses from the system is an important outcome from the nutrient budget. Nutrient loss is a major source of environmental concern, particularly in respect to N and P movement to surface and groundwater sources. Categories for soil/water losses (including nutrient transport with overland flow and erosion), leaching and volatilisation losses were also estimated. Other specific nutrient loss pathways (e.g. fire) were considered minor pathways in these southern meat supply chains and excluded from this assessment. All of the loss pathways identified in the assessment were estimated from an appraisal of the literature and the system under analysis. The data used in the modelling are presented in Table 6. It was beyond the scope of the project to measure nutrient losses for the specific properties on site.

Export of produce

Exports include animals for slaughter, wool and other produce. Other produce (i.e. grain) was excluded from the mass balance except where directly linked to red meat production. Wool production could not easily be excluded from the mass balance, introducing a degree of complexity. Where wool was produced, the impact categories were adjusted to apportion impacts to wool and meat on the basis of mass and economic value. This allowed the environmental impacts associated with meat production to be reduced to account for the impacts of wool production.

Losses to the environment

A large number of nutrient loss pathways could be considered in the nutrient management assessment. Many of these loss pathways account for only small amounts of nutrients, or occur at infrequent intervals (i.e. bushfires). However, some of the loss pathways are essential for calculating other impacts (acidification, eutrophication) and these received more attention. After defining the pool of nutrient inputs to the system, the effect of major loss pathways could be estimated with a greater degree of confidence and the ability to verify assumptions. This is the context to the estimation of nutrient losses to the environment.

Soil/water loss

Losses of nutrients to the environment with eroded soil particles and overland flow can be a significant threat to the environment. Data for this section come from a detailed assessment of erosion losses and water quality impacts. The nutrient balance defines the pool of nutrients in the system that may be lost via different pathways, giving parameters to these estimates. For soil erosion, the nutrient loss pathway was quantified by the product of estimated soil erosion (see the soil erosion assessment) and estimated soil nutrient content. This provided a very broad estimate of nutrient loss, which could only be improved by detailed on-farm testing and research.

Water quality deals specifically with nutrient transfer to waterways. Within this assessment, data for the likely annual nutrient losses with runoff were collected (see Table 6 and Table 11). These data were cross checked with the nutrient balance (inputs less outputs). However, the nutrient loss off-paddock does not necessarily represent the amount of nutrient deposited in waterways, as discussed in the water quality section.

Nutrient leaching

Leaching is the process of nutrient movement through the soil profile with water infiltration. Only nutrients that dissolve in the water rather than being bound in the soil structure can leach in significant quantities. While P and K can be subject to leaching, the greatest concern is usually associated with N leaching in the nitrate (NO_3^{2-}) form. This can lead to groundwater contamination and acidification (see Table 4). K is also mobile in the soil solution and may leach at significant rates in some instances (i.e. Roberts 1970). However the available literature was limited and did not allow estimation of K losses in the systems considered.

Nitrate leaching was quantified by comparing the systems with data found in the literature. These data (see Table 4) are highly variable depending on experimental technique and location effects. Our model used these data as a guide to estimating leaching rates (which the model defines as a percentage of the total N input).

Table 4: Nitrate leaching rates under clover based pastures in southern Australia

Pasture type	Research region	Soil Texture and annual rainfall (mm/yr)	Nitrate leaching (kg N/ha/yr)	Reference
Rye grass / white clover	South eastern VIC	Clay loam, 1114 mm	3.7 – 14.6	(Eckard et al. 2004)
Sub clover (annual)	South western WA	Sand, 460 mm	17 – 28	(Lundie et al. 2005)
Annual	North eastern VIC	Sandy clay loam over clay, 590 mm	82	(Ridley 1990)
Perennial	North eastern VIC	Sandy clay loam over clay, 590 mm	68	(Ridley 1990)

[a] The nitrate leaching rates in the experiment carried out by these authors were estimated from overall observations of pH decline over time rather than direct measurement.

Other factors influencing the selection of the leaching rate include the soil type, annual rainfall and rainfall pattern, pasture production N inputs to the system and other indicators of nitrate leaching (i.e. accelerated soil acidification). The leaching rate was also compared with the overall nutrient mass balance to check the effect of the assumptions used. Even a small difference in nitrate leaching may have a significant effect on other parameters, particularly soil acidification. However, collection of real data on nitrate leaching rates in Australia has been limited, and this limits the scope of nutrient budgeting in the context of this assessment. The data in Table 4 provide a guide to nitrate leaching for the systems analysed. Because of the higher rainfall and sandy loam soils at the Victorian site, leaching formed a significant component of the N losses at this site (30-34 kg/ha/yr), compared to those for NSW and WA (4-15 kg/ha/yr) where significantly lower rainfall was experienced in the years considered.

Volatilisation

Volatilisation and denitrification refer to the loss of N from agricultural systems in a gaseous form (NH_3, N_2, NO). These losses can also have a deleterious effect on the environment through their role in the production of acid rain (NH_3) and the greenhouse effect (nitrous oxides - NOx). Representative loss rates were sourced from the literature to provide some indication of the magnitude of these losses, but they are not considered in further detail. From the literature provided in Table 5, total gaseous N losses from the three systems was estimated to range from 20 – 27 kg/ha/yr depending on the level of N input to the system. Assessment of losses from the WA and NSW systems was difficult as similar systems are not covered as extensively in the literature. In the absence of other data it was assumed that N_2 emissions were equal for all properties. It was assumed that because of the dryer climate in the NSW and WA system NOx losses will be lower (0.2 kg after Dalal et al. (2003)). It is recognised that the estimated N volatilisation rates are conservative with respect to environmental impacts and may be lower depending on specific management practices on farm. These values are included in the LCI for indicative purposes to highlight possible loss pathways only. Quantification of these nutrient losses can be very difficult even with experimental research, and the literature generally represents measurements made at a specific site over a relatively short time frame. These complexities reduce the degree of confidence in the model outputs for this category. Further improvement would require more research in the field of gaseous emissions from intensive and extensive grazing enterprises over time across different systems in Australia.

Table 5: Volatilisation and denitrification losses from agricultural systems in Australia

Pasture type	Research region	N_2 losses (kg N / ha)	NO_x losses (kg N / ha)	NH_3 losses (kg N / ha)	Reference
Rye grass / white clover	South eastern VIC	6	-	17	(Eckard et al. 2003)
Rye / clover + 200 kg N as urea	South eastern VIC	13	-	57	(Eckard et al. 2003)
Dairy pasture	VIC	-	6 – 11 (mean 8.5)	-	(Dalal et al. 2003)
Extensive pasture	Australia wide		0.2		(Dalal et al. 2003)

Table 6 below shows the values used to calculate the nutrient budget for farms in the three supply chains. Data are presented as a range covering the three properties and two years of data collection.

Table 6: Summary of nutrient output values and assumptions used for properties in the red meat supply chains

Nutrient outputs	***Description***	***Value***	***Reference***
Export of produce	Sheep / Cattle	N = 2.4% of liveweight P = 0.7% of liveweight K = 0.2% of liveweight	QDPI&F (2005)
	Wool	N = 16% of clean weight	
Nutrient loss with overland flow (N & P)	Improved pasture	N = 0.2 – 3.0 kg/ha/yr P = 0.1 – 2.5 kg/ha/yr	See Table 11 for a range of references
	Extensive pasture	N = 0.1 – 0.3 kg/ha/yr P = 0.02 – 0.1 kg/ha/yr	
	Cropping	N = 0.2 – 6.0 - kg/ha/yr P = 0.1 – 2.0 kg/ha/yr	
Nutrient loss with soil erosion	Soil loss rates by sheet and rill erosion and, gully erosion (used as input for nutrient losses)	Sheet and rill erosion = 0 – 5 t/ha/yr Gully erosion = 0 – 0.2 t/ha/yr	NLWRA (2001)
	Soil loss estimate multiplied by nutrient concentration within soil	N = 0.0 - 0.1 kg/ha/yr P = 0.0 - 0.1 kg/ha/yr	NLWRA (2001) and on farm soil analysis data
Leaching (N)	N leaching dependant on soil type, rainfall and N mass balance	N= 4-34 kg/ha/yr (10-40% of N inputs from fertiliser and legumes)	See Table 4 for a range of references
Volatilisation (N)	N_2, NO_x, NH_3	N = 20-27 kg/ha/yr	See Table 5 for a range of references

2.8 Soil Acidification Potential

Estimating the acidification potential in this LCA involved incorporating an acid / base balance into the model. This used published data for acidification rates resulting from product removal, N fertiliser acidification and grazed pasture acidification potential on improved or extensively managed pastures. The assumptions of the balance were matched as closely as possible to the known systems, considering the annual rainfall, soil type and the likely leaching potential, proportion of legume pasture, estimated annual dry matter production and grazing management system.

The model is based on five main drivers of acidification, balanced by the inputs of alkali into the system (livestock imports, some fertilisers, lime and other soil ameliorants). The drivers of acidification considered in the model are:

1. The use of N fertilisers.
2. Movement of agricultural products within the system through grazing animal behaviour (transfer of manure to stock camps or laneways).
3. The use of legume-based pastures.

4. The removal of agricultural products resulting in a net export of alkalinity.
5. Management that promotes a build up of soil organic matter.[2]

The impact of agricultural production on acidification was assessed by using the indicator 1 kg of calcium carbonate ($CaCO_3$) equivalent. This indicator represents the amount of a substance, relative to calcium carbonate, required to neutralise the acidifying effect of a process. It is noted that this indicator of acidification potential does not represent the actual change in pH that may be observed from a management practice. This is because a range of factors affect pH change, particularly the buffering capacity of the soil. A summary of the assumptions and data used in the acidification estimates is provided in the following sections and in Table 10.

2.8.1 N fertiliser usage

The first form of acidification considered in the model comes from repeated applications of fertiliser N and particularly ammonium-based fertilisers (Bolan et al. 1991; Moody 2005). While it has been clearly demonstrated that there is no acidification effect from N transformations in a system with no N losses (Helyar 1976), this is rarely the case in practice (Bolan et al. 1991). N is lost from agricultural systems via several main pathways including product offtake, volatilisation and leaching of nitrate. Nitrate leaching was estimated as part of the nutrient management section and the figures produced were used to estimate acidification in this section of the model.

When nitrate (NO_3^{2-}) leaches through the soil profile with a basic cation, H^+ ions are deposited in the soil producing a net acidification effect. For each kmol of H^+ remaining in the soil following nitrate leaching it is assumed that 50 kg of $CaCO_3$ is required to neutralise the acidifying effect (Slattery 1991). Acidification rates (expressed as the amount of lime required to neutralise the effect) resultant from the application of some N fertilisers are presented Table 7 below.

Table 7: Lime required to neutralise the acidifying effects of some nitrogenous fertilisers at different rates of NO_3 leaching

Fertiliser	Lime requirement in kg $CaCO_3$ / kg N applied		
	Percentage of N applied leached (as nitrate)		
	0%	50%	100%
Ammonium sulfate	3.6	5.4	7.1
MAP	3.6	5.4	7.1
DAP	1.8	3.6	5.4
Nitram	0	1.8	3.6
Urea	0	1.8	3.6

Table adapted from (Moody 2005)

The net acidifying potential of ammonium based fertilisers results from surplus H^+ ions being added to the soil following N transformations with or without nitrate leaching. These values are reported in the context of the Queensland broad-acre production

[2] Soil organic matter can act as an acidifying substrate and as a buffer against pH change, resulting in different effects over time and between soil types.

region. However the processes are expected to be similar in other regions. The major variable between regions affecting the acidification resultant from N application is expected to be the amount of nitrate leached from the system.

The model uses the leaching rate to calculate the acidification potential from fertiliser usage based on the data from Table 7 above. This was checked by calculating the kilomoles of N leached and the associated kilomoles of H^+ ions left in the soil matrix following the theory outlined in Bolan et al. (1991). This theory was also used to estimate the acidifying effect of N leaching under legume pastures.

2.8.2 Grazing animal behaviour

The simple calculation of net acidification from product removal is complicated in grazing systems by the transfer of product within the paddock by disproportionate manure deposition across the grazing area. This effect can be attributed to the behaviour pattern of grazing animals, which graze over a large proportion of a paddock but select a small area on which to camp. These stock camps receive higher manure deposition resulting in nutrient transfer from the paddock to the stock camp. This can result in a 34% transfer of manure and urine to the stock camp area (Hilder, 1964, cited in Slattery 1991). While the addition of anions in manure (particularly calcium) could result in decreased acidification on the stock camp area, the higher rate of N addition and organic matter increases acidification on stock camp areas (Cayley et al. 2002).

The result of anion transfer to stock camping areas is acidification of the majority of the paddock where livestock graze. In addition to this, the research by (Cayley et al. 2002) indicates that net acidification also results at the stock camp site because of the higher deposition of N and organic matter. Considering this, the overall grazing effect results in a higher level of net acidification than the net removal of livestock may suggest. Table 8 below shows the acidification potential as a result of grazing behaviour in sheep.

The effect of grazing on acidification is influenced heavily by the management system on the property which affects the behaviour of livestock in establishing stock camp areas. Published data for the acidification potential attributable to sheep grazing are presented in Table 8. These data were used in the model where relevant to the supply chains.

Table 8: Potential acidification from sheep grazing behaviour

Species	Research region	Conditions	Acidification potential kg / ha / yr ($CaCO_3$ equivalents)	Reference
Sheep	South western VIC	Perennial grass / sub clover	9 – 25	(Cayley et al. 2002)
Sheep	South Australia	Extensive grazing	10 – 25	Ag Bureau of SA
Sheep	North eastern VIC	Perennial grass / sub clover	23	(Slattery 1991)

* Numbers presented here are derived from the research of Slattery et al. (1991) (manure and urine acidification potential) and Hilder (1964) (Manure transport to stock camps).

No data were available for the effect of cattle grazing on acidification. However anecdotal evidence suggests that cattle do utilise stock camps under extensive grazing conditions. Considering the lack of research for this effect with cattle production, a mean value from the sheep research referenced above was substituted where cattle are observed to display some camping behaviour on the supply chain properties. Grazing effects were estimated following subjective assessment of the supply chain properties. From this it was assumed that no grazing effect was evident on the Victorian property where cell grazing was the dominant pasture management practice. For the New South Wales and Western Australian properties, a value of 8-10 kg $CaCO_3$ / ha / yr was selected as an approximation from the data presented in the literature.

2.8.3 Net removal of product

The transfer of agricultural products off-farm results in alkalinity exports that cause acidification. Table 9 summarises the values quantified by Moody (2005), NLWRA (2001) and Slattery et al. (1991) which underpin the acid / base balance used in the LCI model. In the situation where hay or grain was produced on-farm and then fed to livestock, the acidification effect from removing this product was still measured. This is because internal transfer of alkalinity may still produce acidification of grazing property land despite the produce not leaving the property.

2.8.4 Legume fixation and N leaching

N fixation from legume based pastures is an essential N source for grazing systems, as identified by the nutrient management section. However, excess N fixation from legume-based pastures can produce acidification from NO_3^{2-} leaching below the root zone.

The nitrate leaching rate below annual and perennial legume based pastures has been studied by several research groups (Ridley et al. 2001; Eckard et al. 2004; Lundie et al. 2005) which reported a range of leaching rates for different pastures, soil types and rainfall patterns. The current research attempted to match the published leaching rates as closely as possible to the case study properties in the supply chains to determine the likely acidification potential. Leaching rates were determined from the nutrient balance, and the acidification potential from this rate of N leaching was determined using the acidification potential theory explained by Bolan et al. (1991).

Table 9: Alkalinity in exported agricultural produce and lime requirement to neutralise acidifying effect of product removal

Product	Unit*	$CaCO_3$ equivalent kg/ t of product	$CaCO_3$ requirement (kg/ha) for some representative yields	Reference
Wheat	1 t	9	18 (2 t/ha yield)	(Slattery 1991)
Barley	1 t	8	16 (2 t/ha yield)	(Slattery 1991)
Lupins	1 t	20	20 (1 t/ha yield)	(Slattery 1991)
Grass hay	1 t	25	125 (5 t/ha yield)	(NLWRA 2001)
Grass hay	1 t	30	150 (5 t/ha yield)	(Moody 2005)
Clover hay	1 t	40	200 (5 t/ha yield)	(NLWRA 2001)
Lucerne hay	1 t	60	300 (5 t/ha yield)	(Slattery 1991)
Legume hay	1 t	50	250 (5 t/ha yield)	(Moody 2005)
Sheep Meat	1 kg livewt	0.017	6 (10 x 35 kg lambs)	(Slattery 1991)
Wool	1 kg	0.014	0.6 (5 kg / sheep x 8 sheep)	(Slattery 1991)

*All values have been translated into standard units of 1 t or 1 kg for ease of comparison.

2.8.5 Increased soil organic matter

Increased soil organic matter levels are generally considered beneficial for soil health, structure and fertility. However, increasing the amount of organic matter cycling in a system by improving plant production or adding organic matter with manure can promote soil acidification (Sandars et al. 2003; Moody 2005). The acidifying process is driven by the dissociation of organic acids from the additional organic matter.

Research suggests that acidification may also result from additions of feedlot manure and effluent to pastures (Bouwman and Van Der Hoek 1997). However, manure can have a variable effect depending on its nutrient and organic matter content (Schoenau 2005). Some research reports decreasing pH from manure application (Chang et al. 1990), while other research (Whalen et al. 2000) reports an increase in pH following manure application on two acid soils under laboratory conditions.

Increased soil organic matter levels under improved pastures can contribute to soil acidification (Sandars et al. 2003), though there is a high degree of variability in the literature as to the extent of this effect (Crawford et al. 1994; Cayley et al. 2002; Sandars et al. 2003).

Organic matter was considered in the assessment of acidification as an influencing factor but not as a direct input. This is due to the lack of rigorous data to quantify the effect in isolation because of the confounding interactions in pasture systems. It was assumed that acidification as a result of organic matter additions was far lower than other acidifying processes and the omission is not expected to cause significant error.

2.8.6 Summary of Soil Acidification Data

Table 10 below summarises the values estimated for the soil acidification balance. The data have been presented as a range covering the three properties and two years of data collection.

Table 10: Summary of acidification potential data used for properties in the supply chains

Acidifying Process	***Description***	***$CaCO_3$ required for Neutralisation***	***References***
N leaching from fertiliser usage	Acidification depends on percentage of N leached (10-40% from nutrient balance)	0 – 6 kg/ha/yr averaged across the whole property	Estimates based on data from Moody (2005) and Slattery (1991)
Animal Grazing Behaviour	Acidification caused by transfer of alkalinity within paddocks to livestock camping areas	0 kg/ha/yr for the VIC supply chain. 10 kg/ha/yr for NSW and WA. Averaged across the whole grazing area	See Table 8
Net product removal	Acidification caused by removal of alkalinity with plant and animal products	7 – 14 kg/ha/yr averaged across the whole property	See Table 9
N leaching from legume pasture	Acidification depends on percentage of N leached (10-40% from nutrient balance).	VIC = 106-121 kg/ha/yr NSW = 13-51 kg/ha/yr WA = 24-45 kg/ha/yr Data averaged across the whole property	Lundie et al. (2005) Eckard et al. (2004) Ridley et al. (2001) Bolan et al. (1991)
Alkalinity Additions	***Description***	***$CaCO_3$ added (kg/ha/yr)***	***References***
Lime and soil additives	Lime added to ameliorate low soil pH	0 kg / ha / yr – NSW and WA supply chains. 1177 kg/ha/yr with lime application on VIC supply chain property in 2002 . Values averaged across the whole property.	-
Net product inputs to property (Hay, grain, livestock)	Main imports are livestock and hay	2 – 21 kg/ha/yr averaged across the whole property	See Table 9 for composition data.

2.9 Soil Erosion

The assessment of erosion for the red meat supply chain properties was based on broad scale erosion estimates sourced from the NLWRA (2001) erosion research. These estimates all relate to water borne erosion and no assessment of wind erosion was considered, although this will be important for future assessments of northern Australian beef production. The erosion mapping was ground-truthed by considering the topography and management system used on each supply chain property. As erosion is a natural process in the Australian landscape, the rate of erosion for each property was compared to natural or pre-European erosion rates calculated by the NLWRA (2001). This reduced the risk of attributing natural erosion processes to red meat production.

The land on which the NSW property is situated has an estimated erosion gully density of 0.1 to 0.5 km/km^2, described as “low density”, while the estimated annual hillslope erosion rate ranges from 0.5 to over 10 t/ha/yr (“low” to “very high”). This reflects the soil types and topography of the area. At the Victorian property, the estimated erosion gully density is 0 to 0.1 km/km^2, described as “very low” density, and the estimated annual hillslope erosion rate ranges from 0 to 0.5 t/ha/yr (also “very low”) which is approximately equal to pre-European erosion rates for this area. Between these two estimates, the WA property has an estimated erosion gully density of 0 to 1 km/km^2, described as “very low” to “medium” density, while the estimated annual hillslope erosion rate ranges from 0 to over 2.5 t/ha/yr (“very low” to “low”).

The model estimates erosion using these NLWRA soil loss mapping data and a subjective assessment of the factors likely to accelerate soil erosion on each of the supply chain properties. This is intended to provide an indication of the erosion risk on land used for red meat production in different regions across the country. It was beyond the scope of this project to assign soil loss to the functional unit (1 kg of HSCW) as this would imply a definite link between meat production and erosion. Assessment of soil erosion risk in the red meat industry would ideally involve establishing new indicators related to soil disturbance from livestock trampling and reduction in vegetative cover from grazing. At this point there is insufficient quantifiable research into the relationship between these processes and erosion potential to establish these indicators. While there are some linkages related to the modification of ground cover through grazing management and land clearing and trampling, these are only partly responsible for accelerated erosion. Further background on erosion as it relates to the red meat industry may be found in Wiedemann et al. (2006).

The model provides an estimate of soil loss from the supply chains on a per hectare basis using a second functional unit ‘1 ha of land used for production’ to identify the magnitude of the effect. This avoids attributing an NRM impact that is related to many factors extraneous to the production of red meat to this one system output.

2.10 Water Quality

Water quality is addressed in the red meat LCA through eutrophication potential by estimating exports of N and P to waterways from red meat supply chain properties. Nutrient loss results from the dissolution of readily available nutrients in overland flow, and the loss of soil and organic matter particles eroded with overland flow and carried to waterways. While there is literature available to quantify nutrient losses from small plot scale experiments, it is not always accurate to assume similar nutrient export rates at the whole property scale (Barlow et al. 2005). This current research is based on a desktop study without on-farm research. It attempts to provide a broad-scale estimate of nutrient loss from the supply chain properties. Nutrient loss at the property scale has been researched by as few as five studies in Australia (Barlow et al. 2005) and none of these are representative of the systems being considered in the red meat LCA. Hence the model uses conservative estimates of nutrient export while matching these as closely as possible to the systems being studied.

2.10.1 Nutrient loss in overland flow

Nutrient loss is a measure of concentration of nutrient and volume of runoff. Hence the model attempted to account for differences in rainfall between regions and across years. Several researchers have reported data for estimated nutrient loss with overland flow (Greenhill et al. 1983; Nash and Murdoch 1997; Nash and Halliwell 1999; Ridley et al. 2003; Barlow et al. 2005; Nash et al. 2005). These data vary widely, as seen by Table 11 below.

Table 11: Nutrient losses from pasture systems is Australia

Pasture type	Research region	N conc. in runoff (mg/L - NO_3-N)	N losses (kg N/ha)	P conc. in runoff (mg/L)	P losses (kg P/ha)	Reference
Control pasture (no fert inputs)	Westernport VIC	<0.01-2.74		0.45-2.0	0.22	(Greenhill et al. 1983)
High fertility dairy pasture	West Gippsland, VIC	-	-	5.2	3.4[a]	(Nash and Murdoch 1997)
Improved pasture sheep grazing	Southern Tablelands NSW	-	0.62	-	0.12	(Costin 1980)
Low – high input sheep grazing	North-east VIC	3-26	0.2-6		0.03-0.91	(Ridley et al. 2003)
Irrigated dairy	South-east VIC	-	-	2.2-11	2.5-23	(Barlow et al. 2005)

[a] Mass of nutrient estimated from the volume of water and the concentration of nutrient

Only one of these researchers attempted to quantify and cross-reference data collected on a plot-scale basis to a whole-farm basis (Barlow et al. 2005). This research showed that over three years there was no accurate proportional scale that could be used to extrapolate the plot measurement to the whole property. Hence, estimates based on plot or paddock-scale P exports will overestimate the whole property P export (Barlow et al.

2005). This may be because of the catchment of water in on-farm dams and the filtration of nutrients out of solution by riparian zones. Variations within paddocks or between different runoff events were not considered in developing estimates of nutrient loss from properties in the supply chains as data were not available to quantify this variation. The reference literature was used to provide an estimate of nutrient runoff per hectare per year. A conservative approach to nutrient loss has been taken because of the diluting effect expected when assessing a whole farm compared to literature presented on a paddock scale (after (Barlow et al. 2005).

Nutrient loss per hectare is influenced by the level of soil fertility and the amount of nutrients at the surface of the soil. Intensively grazed areas have a higher nutrient turnover and higher deposition of manure on the soil surface and hence higher nutrient levels in runoff. At the Victorian site (intensively grazed), average losses of 3 kg N / ha / yr (Ridley et al. 2003) and 2.5 kg P / ha / yr (Barlow et al. 2005) were estimated for intensively grazed areas. Losses at the NSW site were assumed to be 3 kg N / ha / yr and 0.45 kg P / ha / yr because of the lower intensity of the grazing system (Ridley et al. 2003). At the WA site, N losses of 0.2 kg N / ha / yr were estimated (Ridley et al. 2003), while P losses of 0.1 kg P / ha / yr (Costin 1980) were estimated in response to the low soil fertility at this site and lower grazing intensity at this site. Nutrient losses from cropped areas were also relevant at the NSW and WA sites. At the NSW site losses off the alluvial cropping areas were estimated to be 6 kg N / ha / yr and 2 kg P / ha / yr, while estimates for cropping areas in WA were 0.2 kg N / ha / yr and 0.1 kg P / ha / yr reflecting the lower soil fertility at this site.

2.10.2 Nutrient loss with soil and organic matter erosion

Erosion of soil and organic matter particles results in nutrient loss. The model estimated the magnitude of nutrient losses through erosion as the product of soil loss estimates (soil erosion sheet) and the estimated soil nutrient content. As limited data on soil nutrient levels were available for the supply chain properties considered, the values were estimated based on property management and production. These assumptions may introduce error into the evaluation of eutrophication. Also, the estimate of soil erosion rates was made from broad-scale data and supplemented by expert judgement, which may further reduce the accuracy of the eutrophication assessment. It is recognised that the nutrient content of the eroded fraction of soil can vary depending on the enrichment ratio which is a measure of the increase in fertility of eroded soil above that of the in situ soil. The literature review identified no research on enrichment ratios for regions similar to the properties of the supply chains under evaluation; hence it was assumed that the ratio was equal to 1.

Nutrient loss from grazing properties is a frequently-discussed issue of environmental concern. This research conservatively estimated nutrient losses based on the limited data available in the literature. Nutrient losses from one supply chain to the next were adjusted based on our knowledge of rainfall and likely runoff and soil nutrient levels.

3 Goal and Scope Definition

3.1 Goal

MLA's overall goal in commissioning this work is to address the lack of accurate data on the environmental impacts of the red meat industry. In the absence of these data, the industry can come under increasing pressure to justify its "clean, green and safe" image domestically and abroad. Due to increasing competition for export markets, it is to be expected that quantitative justification for this image will be needed at some time in the future. LCA is a useful environmental assessment tool for this purpose.

Therefore the three primary goals of this project are to:

1. Develop LCI data to characterise natural resource management of three red-meat production processes encompassing on-farm and off-farm operations.
2. Analyse these data, and data on feedlots provided by MLA project FLOT328, using an LCA approach to quantify the potential environmental impacts of each process.
3. Communicate the results of this work to MLA in a format suitable for dissemination to members of the industry.

Consistent with these primary goals, the secondary objectives are to:

4. Identify the key steps in the meat production process from an environmental perspective.
5. Identify opportunities for manufacturers to improve environmental performance via product stewardship / supply-chain management (e.g. managing offsite impacts).
6. Identify opportunities for producers to collectively improve resource management through understanding their suppliers.
7. Optimise total system performance.
8. Improve industry competitiveness by increasing the environmental sustainability of operations.

3.1.1 Intended application

This LCA study generated quantitative environmental profiles for each supply chain considered. The results contribute towards an overall assessment of the entire red meat industry and form part of the basis for further debate, planning and policy development in the industry. Publication of the results of this study will demonstrate the industry's commitment to environmental management.

It is envisaged that data from this work will be used in other future studies investigating specific processes in greater detail and including the distribution of red meat products to the supermarket and the final consumer. The results of this work will assist MLA in focusing its future research activities on areas where the greatest potential environmental benefits exist.

3.1.2 Target audience

The main audience for the detailed study are the research and policy managers of MLA. It is intended that the final report will enable them to communicate with their stakeholders.

Beyond this, the audience for the study is other researchers and organisations, such as the United Nations Environmental Program. The public is not an intended audience for the detailed report. Nevertheless, it is the intention of MLA that the research group publish key results in a peer-reviewed scientific journal.

3.1.3 Confidentiality

The data and report will remain confidential until they are released by the authors and MLA. All data that the researchers are at liberty to reveal to MLA are included in the main report and appendices. Where data are confidential, they have been aggregated or omitted from the published information.

3.2 Scope of the Study

This LCA adopts a retrospective rather than forecasting approach, examining the environmental impacts of existing processes in previous years. Recurrent energy and material inputs are considered. On account of its long lifespan, environmental burdens associated with infrastructure were considered to be insignificant compared the environmental burdens associated with recurrent activities. Consistent with normal practice in agricultural LCA they were excluded from the study. Allocation procedures were used to account for co-products like wool and offal. These are discussed in greater detail in section 4.8.3.

In this section, methodological choices and decision are made concerning the functional unit, system boundaries, data quality requirements and critical review of the study.

3.2.1 Functional unit and function

The primary functional unit for this study is the delivery of 1 kg of Hot Standard Carcase Weight (HSCW) at the gate of the meat processing works. “Hot” indicates the meat has not entered any chilling operations and represents a point of measurement within the total supply chain. Nevertheless, as the system boundary is drawn at the meat processing works gate chilling operations are included in the analysis. This output-related functional unit was chosen, rather than an input-related one, to describe the human utility of the processes under consideration – the provision of nutrition for people. Although the meat could be served in different ways, this functional unit makes the different processes under consideration “functionally equivalent” from a dietary perspective.

3.2.2 System boundaries

In LCA methodology all inputs and outputs from the system are usually based on the 'cradle-to-grave' approach. This means that inputs into the system should be flows from the environment without any transformation from humans and outputs should be discarded to the environment without subsequent human transformation (Blamey et al. 1998). Each system considers upstream processes involved in the extraction of raw materials and in the manufacturing of products used in the system and considers downstream processes and all final emissions to the environment.

The systems under consideration are:

1. a sheep meat supply chain in south-western Australia.
2. a beef supply chain in southern Australia suppling organic beef.
3. a beef/sheep meat supply chain in southern Australia supplying a premium export market.

This report is not intended to reveal the identity of the particular farms, feedlots nor meat processing works under study. Nevertheless, some general comments about the management of the supply chains will aid interpretation of this work.

The sheep meat supply chain produces grain, wool and sheep meat. There is no intensive or separate feedlot operation although sheep may access supplementary feed for a short period before slaughter. Feed may be prepared on site. There is no irrigated pasture.

The organic beef supply chain starts at a small specialist beef property. There is no irrigated pasture nor is there any feedlot component in the supply chain.

The other supply chain produces sheep meat and premium export beef. Most of the cattle are finished in a feedlot for 110-120 days to produce beef suitable for the Japanese market. The balance of the herd goes directly to the processing works without feedlot finishing. The property also has some irrigated land for grain production.

In this study the system boundary encompasses all processes within the system starting with the on-farm and farm-related inputs where the sheep or cattle are produced, through to the finished product leaving the abattoir site. The system boundary in this study includes the following processes:

- grazing property (on-farm emissions, electricity generation emissions, water use, chemical production and transportation of commodities).
- feedlot and associated cropping and milling activities.
- transportation.
- abattoir processes.
- energy (electricity and fuel), chemical and water supply.
- capital equipment.
- waste and wastewater treatment.

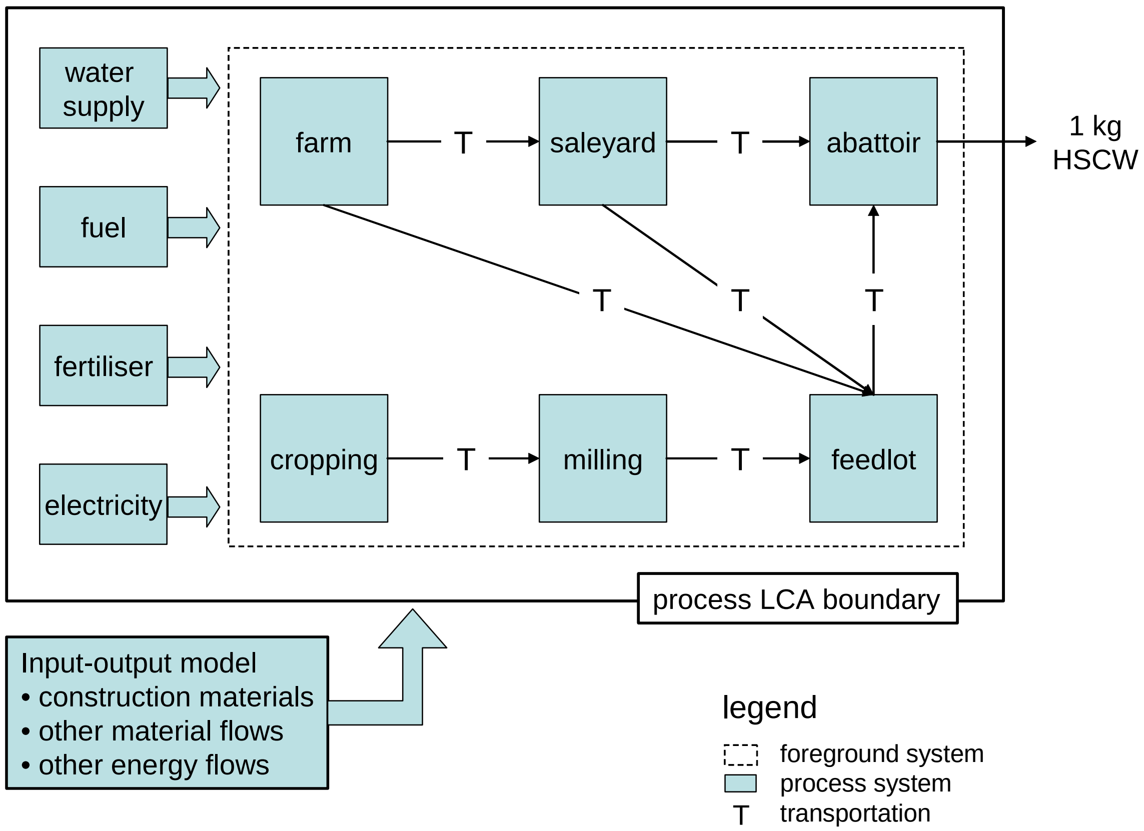

Figure 2: General LCA system model of red meat sector

3.2.3 Data quality requirements

Obtaining high quality data is important in LCA and understanding data quality is important in understanding results. Information used in this study came from the following sources:

- Primary data on the three red meat production systems were obtained by visiting actual sheep and cattle grazing properties. This was supplemented by data provided by FSA Consulting on feedlots and data from MLA on meat processing works.

- *Transportation*: Fuel consumption was calculated by using transport records of the grazing properties in the case studies. Average distances were calculated on this basis. Emission profiles per tonne-kilometre were taken from Australian Data Inventory Project (CRCWMPC 1999).

- *Electricity*: Datasets from Australian Data Inventory Project (CRCWMPC 1999) were used for electricity consumption and for the avoided electricity production. The data sets consider regional differences in electricity supply.

- *Fuel*: Datasets from Australian Data Inventory Project (CRCWMPC 1999) were used for fuel consumption.
- *Chemical Usage*: Australian data were used wherever possible, with international norms used where local data were unavailable.

A more detailed explanation of data sources is given in Section 4.

3.2.4 Critical review of the study

The critical review has been an iterative process during this project. Regular milestone reports were produced and reviewed by MLA.

3.3 LCA Model

GaBi 4.2 is a software system developed by the IKP University of Stuttgart and PE Product Engineering GmbH. GaBi 4.2 is designed to be an analyst's tool for creating life cycle balances. It supports the user in managing large amounts of data and in modelling product life cycles. It calculates different types of balances and helps the user to prepare condensed and readily understandable results.

The databases in *GaBi 4.2 Professional* contain comprehensive data sets (e.g. GaBi 4.2 original processes, inventories for packaging of the Swiss BUWAL, Eco-profiles of the European plastics industry and the Association of Plastics Manufacturers in Europe etc) and these were used for this project (PE Europe 2005). These databases were supplemented by LCI data described in Section 4 and enhanced using IOA, as described in Section 2.2.

4 Life Cycle Inventory

4.1 Introduction

Life cycle inventory (LCI) analysis is the second phase in an LCA and is concerned with data collection and calculation procedures. The LCI analysis phase forms the body of the LCA as it generally accounts for the majority of time spent on an LCA project. As set out in ISO 14040, the operational steps in preparing an LCI are (Blamey et al. 1998):

- Data collection.
- Relating data to unit processes and/or the functional unit.
- Data aggregation.
- Refining the system boundaries.

This section of the report details the data sources and assumptions used in compiling the LCI data for this project, in line with the above steps.

Gate-to-gate LCI data for the production units are reported first, followed by cradle-to-gate LCI data for the inputs to the production units.

4.2 Grazing Properties

4.2.1 Greenhouse gas emissions from livestock

A national inventory of greenhouse gases directly associated with livestock production is compiled by the Australian Greenhouse Office (AGO) annually using a methodology described by the National Greenhouse Gas Inventory Committee (NGGIC 2004) that is in accordance with IPCC guidelines and takes into account Australian conditions.

The methodology and emission factors described by the NGGIC(2004) are intended for application at a state-wide scale and do not take into account property-specific factors such as differences in breeds and management practices. The assumptions underpinning the methodology are likely to be less accurate at a property-specific scale. However, the project team did not discover a suitable alternative method for application to all grazing regions given the data available. Therefore, we have used the NGGIC (2004) methodology and emission factors to estimate livestock emissions for each of the grazing properties for the purpose of this project but used primary farm animal growth-rate data instead of the growth rate assumptions in the published methodology.

Greenhouse gas emission estimates for each of the grazing properties are presented in Table 12. The methodologies used to derive each estimate are detailed by NGGIC

(2004) and are not replicated in this report. The emission sources are briefly described below.

Enteric methane

Enteric fermentation, occurring during digestion in some herbivores, is Australia's major anthropogenic source of methane production (NGGIC 2004). It is particularly pronounced in ruminant animals including cattle and sheep. The methane, produced as a by-product of digestion, is vented by animals via eructation and exhalation.

Table 12: Greenhouse gas emission estimates for the grazing properties

		Enteric Methane Emissions		Manure Methane Emissions		Nitrous Oxide Emissions	
		kg CH_4/yr	t CO_2-e/yr	kg CH_4/yr	t CO_2-e/yr	kg N_2O/yr	t CO_2-e/yr
WA	2002	19,772	415,210	4	86	115	35,788
	2004	26,777	562,322	6	117	150	46,414
VIC	2002	106,876	2,244,394	19	401	636	197,135
	2004	74,300	1,560,303	13	274	456	141,300
NSW	2002	103,367	2,170,709	26	545	385	119,217
	2004	148,939	3,127,714	38	790	545	168,989

The NGGIC (2004) methodology has been developed for several livestock sub-categories, and uses country-specific methodologies where possible, to account for the heterogeneity of feed types available within Australia.

Manure management: Methane

The decomposition of organic matter remaining in manure under anaerobic conditions is another source of methane. The NGGIC (2004) considered that anaerobic decomposition of the manure of range-kept animals was unlikely due to the "generally high temperatures, high solar radiation and low humidity environments of Australia [that] would dry manure rapidly [in] combination with scarab (or dung) beetles that rapidly infest manure in most Australian environments" (p 17). Therefore, use of the methodology results in relatively small methane emissions from manure on the grazing properties.

Manure management: Nitrous oxide

N is an essential nutrient in livestock diets but only some is retained by the animals. The remainder is excreted in milk, urine and faeces. This results in nitrous oxide emissions from manure management systems. The NGGIC (2004) methodology is based on Australian conditions and takes a mass balance approach where N output = N input - N storage.

4.2.2 Material and energy inputs

The project team collected raw LCI data from the operators of three grazing properties, including all recurrent energy use (electricity and fuels), material inputs (e.g. feeds, fertilisers, pesticides, soil modifiers), water use, and solid waste production. Data on stock purchases, sales, transfers, births and deaths, as well as liveweights and dressing percentages, were also collected to quantify each grazing property's production in terms of the functional unit.

Gate-to-gate inventories for each of the grazing properties are presented in Appendix A. Cradle-to-gate LCI data for the material and energy inputs are further described in Section 4.5.

4.3 Lot Feeding Property

LCI data for the lot feeding property in the NSW supply chain were produced by FSA Consulting for the MLA project FLOT.328. The methodology and assumptions are briefly described here, and further details can be found in the relevant FLOT.328 project reports.

4.3.1 Greenhouse gas emissions from livestock

As noted for grazing properties (above), the methodology and emission factors described by the NGGIC (2004) are intended for application at a state-wide scale and do not consider property-specific factors. This may result in some inaccuracy. However, in the absence of a suitable alternative approach, we have used the NGGIC (2004) methodology to estimate livestock emissions for the feedlot in this project.

Greenhouse gas emission estimates for the feedlot are presented in Table 13. The methodologies used to derive each estimate are detailed by NGGIC (2004) and are not replicated in this report. The emission sources are briefly described below.

Table 13: Greenhouse gas emission estimates for the lot feeding property

		Methane Emissions		Nitrous Oxide Emissions	
		kg CH_4/yr	t CO_2-e/yr	kg N_2O/yr	t CO_2-e/yr
NSW	2002	611,709	12,845,897	17,899	5,548,653
	2004	926,820	19,463,224	27,312	8,466,591

Enteric methane

The process of enteric methane production is described above (Section 4.2.1). The NGGIC (2004) considers that an appropriate method for estimating enteric methane emissions from feedlot cattle in Australia is the approach devised by Moe and Tyrrell (1979, cited in NGGIC 2004). This method was developed to predict methane emissions from dairy cattle fed diets consisting mostly of high digestibility grains and concentrates and high quality forages, a diet similar to that of feedlot cattle in Australia. The method estimates gross energy intake and the proportion of this energy that is converted into methane. The proportion converted is based on the digestibility of the feed energy at maintenance and the feed intake relative to that required for maintenance.

Manure management: Methane

Methane is also emitted as a result of the decomposition of organic matter remaining in manure under anaerobic conditions. This typically occurs when large numbers of animals are managed in a confined area and where manure is typically stored in large piles or lagoons (IPCC 1997, cited in NGGIC 2004). The NGGIC (2004) method for estimating methane production from feedlot cattle manure is based on the approach of the IPCC (1997, cited in NGGIC 2004), using a combination of default IPCC and country-specific input values.

The default methane conversion factor (MCF) value of 1.5% from the AGO standard methodology was used in the calculation of manure methane for these 'temperate' regions (NSW, Victoria, southwest WA). Thus, no consideration is given for anaerobic (wet pen) conditions in feedlot pens following rainfall. If MCF is typically closer to the 66% for a wet anaerobic pen surface (as estimated by Steed and Hashimoto 1995), then the AGO method under-predicts methane emissions from manure methane.

Manure management: Nitrous oxide

As described above, nitrous oxide is also emitted from manure storage or composting piles. The NGGIC (2004) methodology is based on the IPCC (1997, cited in NGGIC 2004) guidelines, incorporating manure management systems that reflect Australian conditions and taking a mass balance approach where N output = N input - N storage. The key factors influencing the production of nitrous oxide are the amount of N excreted and the emission factor (Nitrous Oxide/N excreted) of the manure management system.

4.3.2 Material and energy inputs

As part of the previous MLA project FLOT.328, the project team collected primary LCI data from feedlot operators. One of these properties was included in the NSW supply chain modelled in the current project. Data collected from the properties included all recurrent energy use (electricity and fuels), material inputs (e.g. feeds, chemicals), water use, and solid waste production. Data on stock purchases, sales and transfers were also collected to quantify each feedlot's production in terms of the functional unit.

Gate-to-gate inventories for the lot feeding property are presented in Appendix B. Cradle-to-gate LCI data for the material and energy inputs are further described in Section 4.5.

4.4 Meat Processing

Meat and Livestock Australia (MLA 2002) has previously published an eco-efficiency manual for meat processing in Australia. It documents the resource use and waste generation data for a typical meat processing plant in Australia, as illustrated in Figure 3. These inputs and outputs are quantified in Table 14.

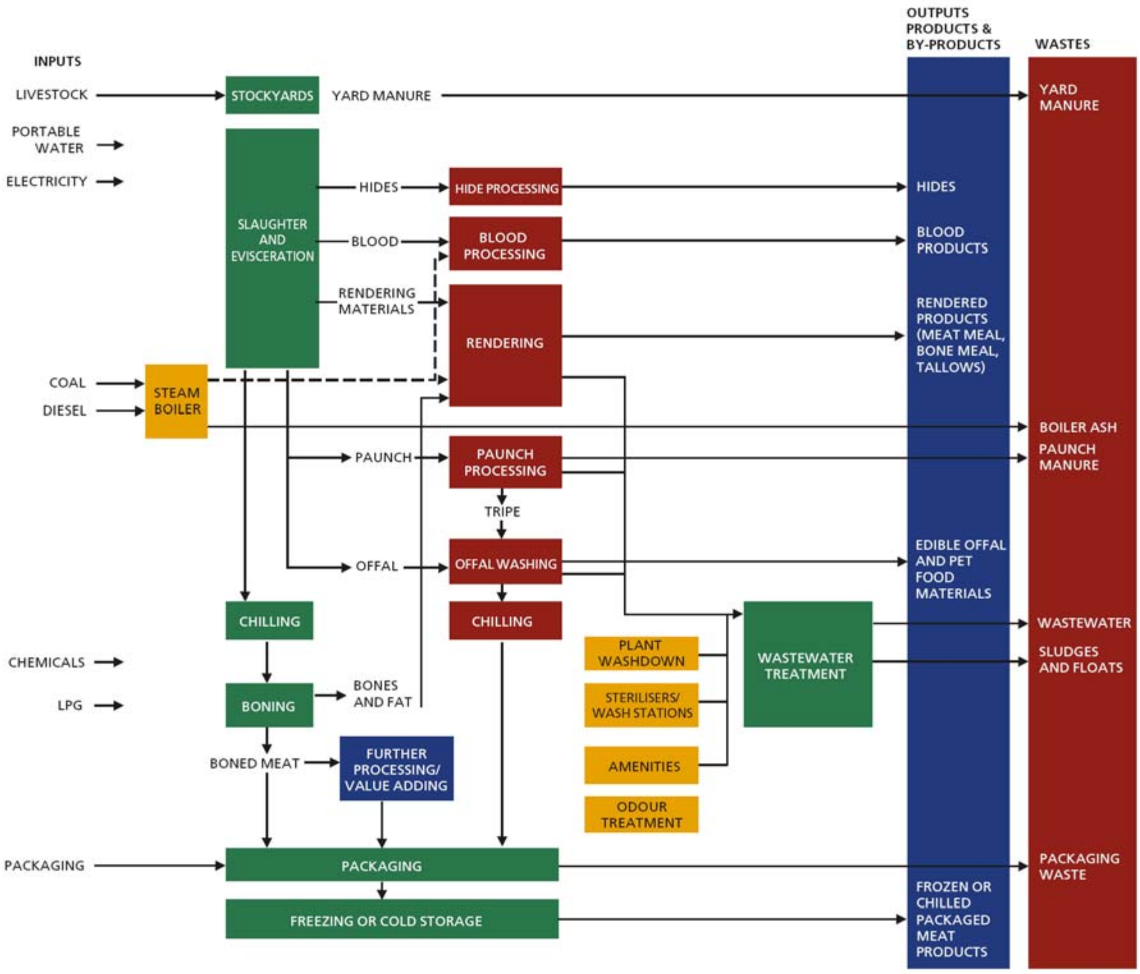

Figure 3: Process flow chart for a typical meat plant showing inputs and outputs (MLA 2002, p 116)

4.5 Inputs to the Agricultural System

4.5.1 Electricity

The Australian Data Inventory Project (CRCWMPC 1999) compiled LCI datasets for high and low voltage electricity production in each Australian state and territory, and as a national average. These datasets take into account regional differences in electricity generation fuels and technologies.

All industrial processes are assumed to operate using high-voltage (HV) electricity supply. Only residential properties are supplied with low-voltage (LV) electricity. As the study contains no *use phase* for the meat (e.g. food preparation using residential power), all electricity in the model is assumed to be HV supply.

Table 14: Resource use and waste generation data for a typical meat processing plant (UNEP Working Group for Cleaner Production, cited in MLA 2002, p 4)

INPUTS		**Daily quantity**		**Per unit of production**	
Water		1,000	kL	7	kL/tHSCW
Energy	Coal	8	t	53	kg/tHSCW
	LPG	113	m^3	0.8	m^3/tHSCW
	Electricity	60,000	kWh	400	kWh/tHSCW
Chemicals	Cleaning chemicals	80	kg	0.52	kg/tHSCW
	Wastewater treatment chemicals	30	kg	0.2	kg/tHSCW
	Oils and lubricants [a]	27	kg	0.2	kg/tHSCW
Packaging	Cardboard	5	t	31	kg/tHSCW
	Plastic	150	kg	1	kg/tHSCW
	Strapping tape	105	kg	0.7	kg/tHSCW
OUTPUTS		**Daily quantity**		**Per unit of production**	
Wastewater	Volume	850	kL	6	kL/tHSCW
	Pollutant load				
	Organic matter (COD)	5,700	kg	38	kg/tHSCW
	Suspended solids	2,055	kg	13.7	kg/tHSCW
	N	255	kg	1.7	kg/tHSCW
	Phosphorous	90	kg	0.6	kg/tHSCW
Solid waste	Paunch and yard manure	7	t	47	kg/tHSCW
	Sludges and floats	6	t	40	kg/tHSCW
	Boiler ash	0.7	t	5	kg/tHSCW
	Cardboard	95	kg	0.6	kg/tHSCW
	Plastic	10	kg	0.07	kg/tHSCW
	Strapping tape	2	kg	0.01	kg/tHSCW

a) Converted from volume to mass assuming a conversion factor of 1100 L/t (Energy Institute n.d.)

4.5.2 Fuels

Diesel

Automotive diesel is used as a direct fuel for many of the processes modelled. Its production was modelled using data from the Australian Data Inventory Project (CRCWMPC 1999). Its combustion was modelled using data from Beer *et al*. (2001, p 314) for diesel combustion in heavy vehicles.

Petrol

Automotive petrol is used as a direct fuel for many of the processes modelled. Its production was modelled using data from the Australian Data Inventory Project (CRCWMPC 1999). Its combustion was modelled using data from Beer *et al*. (1994) for petrol combustion in light vehicles.

Coal

Coal is used as direct fuel for meat processing operations. It was assumed that black coal was used in all cases. LCI data on the extraction of coal in Australia were compiled by the Australian Data Inventory Project (CRCWMPC 1999). These data on black coal extraction for WA (WA supply chain) and NSW (both NSW and VIC supply chains) were used in this project.

Coal combustion also emits greenhouse gases, the quantity of which can be estimated using the following formula (DEH 2006, p 6):

$$\textbf{GHG emissions (t } \mathbf{CO_2}\textbf{-e) = Q x EC x EF/1000}$$

where: **Q** is the quantity of fuel in tonnes or kL
EC is the energy content of fuel in GJ/tonne or GJ/kL, and
EF is the relevant emission factor.

EC and **EF** are reported in Table 15. Emissions are generally expressed in t CO_2-e, which takes into account relatively small emissions of CH_4 and N_2O. It is evident from Table 15 that most of the fuel cycle emissions occur during combustion.

Table 15: Fuel combustion emission factors for coal (stationary energy)

Fuel combusted	EC (gross) GJ/t	EF (combustion) kg CO2-e/GJ	EF (fuel extraction) kg CO2-e/GJ
Black coal – NSW Electricity Generation	27.0 (washed) 23.9 (unwashed)	89.8	7.8
Black coal – NSW other uses	27.0 (washed) 23.9 (unwashed)	88.5	6.7
Black coal – Qld Electricity Generation	27.0 (washed) 23.9 (unwashed)	91.1	2.7
Black coal – Qld other uses	27.0 (washed) 23.9 (unwashed)	88.5	4.6
Black coal – WA Electricity Generation	19.7 (unwashed)	93.1	1.1
Brown coal [a]	10.0	92.7	0.0
Coal used in steel industry	30.0	90.2	20.7
Brown Coal Briquettes	22.1	93.5	10.3

a) No data are available to separately estimate fuel extraction emissions from combustion of Victorian brown coal. Table source: DEH (2006, p 7)

It was assumed that the coal combusted at the meat processing facility is unwashed. This assumption is supported by at least one coal supplier which notes that its coal is either "[blended and] washed to produce coking and thermal coals for the export market or sold as an unwashed thermal coal into the domestic market"(GCL 2007). Using the above data, it was calculated that the combustion of unwashed black coal in NSW or QLD for uses other than electricity generation emits 2115.15 kg CO_2-e/t. This datum was used to model the combustion of coal for heat in meat processing in all three supply chains.

4.5.3 Transport

Throughout the system, transport impact was measured in units of tonne-kilometres (tkm). This facilitated use of existing LCI datasets from the Australian Data Inventory Project (CRCWMPC 1999) which have a functional unit of 1 tkm.

Stock transport

Stock transport from the grazing property to processing was modelled using existing LCI data from the CRCWMPC (1999) database (articulated truck, 28t load, rural). Stock transport to and from the feedlot was reported in terms of the quantity of diesel required and was modelled accordingly using the data on diesel production and combustion described above.

Commodity delivery

Where known, commodity delivery distances were provided by grazing property managers. This was generally the case for feeds and some bulk soil improvers. Delivery distances for other commodities were estimated by locating the producer of each product and utilising an online road transport distance calculator (Sensis 2005).[3] An average Australian trucking process from the CRCWMPC (1999) database was used to model commodity delivery in terms of tkm. Shipping distances for imported commodities were estimated using an online calculator (maritimeChain.com 2000). Shipping was modelled in terms of tkm using existing LCI data for international shipping (CRCWMPC 1999).

Commodity delivery to the feedlot was reported in terms of the quantity of diesel required and was modelled accordingly, using the data on diesel production and combustion described above.

Commodity delivery to meat processing is expected to make a minor contribution and is excluded from the system boundary.

4.5.4 Feeds

Wheat, Barley and Canola

Narayanaswamy *et al*. (2004) compiled LCI datasets for wheat, barley and canola production in Western Australia. The pre-farm and farming datasets from that study were utilised in this project, after conversion to a basis of 1 t of grain produced.

Inventories for the production of these crops are presented in Table 16.

An LCI for canola meal was estimated by multiplying the LCI for canola oil production by 3/7, reflecting the allocation performed by Narayanaswamy *et al*. (2004).

Triticale

Triticale is a cereal hybrid derived by crossing wheat and rye. The soil nutrient requirements of triticale are similar to those of wheat (Mills 2002), although some required inputs may differ. In the absence of specific LCI data, triticale production was modelled as being identical to wheat production.

Grain (unspecified)

Previous Australian LCAs have modelled unspecified grain production based on wheat production Swedish LCI data reported by Cederberg (1998) but more recent Australian wheat production data are now available. Therefore, unspecified grain was represented by the LCI model for wheat described above.

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[3] In using the online distance calculator, it was assumed that delivery trucks would take the fastest route, rather than the shortest route, because they would generally utilise major roads rather than shortcuts.

Table 16: LCI data for grains production (after Narayanaswamy et al. 2004)

	Unit	Wheat	Barley	Canola
Inputs				
Resources				
Land use	Ha	0.47	0.45	0.91
Water (process)	kg	526.35	413.12	1,968.21
Phosphate (ore)	kg	47.56	48.38	121.75
Sylvinite	kg	20.01	18.06	31.52
Materials/fuels				
Auto diesel	kg	5.32	5.16	10.26
Lime stone	kg	58.87	54.83	68.30
Ammonia	kg	4.28	3.36	60.60
CO2 Aus	kg	5.64	4.43	10.30
Steam energy from natural gas	kg	23.42	22.37	45.93
Sulphuric acid	kg	9.70	9.87	23.62
Water demineralised	kg	26.83	28.50	1,509.71
Chemicals organic	kg	4.57	4.84	43.83
Electricity/heat				
Electricity	kWh	8.27	8.31	20.27
Energy from natural gas	MJ	422.82	345.61	16.02
Energy from petroleum	MJ	2.82	2.55	4.44
Outputs				
Grain (net of seed input)	kg	933.74	939.85	994.98
Emissions to air				
Methane	kg	0.13	0.13	0.21
N2O	kg	0.83	0.68	2.47
NOx	kg	0.29	0.13	0.42
SOx (as SO2)	kg	0.11	0.10	0.27
Fluoride	kg	0.00	0.00	0.00
Ammonia	kg	0.01	0.00	0.02
Urea	kg	0.01	0.00	0.02
CO2	kg	57.81	53.04	124.09
CO	kg	7.72	1.16	2.47
VOC	kg	0.24	0.27	0.19
Pesticides (active constituents)	kg	0.03	0.05	0.08
Emissions to water				
Nitrate	kg	0.08	0.06	0.29
Phosphate	kg	0.14	0.15	0.37
Pesticides	kg	0.00	0.00	0.00
COD soluble	kg	0.00	0.00	0.01
Unspecified chlorinated hydrocarbons	kg	0.01	0.02	0.03
Fluoride	kg	0.19	0.19	0.48
Heavy metals	kg	0.00	0.00	0.00
Solid emissions				
Mining waste	kg	9.99	9.03	15.76
Emissions to soil				
Pesticides	kg	0.55	0.50	1.50
Phosphate (agr.)	kg	10.59	9.80	30.00
Nitrate (agr.)	kg	0.00	0.00	63.30
Non-material emissions				
Waste heat to air	MJ	58.15	45.68	217.63

Lupins

Lupins were assumed to be grown without irrigation. In the absence of specific LCI data, lupin production was represented by the LCI model for wheat described above.

Hay

Previous Australian LCAs have modelled hay production based on LCI data reported by Cederberg (1998), which are still the most recent data available and were therefore also utilised in this project. The data are presented in Table 17.

Table 17: LCI data for hay production (after Cederberg 1998)

Inputs		
Diesel	L	81
Fertiliser (urea)	kg	204
Land (cropping area)	Ha	1
Electricity	kWh	200
Outputs		
Glyphosate to agricultural soil	kg	0.324
Hay	kg	5700

Minerals

Cederberg (1998) reports that the key ingredients of mineral fertiliser are lime, phosphoric acid (as P_2O_5), magnesium oxide and dicalcium phosphate. In-keeping with that work, mineral fertiliser was modelled as a mixture of 65% lime and 35% P_2O_5, the production of which was represented by existing LCI datasets for crushed limestone and phosphate fertiliser. The energy required to produce one tonne of mineral fertiliser was taken to be 1080 MJ of electricity and 1080 MJ gas (consistent with Cederberg 1998).

Molasses

The Australian Data Inventory Project (CRCWMPC 1999) compiled LCI datasets on sugar production processes. An LCI model for molasses was constructed based on the existing data for raw sugar production, combined with data on the ratio of molasses to raw sugar (3:14) obtained by a producer (Manson 2007).

Other feeds

No LCI data were available for feed materials such as fluffy cottonseed and tallow. In these cases, data were obtained using an input-output approach described later in this chapter.

4.5.5 Fertilisers and soil modifiers

Ammonia

Ammonia was modelled using LCI data from the Australian Data Inventory Project (CRCWMPC 1999).

Cobalt sulphate

Cobalt sulphate was modelled from its component ingredients in the GaBi4 database. The production energy requirement was unknown but presumed to be relatively small, and was therefore omitted.

Ferric chloride

Ferric chloride was modelled using existing LCI data from previous work.

Lime

Crushed limestone was modelled using existing LCI data from previous work.

MAP and DAP (Mono- and diammonium phosphate)

Monoammonium phosphate and Diammonium phosphate were modelled from their component ingredients in the GaBi4 database, based on stoichiometry. The component ingredients were not fully represented but informed approximations were drawn where required. The final stage production energy requirement was unknown but presumed to be small, and was therefore omitted.

Pivot 15

Pivot 15 is predominantly a N and P fertiliser. Production of Pivot 15 was modelled based on the production of DAP as the most similar N/P fertiliser.

Sulphate of ammonia

Sulphate of ammonia was modelled from its component ingredients in the GaBi4 database, based on stoichiometry. The production energy requirement was unknown but presumed to be small, and was therefore omitted.

4.5.6 Pesticides and other chemical inputs

Pesticides and other chemical inputs – such as animal husbandry requirements – are used in relatively small quantities compared to inputs like fertiliser. There are also no readily-accessible LCI data on their production requirements. Therefore, the production of these items was excluded from the system boundary of the process analysis. However, this constitutes part of the result for the extended supply chain analysis using IOA.

Data on non-nutrient emissions to soil were not gathered for this project because the analysis of toxicity impacts, for which such data are often gathered, is not within the project scope.

4.6 Outputs from the Agricultural Production System

4.6.1 Manure

Manure is a significant output from all stages of the production system. However, on the grazing properties and the feedlot, the manure is not considered a waste because it is internally recycled within the defined production system. The results for solid waste are presented in Section 5.1.5 both including and excluding the yard and paunch manure produced by meat processing.

4.6.2 Saleable products

The method and assumptions used in modelling production are discussed in Section 4.8.1.

4.7 Expanded Supply Chain (Input-Output Analysis)

The research team developed a sophisticated hybrid model to improve the accuracy of LCA by incorporating IOA results, as described in Section 2.2.

The required input for the IOA model is simply a list of a producer's expenditure, itemised in as much detail as is practicable from the producer's viewpoint. These data were provided by managers of the three grazing properties and were estimated for the feedlot using year-adjusted commodity prices and known quantities purchased. The raw expenditure data are not reported here because of confidentiality considerations.

The calculation using the hybrid model involved two major steps. First, the expenditure data were assigned to industry sectors as defined in the model (see Appendix C). Second, the location of the interface between the process-based and input-output parts of the model was defined. The definition of the interface location based on the extent to which each of the industry sectors is included in the process analysis. This overcomes the potential for double-counting (for example, where expenditure on fuel is recorded and its production is also modelled in the process analysis). As discussed by Rowley (2005), these 'depths' of investigation are an average estimate only as in reality they cannot be as simply defined as they are here. 'Depth' in this case refers to the number of economic transactions there is between a final consumer and an economic activity occurring upstream in the supply system leading to that consumer. The locations of the system interfaces for each supply chain and year, in terms of the depths of production orders included in the process analysis, are presented in Table 18 for those industry sectors and system components for which we used input-output analysis to complement the process data.

Table 18: 'Depths' of production orders included in the process analysis

System component		WA farm	WA farm	VIC farm	VIC farm	NSW farm	NSW farm	NSW feedlot	NSW feedlot
Year		2002	2004	2002	2004	2002	2004	2002	2004
Industry sector									
0102	Grains	4	4	4	4	4	4	4	4
2108	Other food products	n/a	n/a	n/a	n/a	3	3	n/a	n/a
2501	Petroleum & coal products	3	3	3	3	3	3	n/a	n/a
2502	Basic chemicals	n/a	n/a	3	3	3	3	n/a	n/a
3601	Electricity supply	3	3	3	3	3	3	n/a	n/a
3701	Water supply; sewerage & drainage services	3	3	n/a	n/a	3	3	n/a	n/a

4.8 Relating LCI Data to the Functional Unit

4.8.1 Quantifying production

The functional unit of this LCA is defined as "the delivery of 1 kg of HSCW meat to the meat processing works product gate".

In many industries, production and sales are relatively constant and inventory is small. Such a model was applied to the lot feeding property, where net HSCW gain was quite easily modelled as the difference between outgoing and incoming HSCW.

However, in the context of a grazing property, the 'production cycle' exceeds the annual study period and stocking rates can be highly variable. For example, a grazier may choose to hold off selling or buying stock due to market price fluctuations or environmental factors (e.g. feed availability). For the grazing properties, it is therefore sensible to consider production of carcase weight that is not sold during the study year.

The project team derived a methodology to correctly account for all incoming and outgoing transactions on a grazing property plus production of HSCW not exported from the property. This methodology is now described.

4.8.2 Net HSCW gain in each cattle class

For simplicity, it was assumed that all animals within a class grow at the same rate, whether they were initially present on the property or bought during the year. Livestock classes and growth rates for livestock on the three supply chain properties are shown in Table 19 and Table 20. The livestock classes used reflect common age brackets reported by the property owners (calf age is through to weaning at seven months as practiced on the supply chain properties) and also to reflect the National Greenhouse Gas Inventory Committee (NGGIC 2006) age brackets (> 1 year, 1-2 years, > 2 years). All livestock were distributed into these categories and final weight gain from the property data was determined by using a livestock production model based on the growth rate multiplied by the number of days that an animal remains within a particular class.

Growth rate data sourced from the NGGIC (2006) were significantly lower for cattle and sheep in young livestock classes (< 2 years) compared to growth rates observed on the supply chain properties. Growth rates for the supply chain properties were estimated from average weight (sale weight, purchase weight, weaning weight) and age of livestock in each class. The growth rates are averages over the life of the animal to the point of sale and may vary with season, however this could not be accounted for without detailed growth rate data and is not expected to result in significant error. This is contrasted to the NGGIC (2006) growth rate data which supply variable growth rates across seasons. This may leave room for error in animal classes that are only present on farm for one season (such as calves born in spring of the survey year) but this will be slight.

Table 19 – Livestock classes and growth rates for the cattle supply chain properties

Livestock Class	Growth rate from NGGIC* (kg lwt/hd/day)	Growth Rate from property data (kg lwt/hd/day)
Calves 0-7 months	0.63	0.75 – 0.86
Weaners 7-12 months	0.63	0.86 - 0.9
Steers / Heifers 12-24 months	0.3 – 0.63	0.3-0.94
Cows > 2 years	0.23 – 0.33	0
Bulls < 1 year	0.62 – 0.68	0.9
Bulls > 2 years	0.25 – 0.46	0

* Data quoted are averages over 12 months for the class of livestock in Victoria and NSW. The ranges shown are where two different figures are supplied for the two states.

Trade lambs on the WA supply chain property had a growth rate three times higher than the NGGIC (2006) data, largely in response to grain feeding on this property. Lambs are regularly weighed and growth rates were reported by the farmer.

Property observed growth rates varied significantly in the mature cattle classes (cows and bulls over 2 years) compared with the NGGIC (2006) data. The NGGIC (2006) provide average growth rates in the order of 0.23-0.46 kg lwt/hd/day for mature breeding stock compared to an estimated zero growth rate for the supply chain properties.

Mature animals generally cease to grow after approximately 2-3 years. This brings into question the accuracy of the NGGIC data for mature cattle. For example, if it is assumed that an Angus cow reaches a liveweight of 450 kg at two years, then continues to grow at 0.23 kg/day through to ten years, the final liveweight of the cow will be over 1100 kg, which is clearly not the case in practice. One exception was made to the zero growth rate for mature age cattle. If cows were culled and finished for slaughter, the growth rate of 0.23 kg/hd/day was applied for these animals for the six months prior to slaughter to account for weight gain as these animals are finished.

Table 20 – Livestock classes and growth rates for the sheep supply chain property

Livestock Class	Growth rate from NGGIC* (kg lwt/hd/day)	Growth Rate from property data (kg lwt/hd/day)
Lambs 0-7.5 months (Merino)	0.11	0.14
Lambs 0-7.5 months (Crossbred)	0.11	0.25
Weaners 7.5-12 months (Merino)	0.08	0.07
Trade Lambs 10-14 months (Merino & Crossbred)	0.08	0.3
Ewes < 1 year	0.04	0.04
Ewes > 2 years	0.0	0.0
Rams > 2 years	0.0	0.0

* Data quoted are averages over 12 months for the class of livestock in WA.

Using growth rates estimated from records on the supply chain properties rather than NGGIC (2006) growth rates generally led to higher total HSCW production estimates. In years where large numbers of young livestock were present on farm this increased productivity is quite marked.

This reflects an important aspect of the system boundary concept in respect of the determination of environmental burdens associated with imported energy, materials and livestock. For all materials (including hay and grain) brought onto the property, resources and emissions associated with producing the material are included as an input to production. Livestock (young and mature animals) are treated differently to crop products because they are not only an input to the property, but also bring with them an amount of product not produced on-farm. That red meat is not included in the calculation of the system's productivity for two reasons:

(1) Imported animal growth occurs outside the temporal boundaries of the study (not produced in the 2002 or 2004 calendar years) and therefore subject to other climatic and business conditions. This project (CMP094) has to be consistent with the related feedlot

project (CMP328) and it was agreed early in the process that they would both focus on production within these calendar years.

(2) Imported animal growth involves production of the functional unit that occurs outside the geographic boundaries associated with the systems under study (where we are able to perform detailed pasture modelling and assessments of the other inputs to production).

So because the growth of purchased weaners did not occur in a location for which detailed data were available nor in the years the study aims to compare, both this red meat produced outside the system and the environmental burdens associated with producing it are consistently excluded from the calculus. By excluding this information we get a more accurate picture of what happens within the properties that make up the system under investigation. It also means that using the indicator data per HSCW from this study to estimate the total environmental burdens of the Australian red meat sector will produce an underestimate – but generalising from three very different production systems to the whole sector would be very inaccurate in any case. One alternative would be a longitudinal study of a particular animal or group of identifiable animals – an LCA of animal life rather than a particular supply system. Another would be to expand the system by adding the interannually variable and potentially large number of breeding properties to it, making it meaningless to compare production within the system year-on-year and creating a task which would either be outside the scope of the project budget or based on very broad literature averages. Our systems analytical approach reflects inter-annual variation in process chain resource use, for example when in some years the relevant properties were engaged in producing weaners and in other years had a different business practice focused on finishing cattle produced elsewhere. It brings new primary data to light rather than relying on old averages. This point is elaborated further in the discussion of the results.

4.8.3 Allocation

In this LCA, some individual process units generate more than one saleable product. For example, a grazing property may produce livestock, wool and grain.

To assign environmental burdens to the functional unit in a system with multiple outputs standard LCA practice uses a procedure known as allocation as described by the International Organization for Standardization (Blamey et al. 1998).

Allocation may be based on mass or energy flows, or economic value. In general, ISO (1998) recommends allocation on a mass basis over allocation on an economic basis. However, it recognises that in some cases, where co-product prices per unit of mass are very disparate, economic allocation may be more relevant. In this work we have, for completeness, calculated the results of the LCA on both bases.

Allocation was done at the scale of individual process units (e.g. grazing property, feedlot, processing) because relative production rates vary between the process units. Mass and economic allocation factors used are summarised in Table 21 and their formulation is described below.

Grazing properties

The grazing properties under study produced multiple products, i.e.:

- HSCW
- Non-HSCW liveweight components (e.g. offal, tallow, hides)
- Wool
- Grain

Data were collected from each property on the relative mass and economic value of outputs produced, and these were used to assign an appropriate proportion of the LCI to the HSCW production system. Year-adjusted commodity prices were used to supplement these data where economic values were unavailable.

In the case of the grazing property in the WA supply chain, which produces a large mass of grain for sale as well as livestock, we allocated 100% of the livestock greenhouse gas emissions to the livestock production system (then further allocated to HSCW). This was not necessary for the other supply chains where livestock dominated production and/or grain products were for on-farm use.

Table 21: Allocation data for process units

			Allocation factors (kg HSCW relative to total production)			
			Total		Excluding grain sold	
Supply chain	Year	**Stage**	**Mass basis**	**Economic basis**	**Mass basis**	**Economic basis**
WA	2002	Farm	0.09	0.34	0.35	0.42
		Processing	0.44	0.89		
	2004	Farm	0.17	0.49	0.39	0.54
		Processing	0.45	0.89		
NSW	2002	Farm	0.39	0.38		
		Feedlot	0.59	0.89		
		Processing	0.59	0.89		
	2004	Farm	0.41	0.48		
		Feedlot	0.59	0.89		
		Processing	0.59	0.89		
VIC	2002	Farm	0.59	0.86		
		Processing	0.59	0.86		
	2004	Farm	0.56	0.86		
		Processing	0.56	0.86		

Feedlot

The feedlot in the NSW supply chain produces finished cattle for two markets. This LCA was interested in the premium export supply chain. The cattle produced for this market exhibited 73% of the total HSCW gain on the property but consumed 76% of feed (i.e. they were slightly less efficient feed converters than the cattle produced for the local market). The research team assumed that the LCI would be proportional to feed consumption and allocated accordingly, then further allocated to HSCW production.

Meat processing

Figure 4 indicates a theoretical mass balance for a typical beef processing plant in which HSCW accounts for 55% of liveweight by mass. Based on this figure and on data relating to the economic value of carcase components (MLA 2007), we established that in a conventional meat processing works, HSCW accounts for 89.4% of liveweight, in terms of economic value.

In the case of the Victorian supply chain, which is an organic supply chain, we assumed a higher offal retention rate, as suggested by recent research (Radford 2005; 2007). This did not affect the mass allocation but reduced the relative economic value of the HSCW component to 86.0% of liveweight.

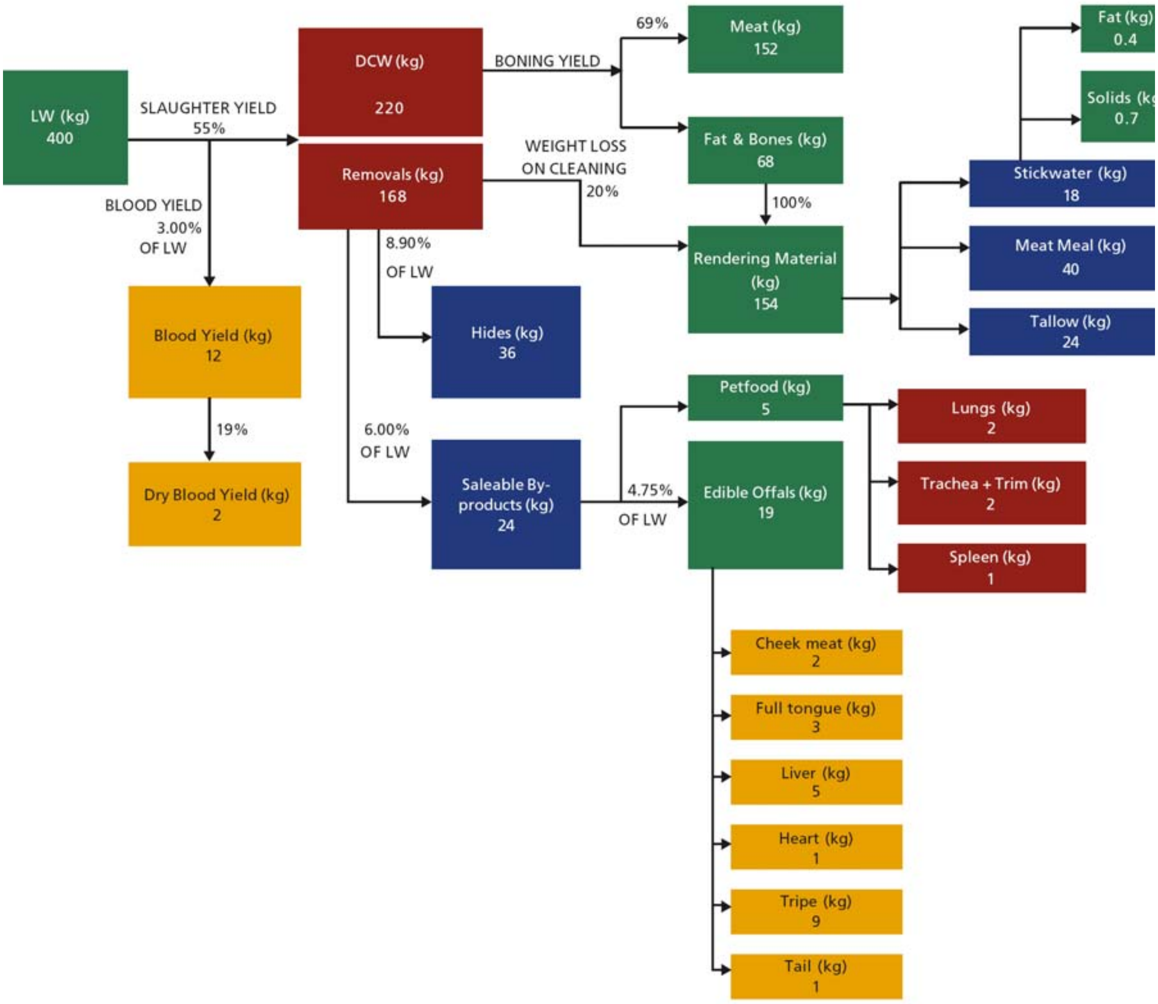


Figure 4: Theoretical mass balance for a beef processing plant (MLA 2002, p 89)

5 Life Cycle Impact Assessment: results and discussion

5.1 Conventional LCIA Indicators

5.1.1 Global warming potential

The contribution each supply chain makes to climate change is summarised in Figure 5. The results indicate that the differences between the performance of the three systems is potentially of a similar magnitude to the differences in performance of at least the Victorian system between years. This is due in part to the different product mixes of the three supply chains.

We might have expected the beef supply chains to perform better on the basis of per head data. For example, focussing on enteric methane data (the principal greenhouse gas emission) for 2002, the average daily emission rate in the NSW supply chain was equivalent to 0.18 kg CH_4/hd/d for cattle which typically produce between 200 and 250 kg HSCW on slaughter. The corresponding figures for sheep in the WA system that year are 0.02 kg CH_4/hd/d and 18 to 21 kg HSCW. However, cattle are kept on the grazing property longer on average than lambs and sheep before slaughter and this may partly account for the superior performance of the WA supply chain. Typical cattle lifespans prior to slaughter are 18 to 24 months for the Australian markets, or 2-3 years for premium export markets. Lambs are typically turned off between 10 and 18 months of age. While our data do not permit us to calculate animal ages for the three supply chains, animal lifetime will have influenced the results.

As discussed previously, it is also important to be aware of the effect of inter-annual fluctuations in the kind of agricultural business being run at the properties we studied. Particular attention is drawn to the Victorian property which in 2002 operated as a finishing enterprise for traded cattle purchased as weaners. Since this type of system excludes the breeding stock needed to produce the weaners, greenhouse emissions are lower than a system including these cattle. Total enteric methane emissions are 34% lower in 2004 but HSCW gain is 44% lower, contributing to a 40% higher global warming potential per kg HSCW. Similarly, lamb purchases by the WA property varied significantly between years (zero in 2002 and 20% of exports in 2004) and the number of bred lambs was higher in 2004. These two factors contributed approximately equally to the farm producing 76% more HSCW gain for only a 33% increase in total enteric methane emissions, contributing to a 13% improvement in the global warming potential result on a HSCW basis. These two cases illustrate the responsiveness of the model to such changes in the underlying systems.

Another factor is the allocation of non-animal greenhouse gas emissions on and off the grazing properties. In the case of the WA supply chain, a very large quantity of grain is produced for sale which reduces the allocation factors associated with non-animal greenhouse gases on this property. Additionally, the animal-associated greenhouse gases (methane and nitrous oxide associated with enteric processes and manure) are allocated to wool and meat in the WA sheep meat supply chain. This is discussed further in Section 4.8.3.

The other key message apparent in these results is the significance of the feedlot in the overall burden of the supply chain. The WA and Victorian supply chains do not include a feedlot. In the WA supply chain, animals are supplementary fed in the paddock for finishing prior to slaughter. In the NSW supply chain, the feedlot is responsible for a significant portion of the total GWP of the whole supply chain despite the relatively short time period in which the cattle are at the feedlot compared with the grazing property. However, this should be considered in relation to the weight gain for that period. The comparison between grass and grain finished cattle is taken further in Section 5.3.1.

The data by activity shown in Figure 6 is split into supply chain stages in Figure 7 (the grazing properties), Figure 8 (the feedlot) and Figure 9 (the meat processing works). In the figures "onsite" refers to emissions occurring on the farm, feedlot or meat processing property, as distinct from those which occur at other locations in the total supply system. For GWP, this includes enteric methane, and methane and nitrous oxide derived from manure.

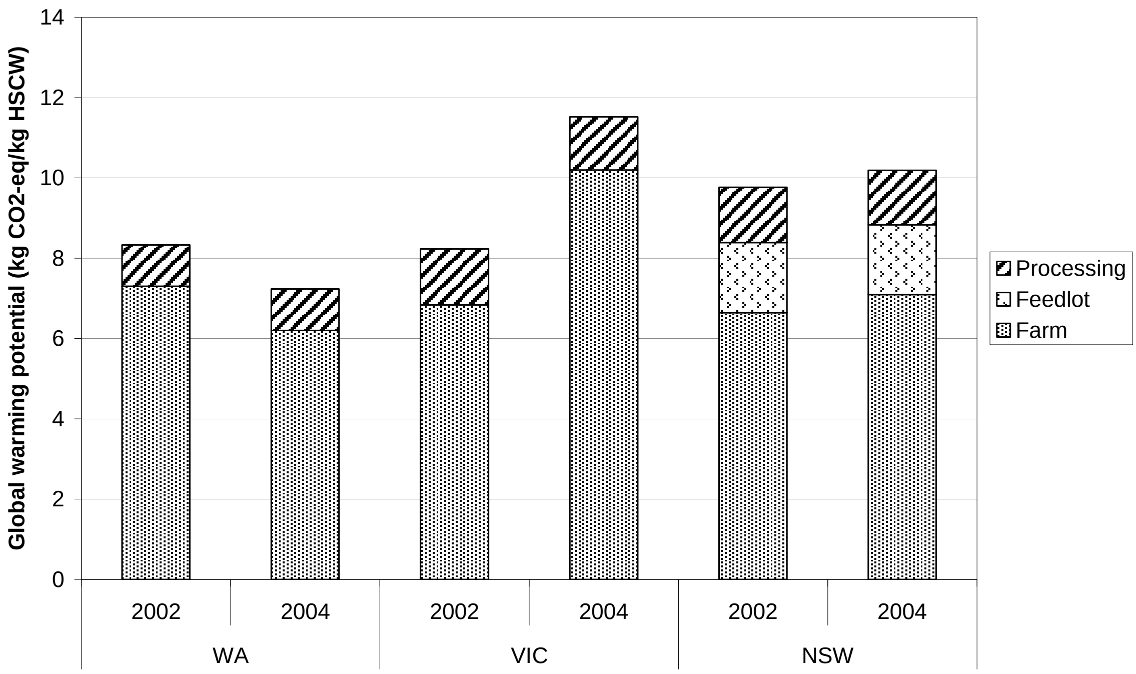


Figure 5: GWP contributions in the entire supply chain (by stage)

The contributions of different supply-chain processes to the overall picture are shown in Figure 6. As might be expected, the main source of greenhouse emissions in the supply chain is the animals themselves. Enteric methane produced at the grazing property or feedlot accounts for most of the greenhouse gas burden from the three supply chains because of the relative strength of methane as a greenhouse gas.

The pie charts for the grazing property operations are relatively consistent in terms of the overall distribution by emitting activities. The main differences relate to the activity we have labelled "chemical production". This is significantly larger in the Victorian supply chain because of the farmer's purchase of a relatively large amount of soil improving additives: particularly lime, basalt rock dust, flyash, organic humates and zeolite. The farmer had purchased the property in a suboptimal state with a view to making a significant initial investment in soil quality so it is unlikely that this activity will make as large a contribution to this property's greenhouse gas emissions in future years.

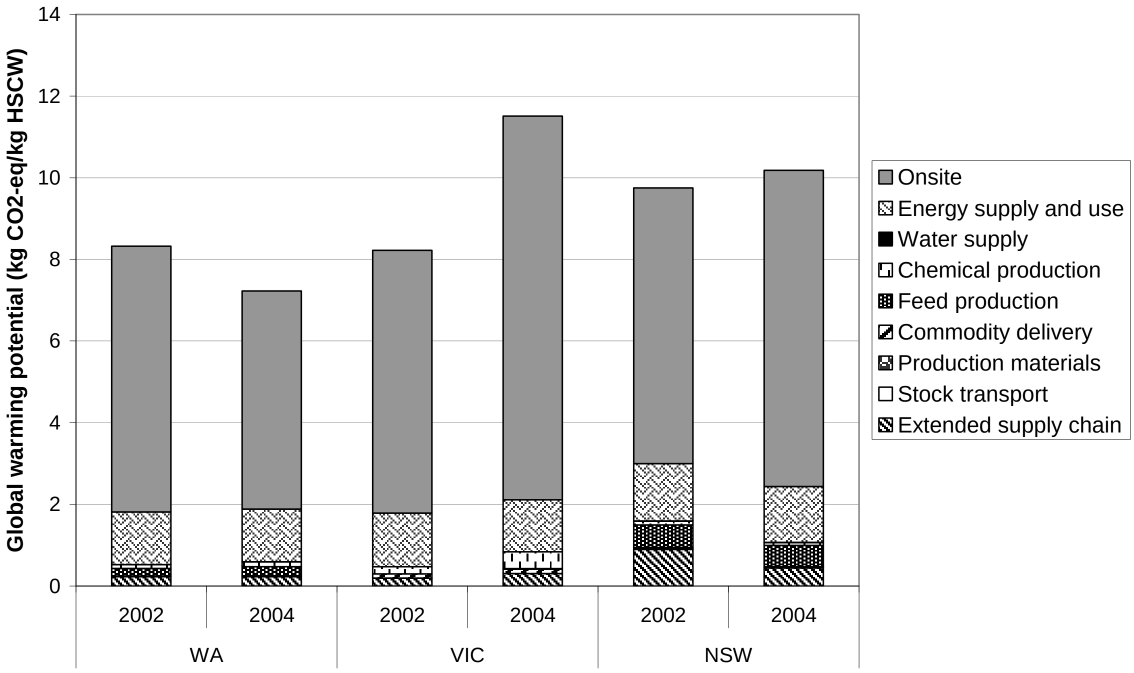


Figure 6: GWP contributions in the entire supply chain (by activity)

Energy consumption at the grazing property in the WA supply chain is relatively high as a proportion of the total values compared with the other two grazing properties. This may be explained by the operation of a form of low-density feedlot for finishing sheep, and the use of energy in the preparation of feed for this operation.

As previously noted, only one feedlot operation (part of the NSW supply chain) is considered. The main source of greenhouse gas emissions is, as it is at the grazing property, enteric methanogenesis. As expected, the production of feed for the feedlot is a significant component of the total burden of the NSW operation at 13-14% of the total figure. A reduction in the burdens associated with the extended upstream supply chain is apparent at the NSW grazing property when comparing 2002 and 2004 in Figure 6 and Figure 7. This is because of expenditure in the former year only in relation to tree management, which is a relatively greenhouse gas-intensive industry.

Unlike the grazing properties and feedlots, the GWP of the meat processing facilities is dominated by their energy demand as shown in Figure 9. The contribution associated with other non-livestock inputs to the facilities is small. The main difference between the three states is due to the greater allocation of processor environmental burdens to meat relative to offal in the case of beef producers. Allocation of these burdens is made on the basis of average dressing percentage, which is higher for the beef product than the sheep meat product. The variation between the transportation effort associated with getting cattle and sheep to the processing facility is small - less than 2% of the total figure. There is also some variation due to slightly different electrical energy supplies in each state.

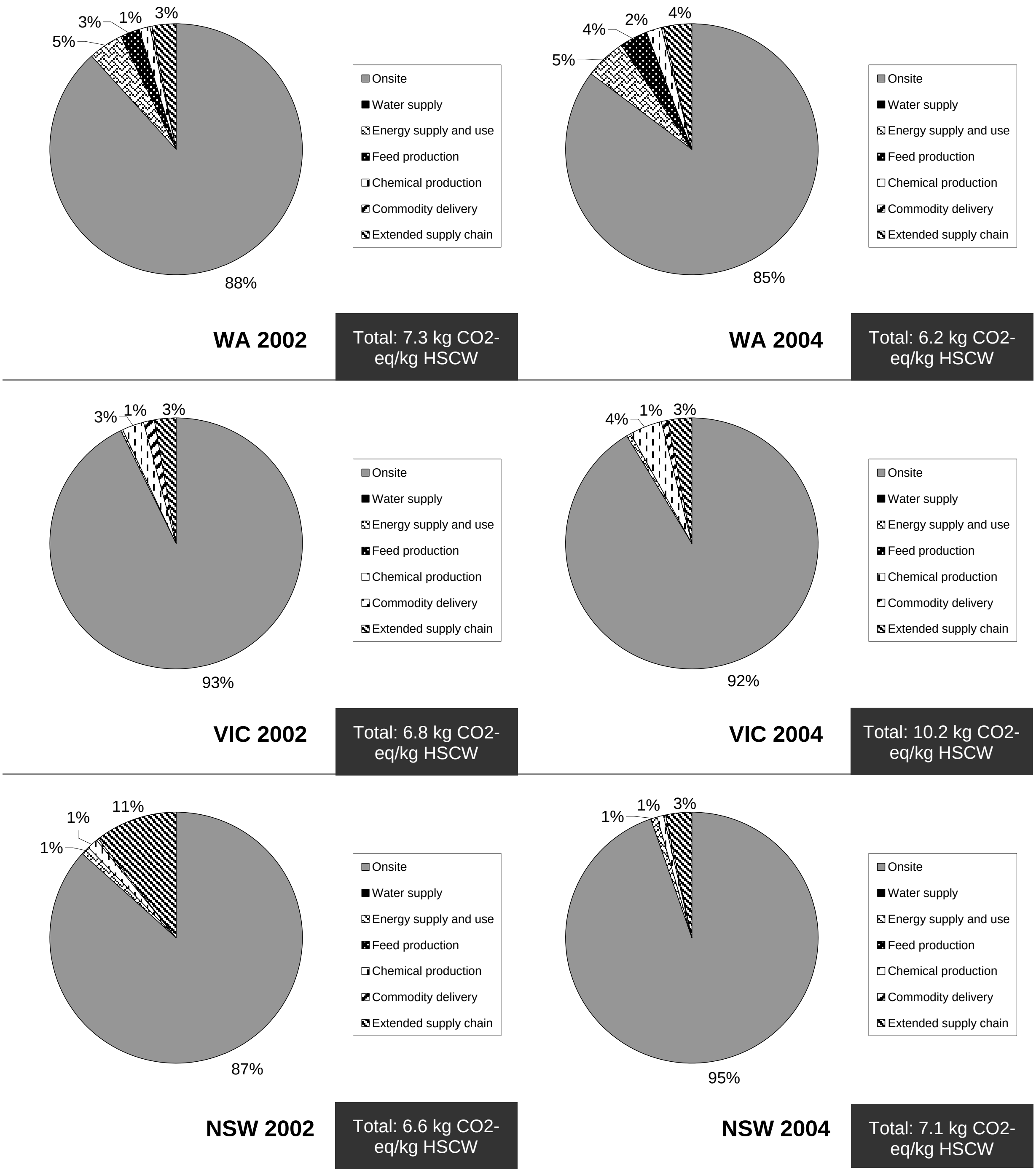


Figure 7: GWP contributions of activities at each of the grazing properties

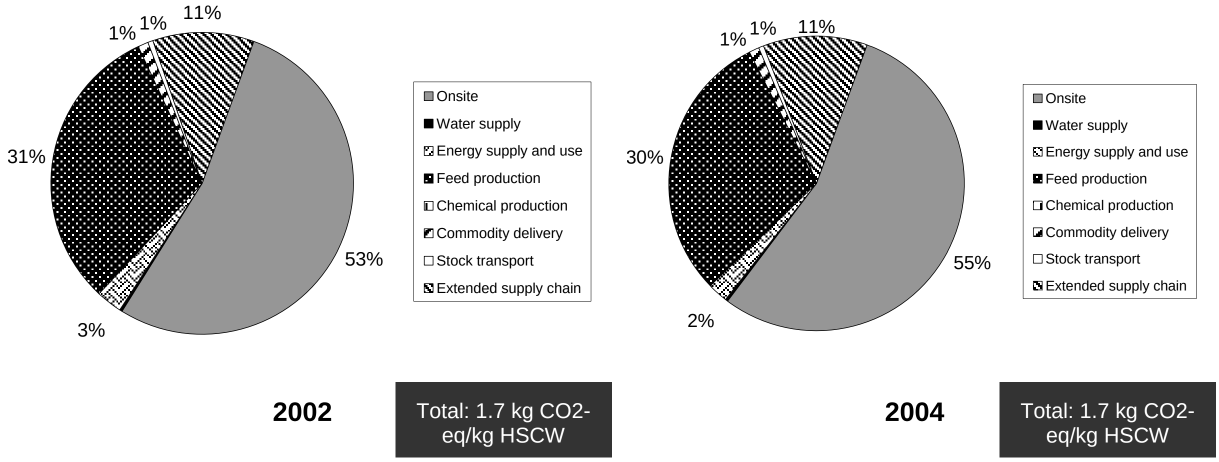


Figure 8: GWP contributions of activities at the feedlot (NSW)

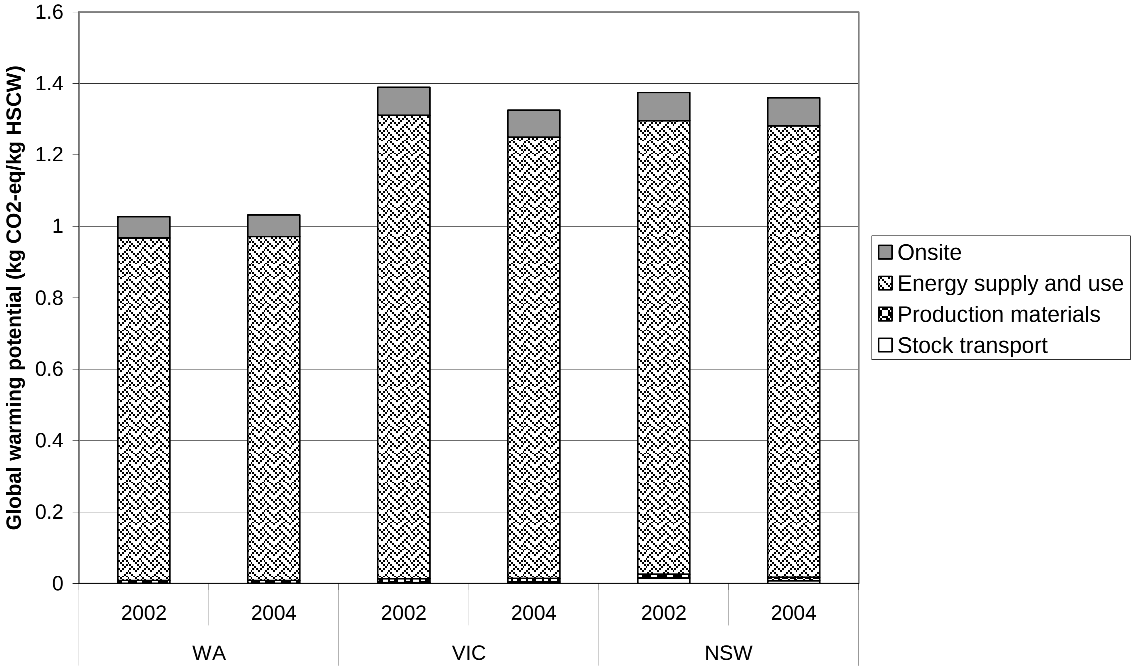


Figure 9: GWP contributions of activities in meat processing

5.1.2 Primary energy use

Primary energy use in LCA often reflects the consumption of electricity. This is because of the relatively low efficiency of electricity generation in terms of the chemical energy available in the original fuel. This chemical energy has to be converted to thermal energy, then pressure head, mechanical momentum and finally electrical potential – a large number of transformations, each causing a loss of efficiency. The LCA results shown in Figure 10 reflect this norm – the primary energy consumption of the supply chains is dominated by the processing facilities with their large refrigeration equipment.

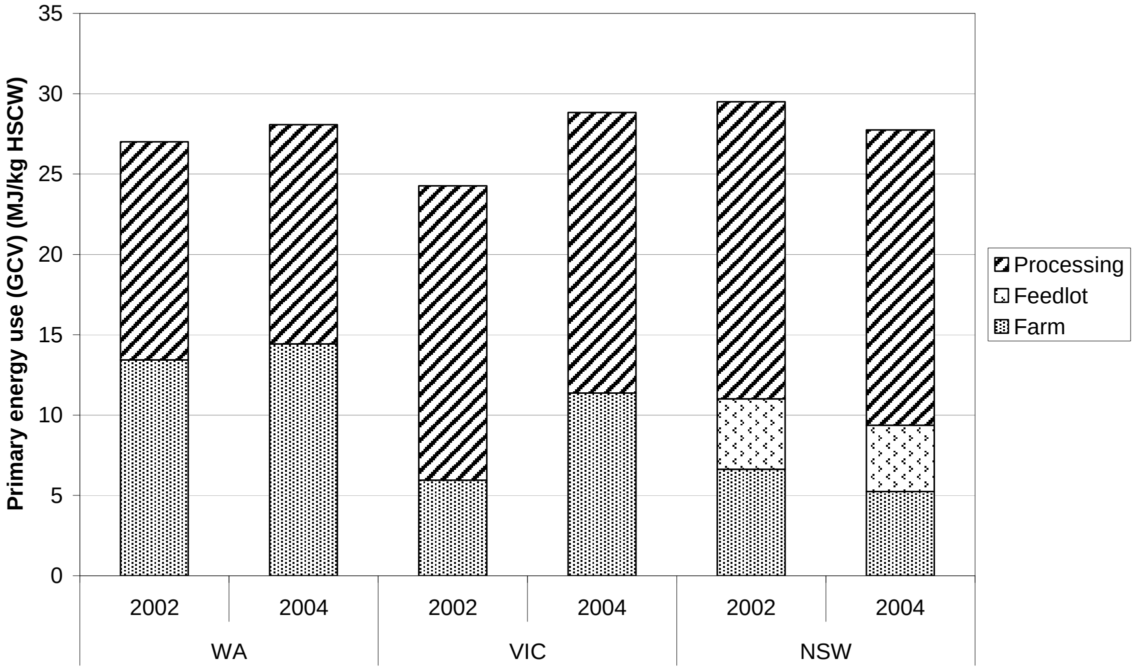


Figure 10: Primary energy use in the entire supply chain (by stage)

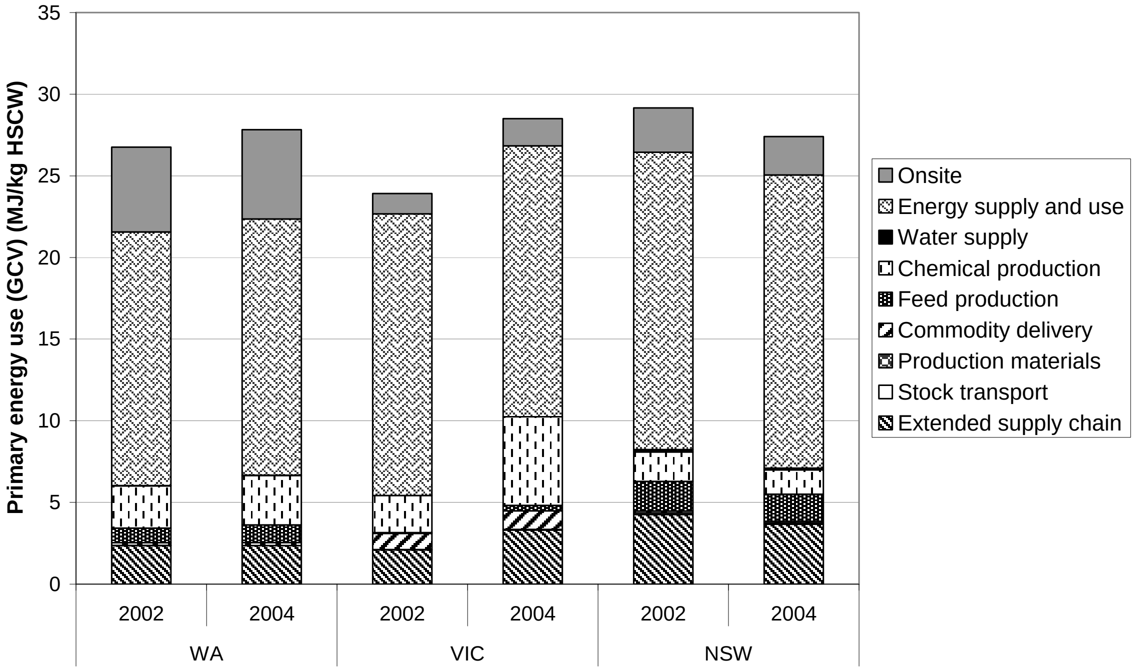


Figure 11: Primary energy use in the entire supply chain (by activity)

Figure 11 and Figure 14 emphasise the significance of refrigeration equipment by the scale of "energy supply and use" relative to the production of other supply-chain inputs. Note the significant input of primary energy to the provision of soil modifiers for the Victorian supply chain as discussed in Section 5.1.1.

Despite the relatively consistent total figures, Figure 12 shows significant variation between the energy consuming activities at the grazing property. Electricity use on the property is counted in "Energy supply and use" on account of the coal combustion occurring offsite, so "Onsite" refers to fuel combusted on site (i.e. generally diesel and petrol supplies). The proportion of onsite energy demand is naturally higher at the larger properties: the WA grazing property is the largest, followed by the NSW property. The area of the Victorian property is an order of magnitude smaller than the other two and its topography is the flattest.

The other factor varying considerably is the energy demand associated with the extended supply chain. In NSW, significant expenditure in the agricultural services industry (which includes cattle selling costs and shearing) contributed to energy consumption in the extended supply chain. All three grazing properties made significant expenditure in this category and on freight and the Victorian grazing property had significant agistment costs.

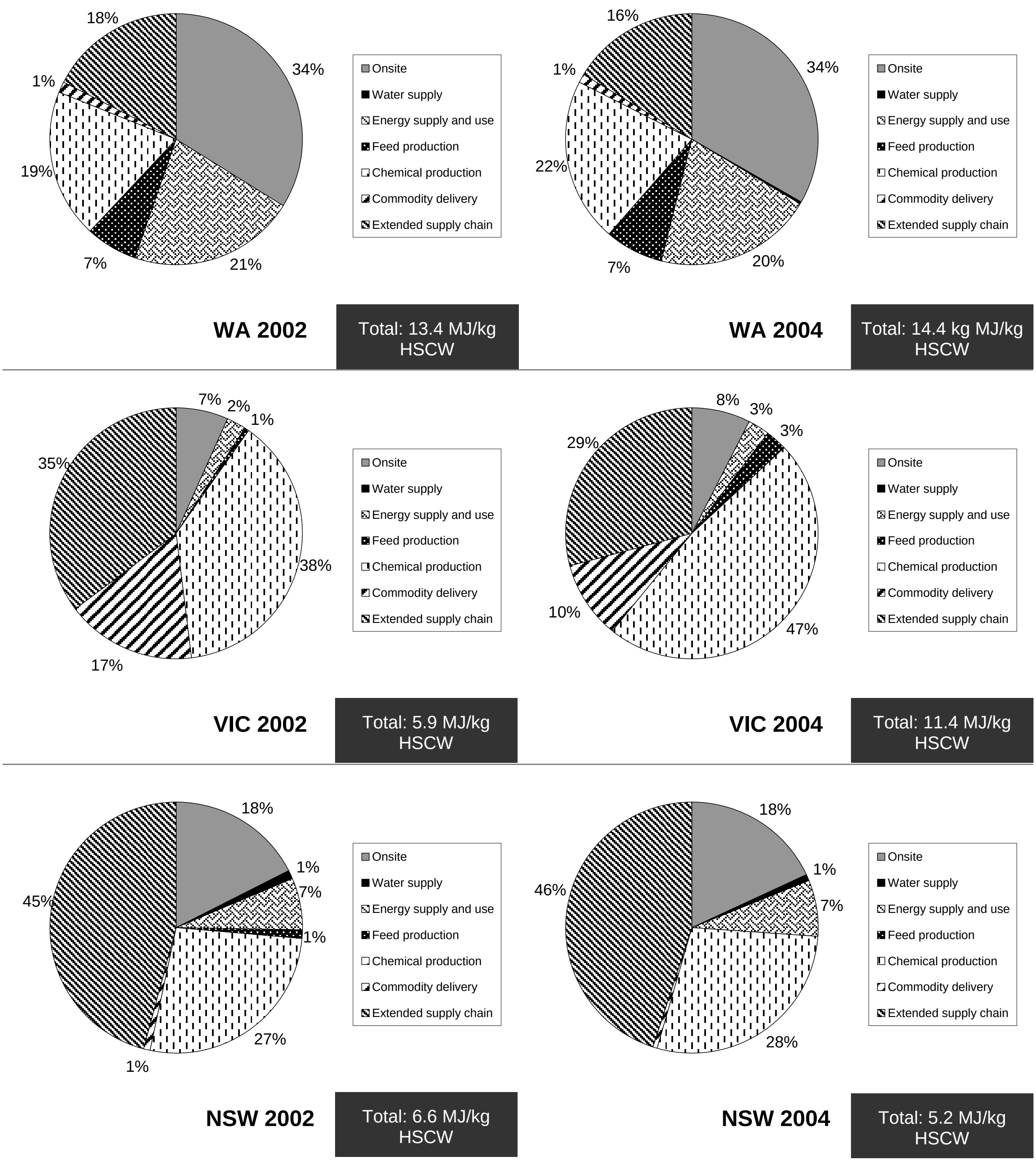


Figure 12: Primary energy use of activities at each of the grazing properties

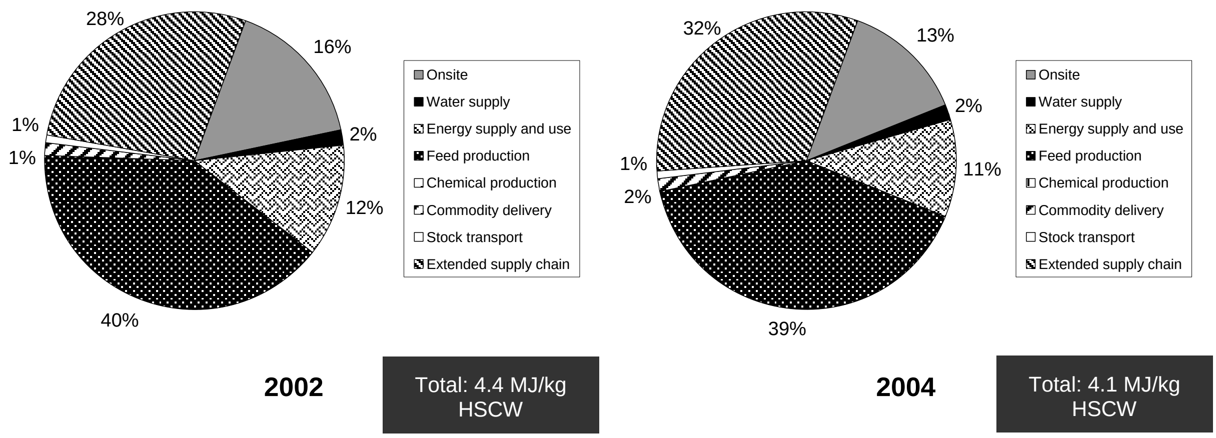


Figure 13: Primary energy use of activities at the feedlot (NSW)

The feedlot energy demand shown in Figure 13 presents a very different picture to the greenhouse gas results in Figure 8, demonstrating a more significant contribution made by feed production. The significant components of these pie charts associated with the extended supply chain also relate mainly to feed production. This accounts for feeds for which there was no available process-based LCA data, such as fluffy cottonseed, tallow, and supplementary feed mixes.

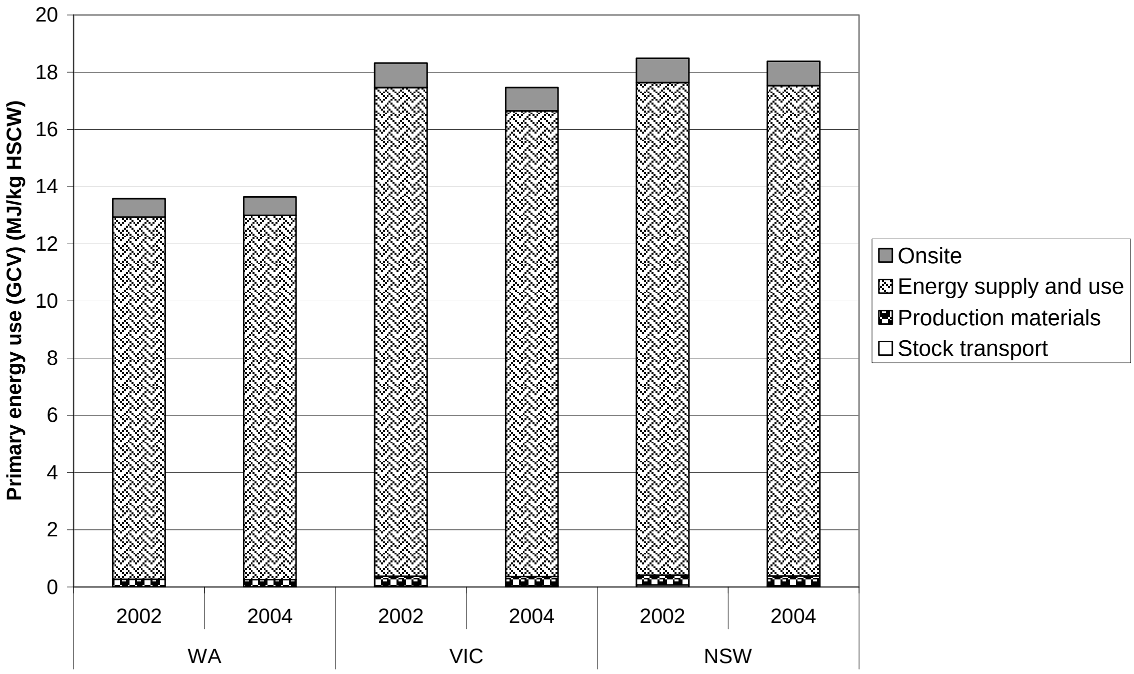


Figure 14: Primary energy use of activities in meat processing

5.1.3 Water use

Water use estimates are reproduced here from a previous report for completeness. However, the definition of water use is currently a subject of wide-ranging debate in LCA methodology circles, and the full report, which is included as Appendix E, should be cited rather than these results, as a full definition and interpretation of the water use estimates is included there.

Table 22 – Water use (should not be cited without reference to the full report)

Production system	**Victoria**		**WA**		**NSW**	
Production year	2002	2004	2002	2004	2002	2004
Water use definition						
ABS - water transferred from source	27	40	214	136	540	464
"net use" - water quality low or alienated	46	52	22	18	34	49

5.1.4 Water quality (eutrophication potential)

Eutrophication potential is an indicator of nutrient contributions to aquatic ecosystems. Like GWP, it does not demonstrate that a particular eutrophication endpoint (e.g. an algal bloom) has or will take place. Rather, it aggregates the nutrient inputs that may contribute to eutrophication according to their relative potential to cause problems, in a manner analogous to the way GWP aggregates contributions to possible effects on the atmosphere.

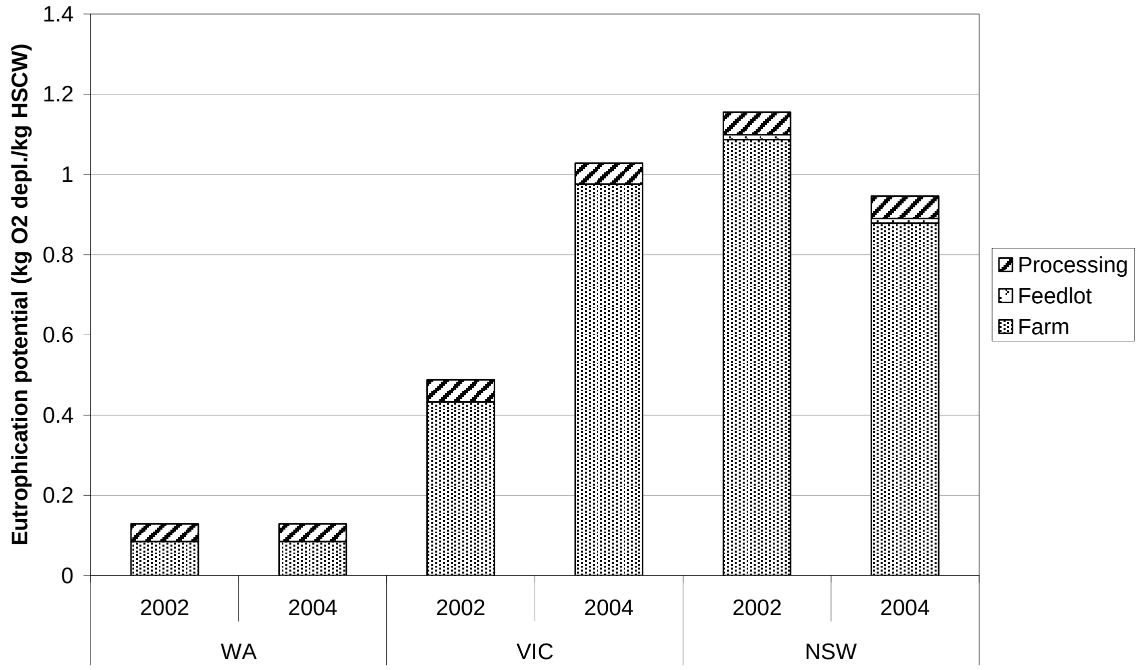


Figure 15: Eutrophication potential contribution in the entire supply chain (by stage)

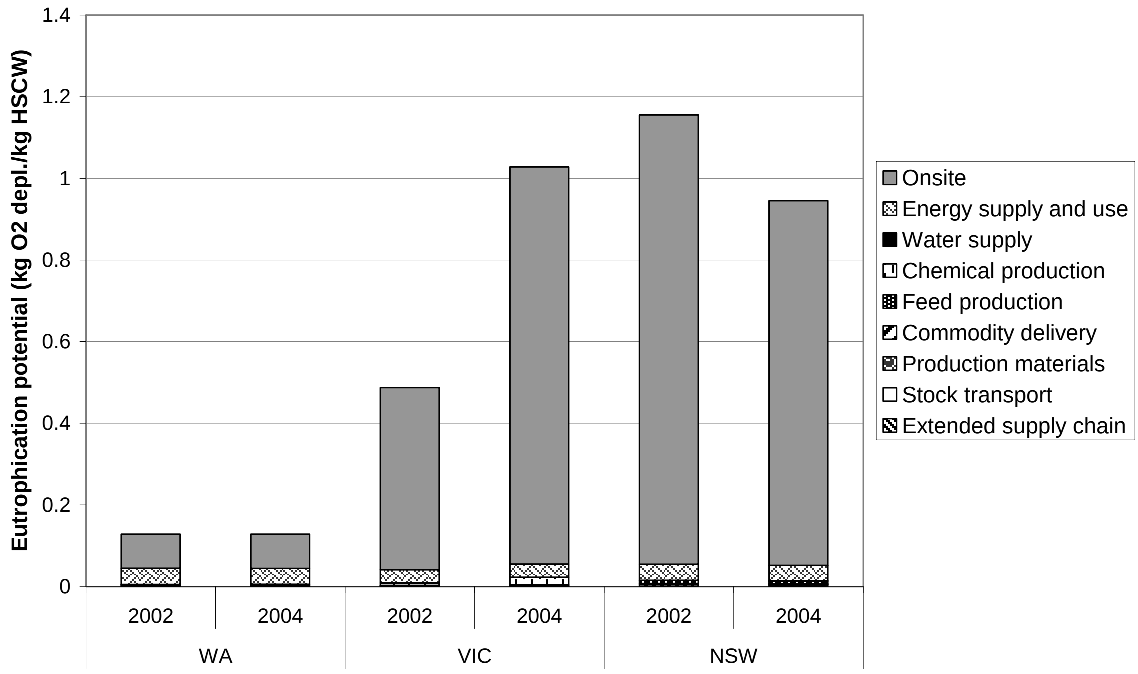
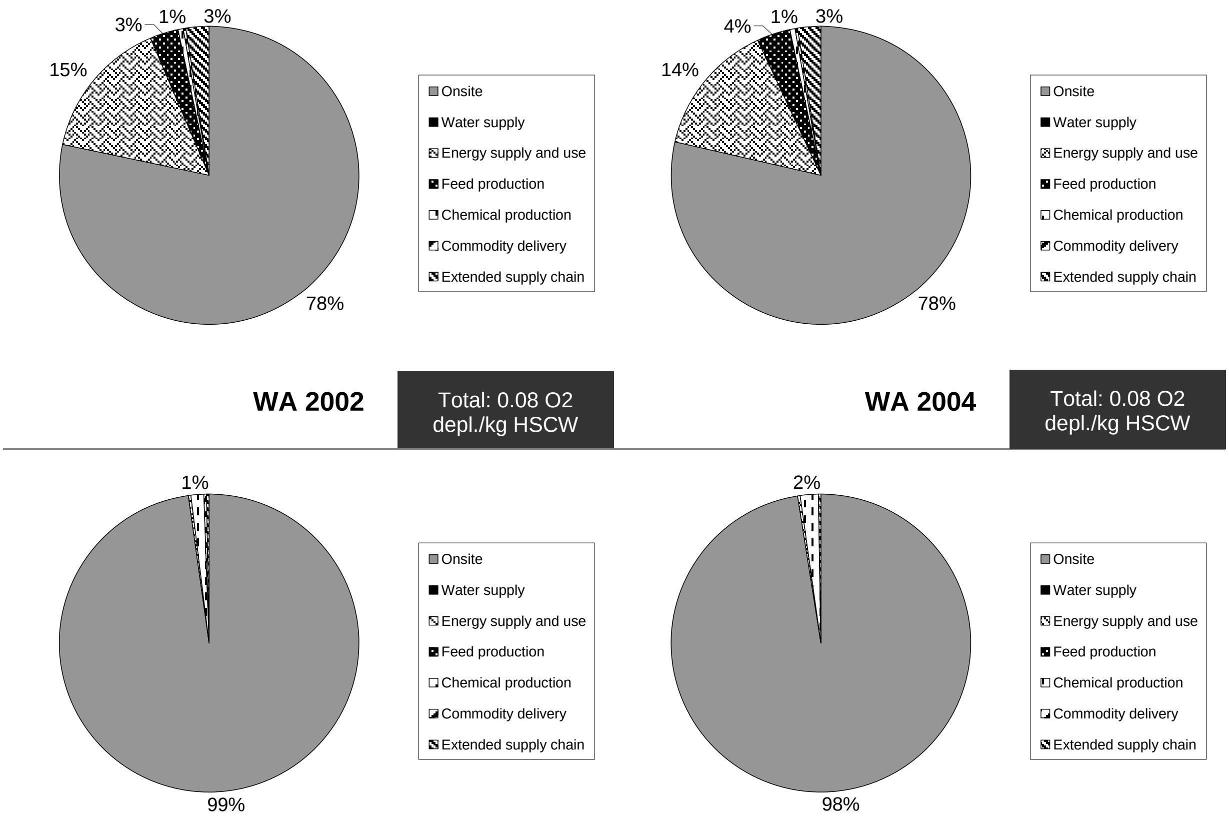


Figure 16: Eutrophication potential contribution in the entire supply chain (by activity)

The eutrophication potential data provided in Figure 15 and Figure 16 show that this environmental indicator is dominated by grazing property inputs and that these inputs are quite variable compared to the other LCA indicators discussed thus far. The differences between the WA supply chain and the other two arise from two principal factors. One is the contribution from soil erosion at each grazing property. Estimated soil erosion at the WA property is relatively low. The other is the contribution of dissolved nutrients associated with runoff, which is assumed to be 0.2 kg/ha/y in WA and 3.0 kg/ha/y for the other two grazing properties on the basis of Ridley (2003). These two factors favour WA by an order of magnitude.

The small contributions to the overall eutrophication figures made by the feedlot and the meat processing works are shown in Figure 18 and Figure 19 respectively. For the feedlot the most important components of the total figure are feed production and the extended supply chain. As previously noted, much of the extended supply chain figure relates to feed supplies for which there were no available process LCA data, so it is clear that feed production accounts for more than two thirds of the eutrophication potential of the feedlot.



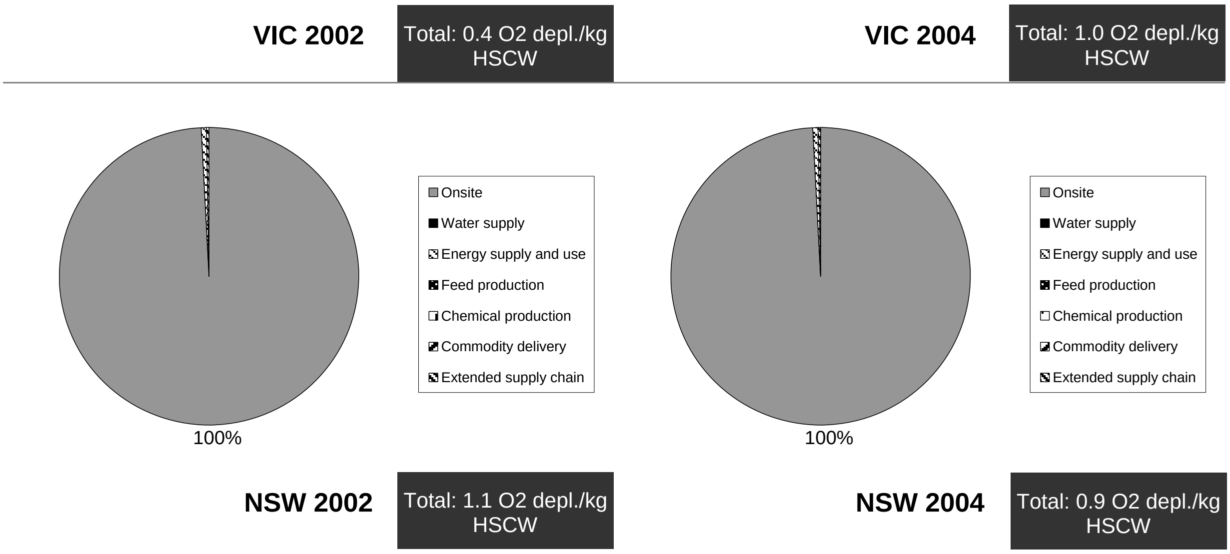


Figure 17: Eutrophication potential of activities at each of the grazing properties

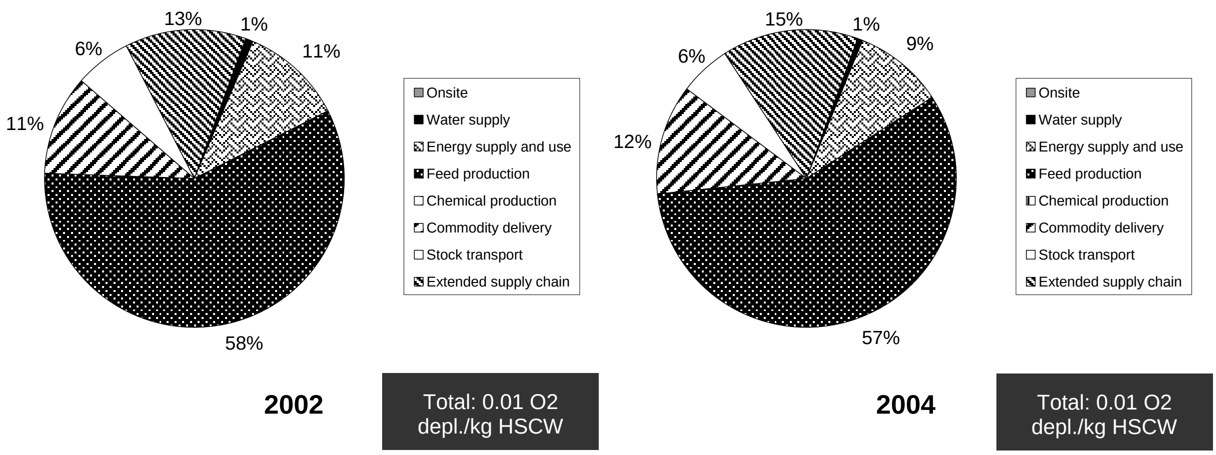


Figure 18: Eutrophication potential of activities at the feedlot (NSW)

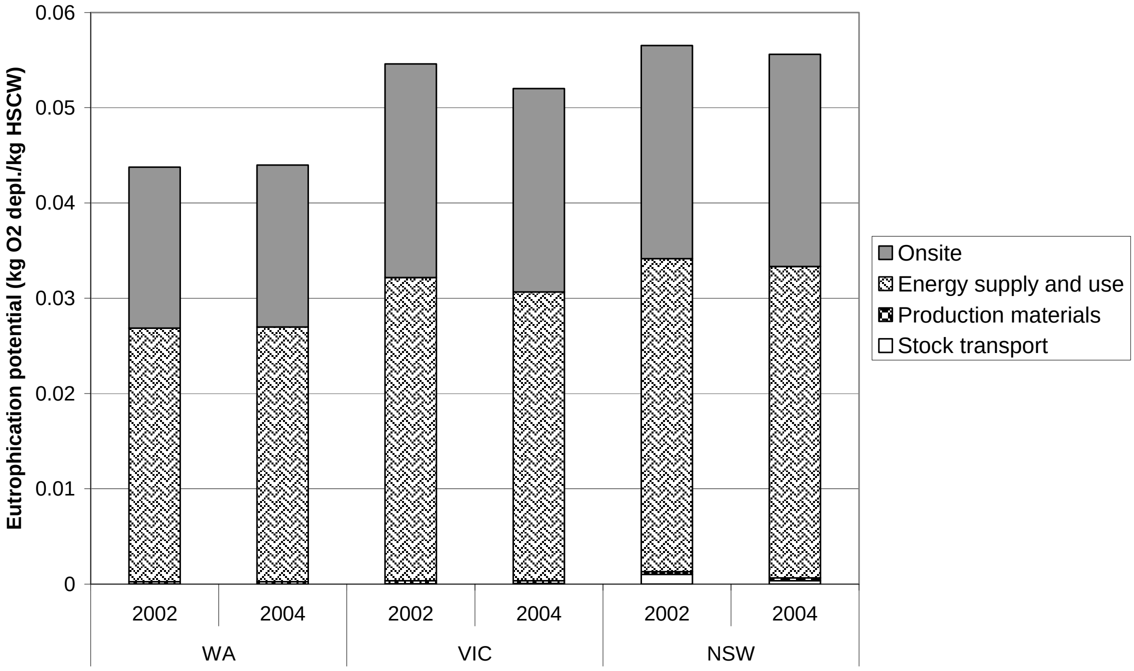


Figure 19: Eutrophication potential of activities in meat processing

Most of the eutrophication potential in the meat processing operations is the consequence of energy supply. This reflects the emission of significant quantities of N oxides by coal-burning electrical power stations. Although these are emissions to the atmosphere, they account for the majority of the substances responsible for eutrophication of freshwater bodies. However, all activities at the meat processing facility are insignificant when compared to the on-farm activities.

5.1.5 Solid waste generation

Solid waste including manure

As foreshadowed in Section 2.6, we present the data for solid waste on two bases. Firstly, we include paunch and yard manure from the meat processing works. This material is produced at a centralised processing facility and typically requires waste management outside the boundaries of the processing works. So from this point of view it may be appropriate to include this waste in the total solid waste data.

On the other hand, it is inappropriate to consider manure wastes produced at the grazing property or feedlot as solid wastes. In those two contexts, they may be spread around parts of the property used for pasture or crop production, whether by machinery on feedlot paddocks or by the animals themselves on grazing properties. So the same definition of solid waste may not be appropriate for the entire red meat supply chain. In this section we show the solid waste flows from both points of view.[4]

The total solid waste generation of each supply chain, including paunch and yard manure from the meat processing works, is shown in Figure 20.

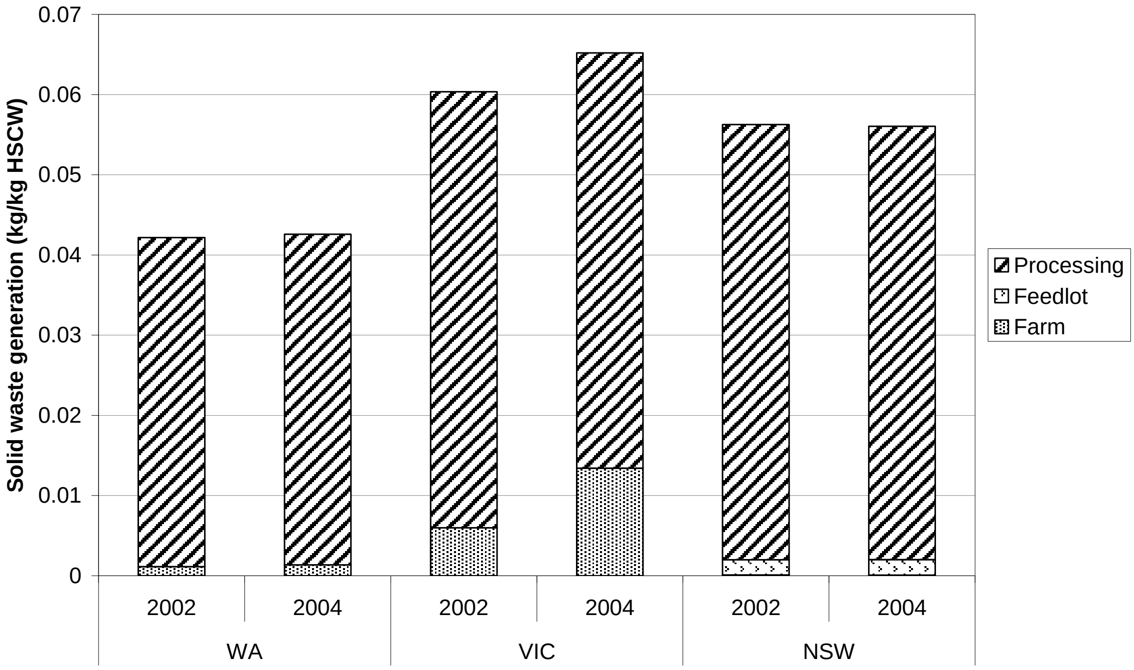


Figure 20: Solid waste generation in the entire supply chain (by stage)

[4] Note that, since this variation in the definition only affects the meat processors, we have only included figures excluding paunch and yard waste for the total solid waste flows and the flows at the meat processors.

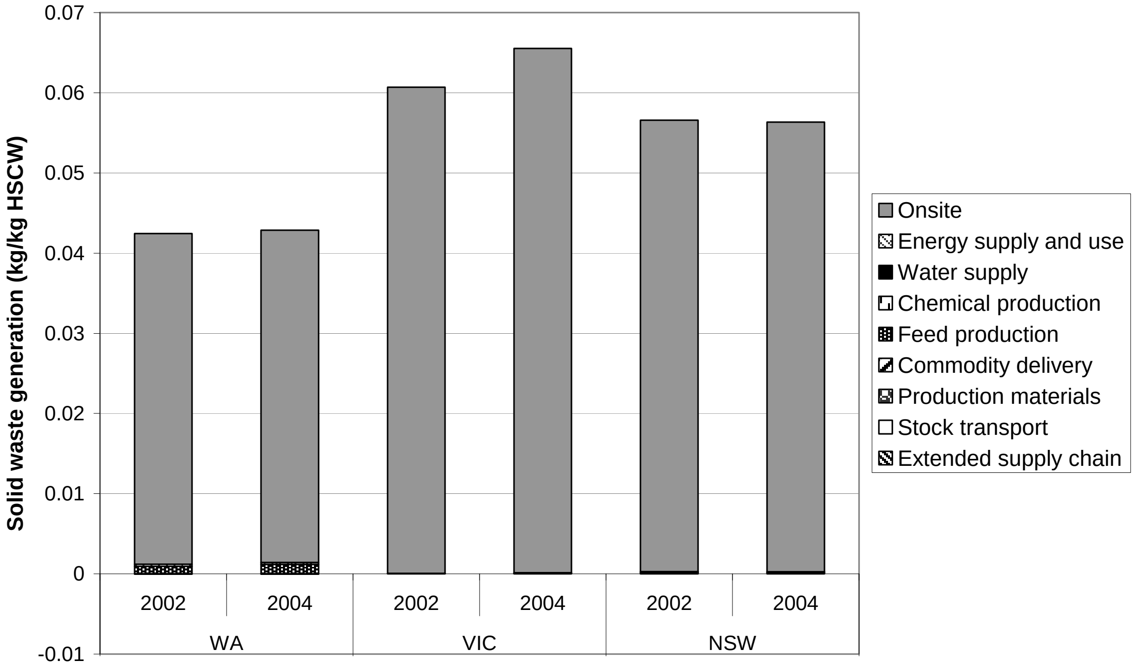


Figure 21: Solid waste generation in the entire supply chain (by activity)

Comparing Figure 20 and Figure 21, it is clear that most of the waste generated in the supply chain arises onsite, whether at the meat processing works or the grazing property, with most produced at the meat processing works. Comparing these figures with Figure 25, Figure 26 and Figure 27 we can see that yard and paunch manure are approximately half of the total solid waste produced by meat processors.

The waste flows from grazing properties are not rigorously reported and were estimated by the research team in discussion with the property managers. While solid waste was identified as an issue of concern by the project stakeholders as a whole, it does not appear to be a major issue for the property managers in practice. For the Victorian supply chain, on-farm solid waste could not be estimated. This is a relatively small grazing property and it may be that the small quantities of solid waste arising from its operations can be managed by the regular council waste collection processes.

Consequently, when LCI calculations are made regarding solid waste at the grazing property, the proportions due to different aspects of the production process vary considerably (see Figure 22). In the case of the WA supply chain the principal waste source is a consequence of feed processing while in the Victorian case it is onsite waste generation and for the NSW supply chain it is the production of chemicals. We do not regard this data as adequately accurate to inform policy initiatives in the area of waste minimisation other than indicating the potential for improved (continuous) data collection.

The same is true of the waste data from the feedlot operations. In our feedlot data collection project (FLOT.328) we noted that most feedlots responding to the survey did not have good records of solid waste disposal. However, the data supplied indicated that the amounts were very small when expressed on a per kg HSCW basis. Waste reduction occurs through the recycling of solid wastes (old tyres, spent oil, waste paper) by many feedlots.

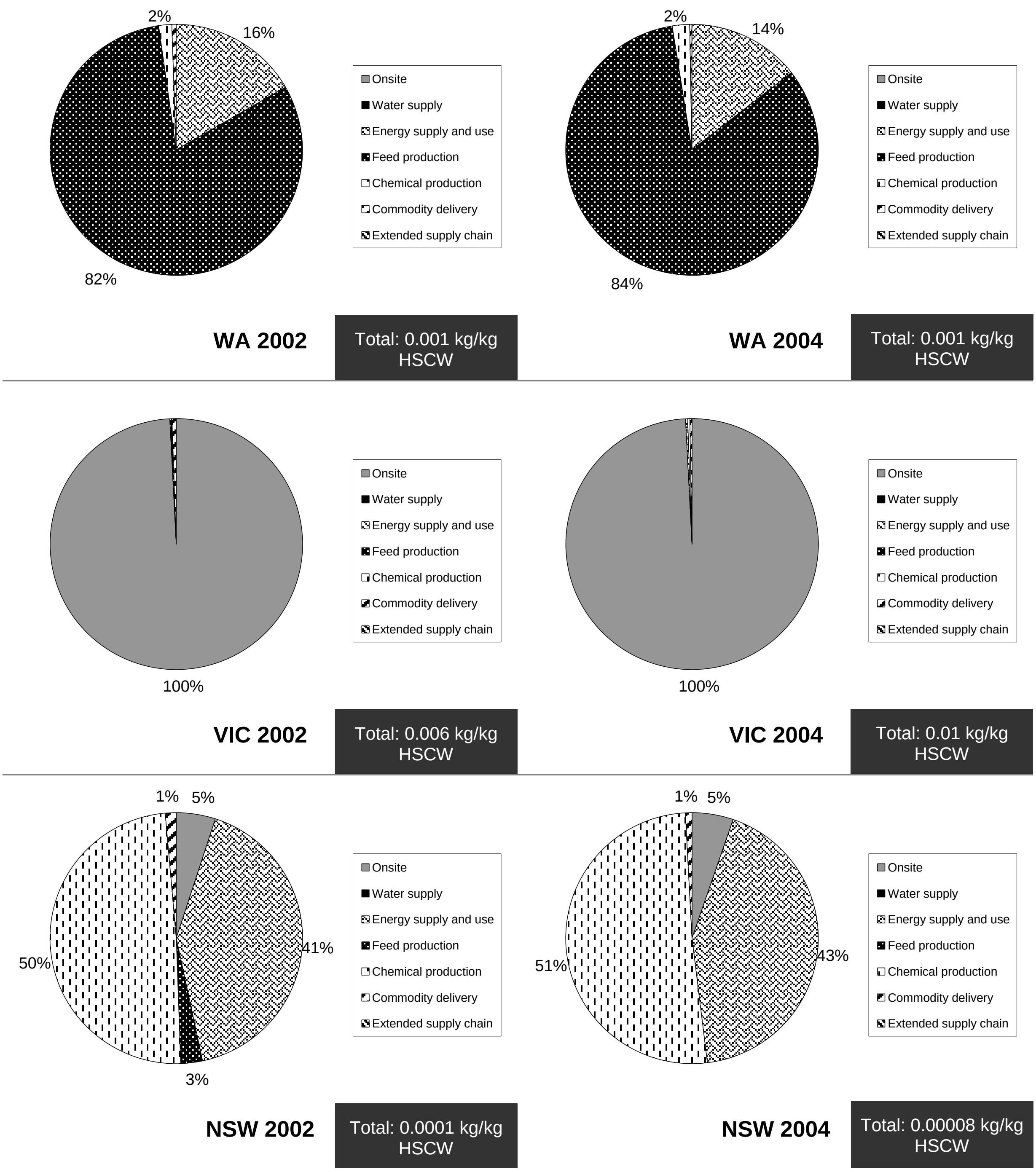


Figure 22: Solid waste generation by activities at each of the grazing properties

Data on waste generation at the meat processing works were available from MLA's study of these operations (MLA 2002).

The inorganic waste identified in the LCI phase of this project was predominantly plastic packaging associated with feed or seed-grain inputs. A very small waste credit is evident in Figure 24 due to production materials. Inspection of the GaBi database indicated that this is related to the production of sodium hydroxide. Sodium hydroxide is an important cleaning chemical in meat processing works but there is no recent LCI database for Australian sodium hydroxide production. We therefore used European data for this chemical, which seems to indicate municipal waste as a small part of the energy supply for the relevant facilities. This is why some "production materials" appear below the x-axis in the figure.

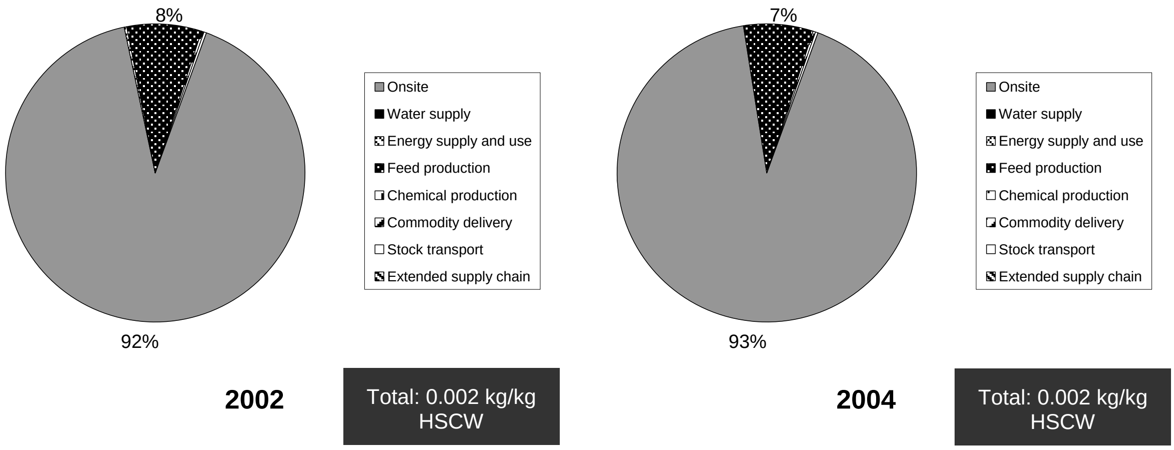


Figure 23: Solid waste generation by activities at the feedlot (NSW)

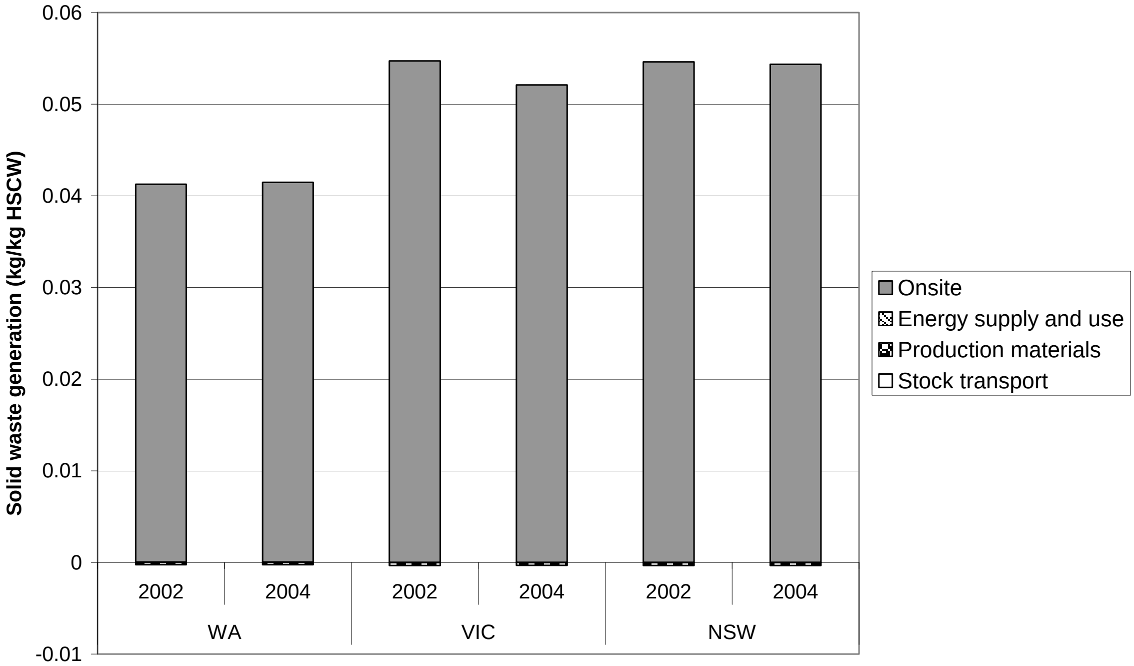


Figure 24: Solid waste generation by activities in meat processing

Solid waste excluding manure

As stated previously, the inorganic waste identified in the LCI phase of this project was predominantly plastic packaging associated with feed or seed-grain inputs. The following three figures show the influence of excluding yard and paunch manure from the overall data and the data for meat processing works.

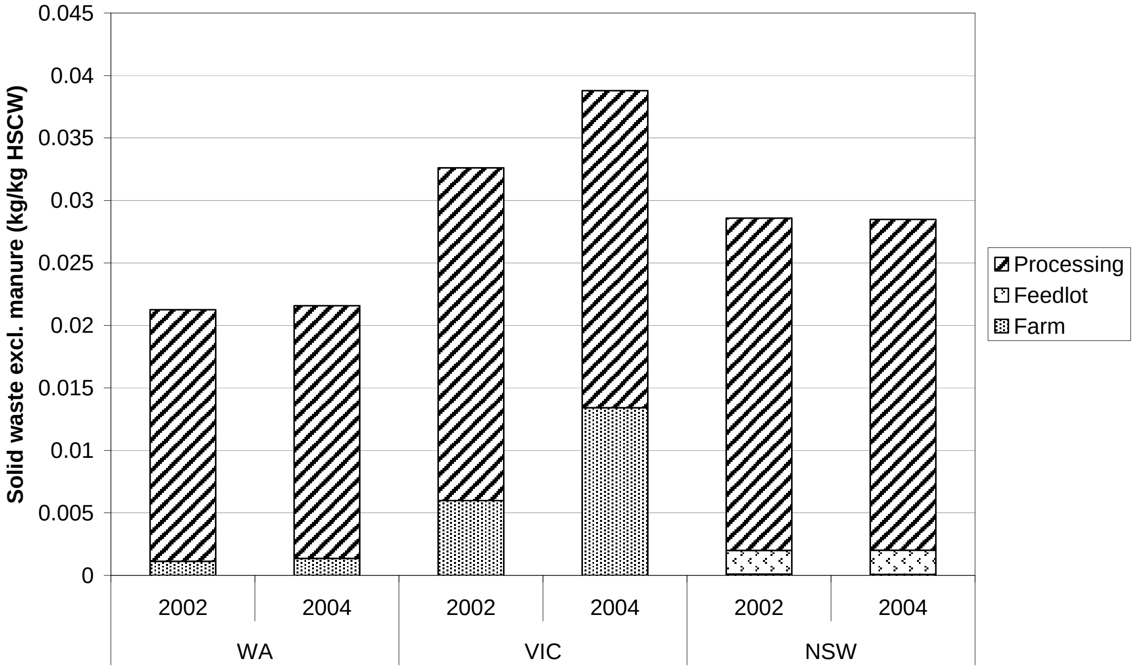


Figure 25: Solid waste generation (excluding manure+paunch) in the entire supply chain (by stage)

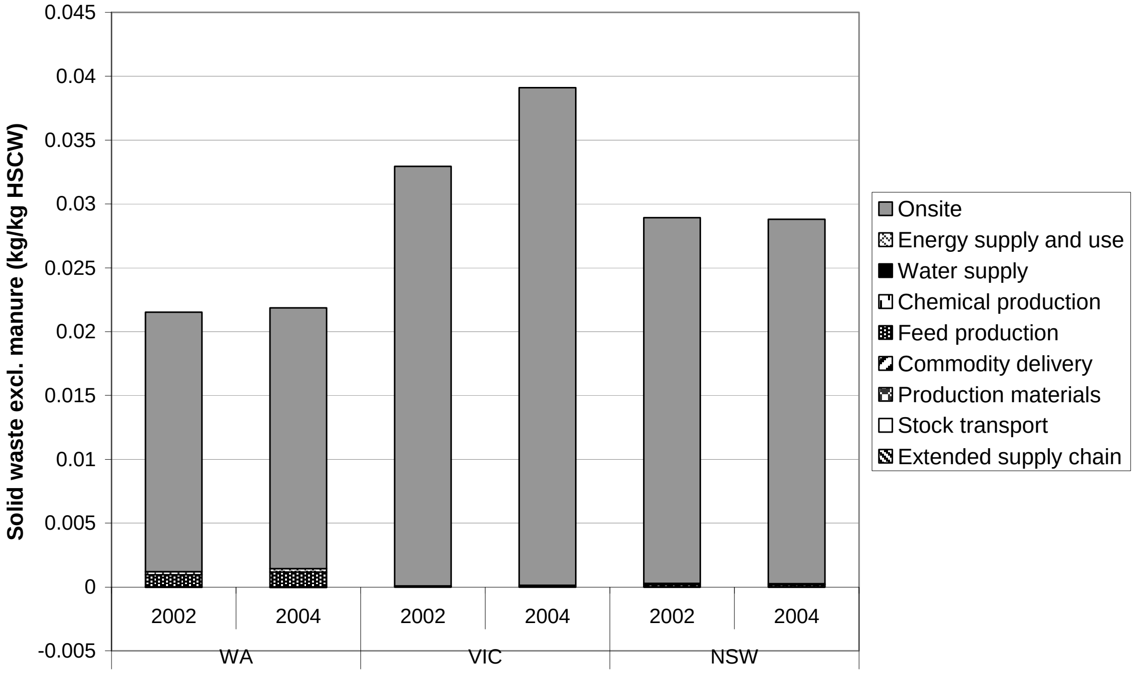


Figure 26: Solid waste generation (excluding manure+paunch) in the entire supply chain (by activity)

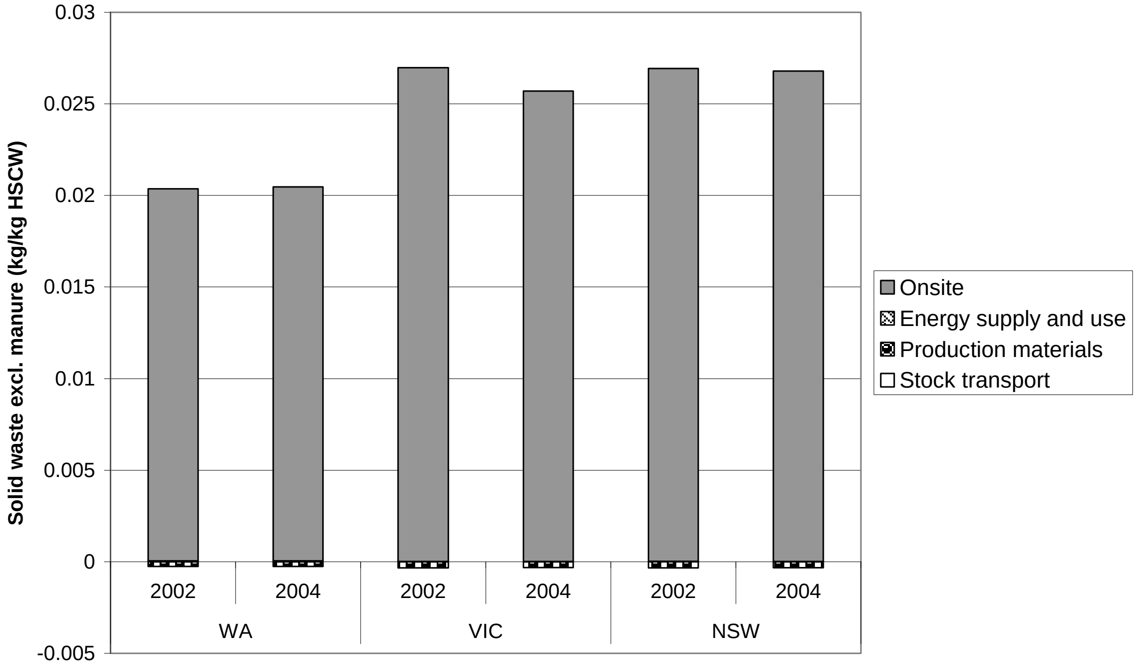


Figure 27: Solid waste generation (excluding manure+paunch) by activities in meat processing

5.2 Results for Natural Resource Management Indicators

This section describes the results of calculations of the new natural resource management indicators identified for development in Section 2.3 this report. Because they are intended to enumerate environmental issues related to grazing property soils, they refer only to the grazing property component of the red meat supply chain. It should be noted that these results, while built on dialogue regarding farm management practices with farmers, are enumerated using secondary (literature) data and therefore more uncertain than the traditional LCA indicators.

5.2.1 Nutrient management

Originally we intended to call this section "nutrient balance" but the data identified that in some situations farmers deliberately change the nutrient content of their soils to correct inherited deficiencies or imbalances. "Nutrient management" describes indicators where absolute balance in any year may not be the desired outcome.

Nitrogen

The results of the assessment of the overall N balance for the three grazing properties are shown in Figure 28 as a negative indicator. Both the direction of change and the magnitude of the changes appear to reflect climatic effects so one should not generalise from two years to a decade given Australia's highly variable climate. With the exception of the NSW grazing property in 2002, all these results are negative, suggesting that accumulation of N in the grazing property soils may have occurred in these years. The difference between the 2002 and 2004 results for the NSW grazing property is the result of our assumption that the rate of N fixation by sub clover was halved in 2002 because of the very dry conditions on that property in that year. In all six cases, the dominant N input is the result of N fixation by the clover-based pastures, with a smaller amount input to the property via fertilisers.

The largest N losses are the result of volatilisation from pastures in the NSW and WA supply chains, while leaching losses are most important for the Victorian property with its much higher rainfall and light soils. For the NSW property, removals in livestock product exports, then losses in overland flow and erosion were next most important in 2002, a dry year. This was not the case in 2004, a wet year, when N losses through leaching were very important, followed by removals in livestock exports, with losses through overland flow and erosion still important. For the WA property, leaching losses were more important than removals through livestock product exports, with leaching losses minimal. After leaching losses, volatilisation losses are the next most important factor for the Victorian property, followed by removals through the export of livestock with minimal removal through overland flow and soil erosion.

Figure 28: N balance for the grazing properties

Phosphorus

The results for P are shown in Figure 29. The NSW and WA grazing properties laid down more P than they lost in both years. In these cases, the main inputs were fertilisers and the main output was the P in the animals themselves. Only the Victorian supply chain exhibited a net loss of P – roughly equally shared between the animal products and dissolved losses in runoff. This reflects the decision by the farmer to allow the P concentration of the property's soils to decrease from the high concentrations they had reached under the previous owner's stewardship of the land.

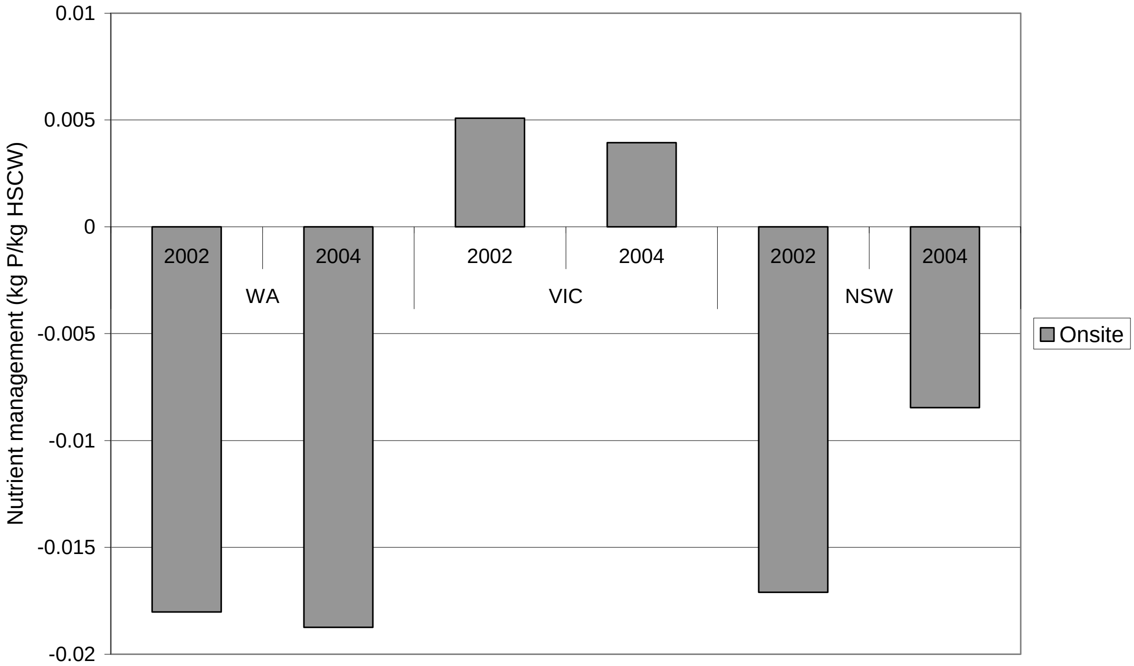


Figure 29: P balance for the grazing properties

Potassium

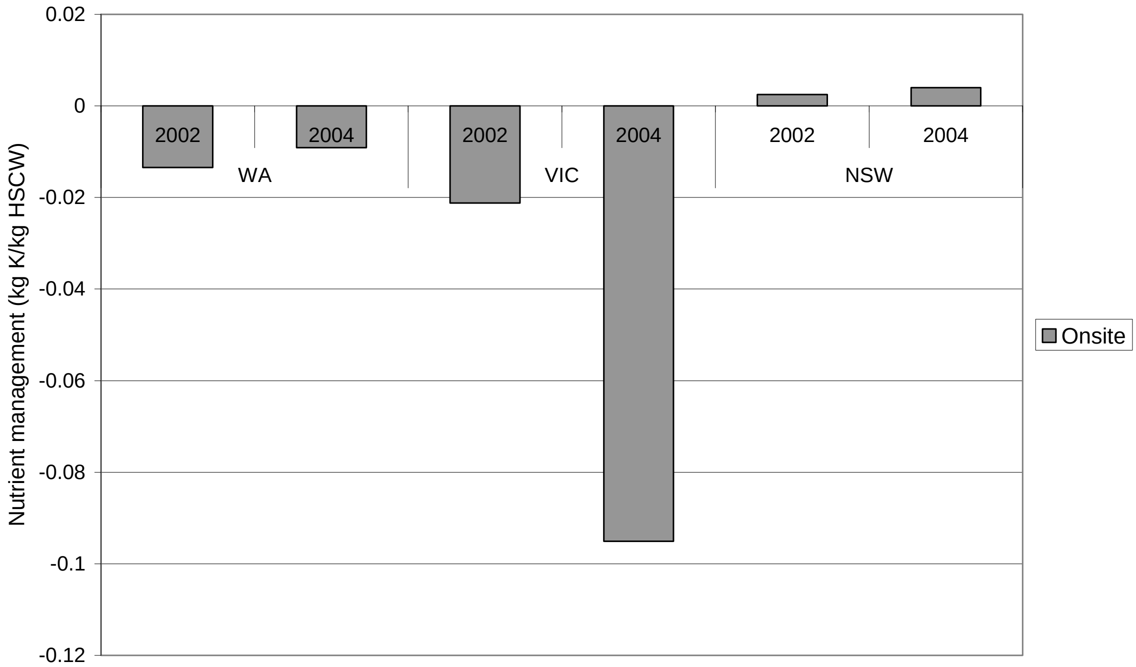


Figure 30: K balance for the grazing properties

The K balance shows significant differences between the three grazing properties (see Figure 30). The WA and Victorian properties added significant quantities of K through fertiliser. In particular, large quantities of K sulphate (26 t over 2 years) were spread on the Victorian property to correct a small deficit of K and a large deficit of sulphur. For both these grazing properties, exports through livestock products are likely to represent the only significant losses from the system in both years. For the NSW property, no K fertiliser was spread in either year. Nevertheless, some K losses through soil erosion and dissolution in runoff would be expected.

5.2.2 Soil acidification potential

We present the soil acidification potential results as both kg HSCW (Figure 31) and ha/yr (Figure 32) to reflect the weaker relationship between production and soil acidification than exists for greenhouse gas emissions (for example). Naturally, the two presentations display a similar pattern. The results for the NSW and WA grazing properties show some acidification potential which is predominantly the consequence of N leaching from legume pastures and grazing effects (see Section 2.8.2 above). The outlier in the results is the Victorian grazing property, which in 2002 was the site of a deliberate and very significant base cation addition, consisting of lime and basalt rock dust equivalent to 1200 kg $CaCO_3$/ha/yr. In acidification potential terms, this was more than ten times the effect of livestock export and N leaching from legume pastures.

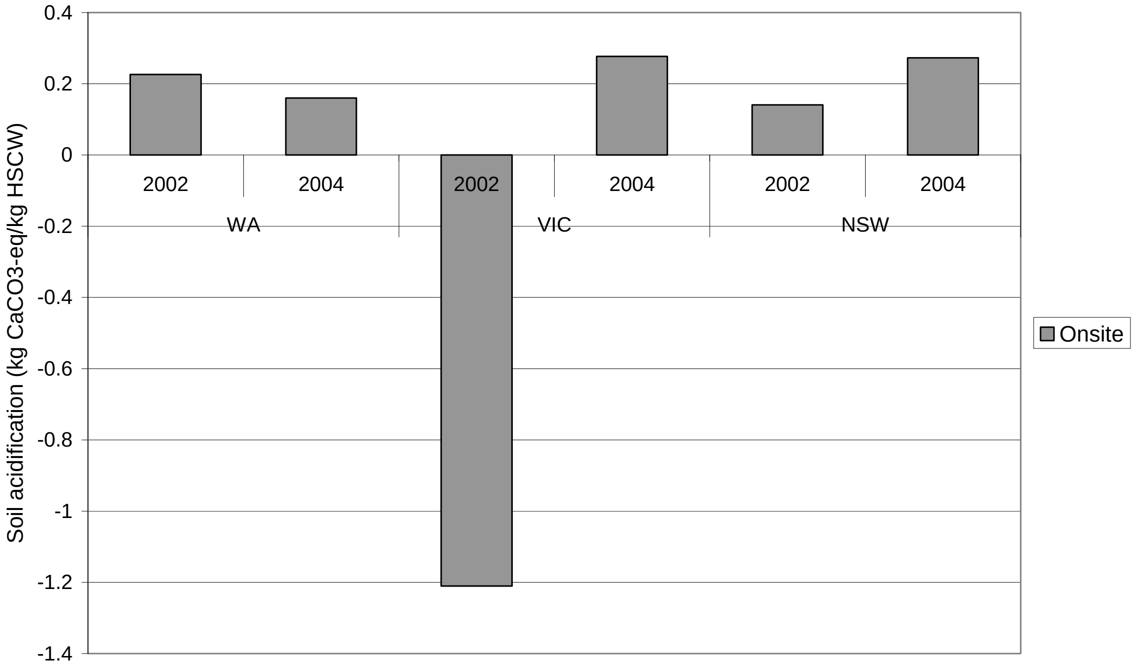


Figure 31: Soil acidification at the grazing properties (per kg HSCW)

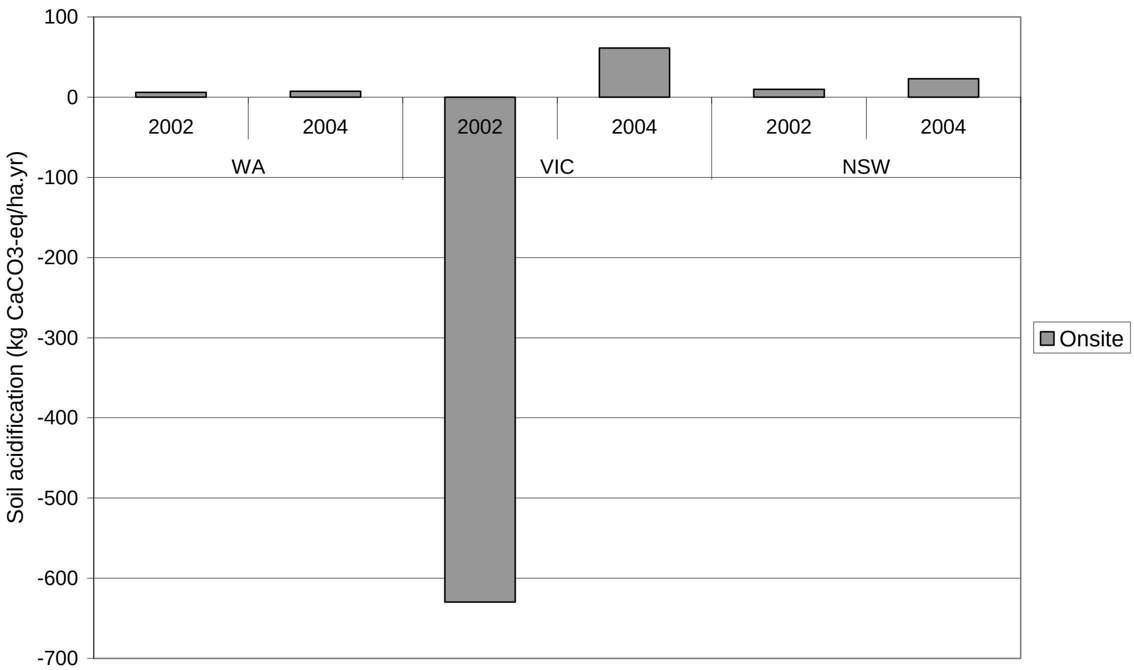


Figure 32: Soil acidification at the grazing properties (per ha.yr)

5.2.3 Soil erosion

The soil erosion potential results are also very different when grazing properties are compared. As shown in Figure 33, the NSW property has much higher soil erosion potential than the other two, with the estimate for the Victorian property equal to zero. This is based on the assessment of these areas by the National Land and Water Resources Audit (NLWRA 2001). The land on which the NSW property is situated has an estimated erosion gully density of 0.1 to 0.5 km/km^2, described as "low density", while the estimated annual hillslope erosion rate ranges from 0.5 to over 10 t/ha/yr ("low" to "very high"). This reflects the soil types and topography of the area.

On the other hand, at the Victorian property, the estimated erosion gully density is 0 to 0.1 km/km^2, described as "very low" density, and the estimated annual hillslope erosion rate ranges from 0 to 0.5 t/ha/yr (also "very low") which is approximately equal to pre-European erosion rates for this area.

Between these two estimates, the WA property has an estimated erosion gully density of 0 to 1 km/km^2, described as "very low" to "medium" density, while the estimated annual hillslope erosion rate ranges from 0 to over 2.5 t/ha/yr ("very low" to "low").

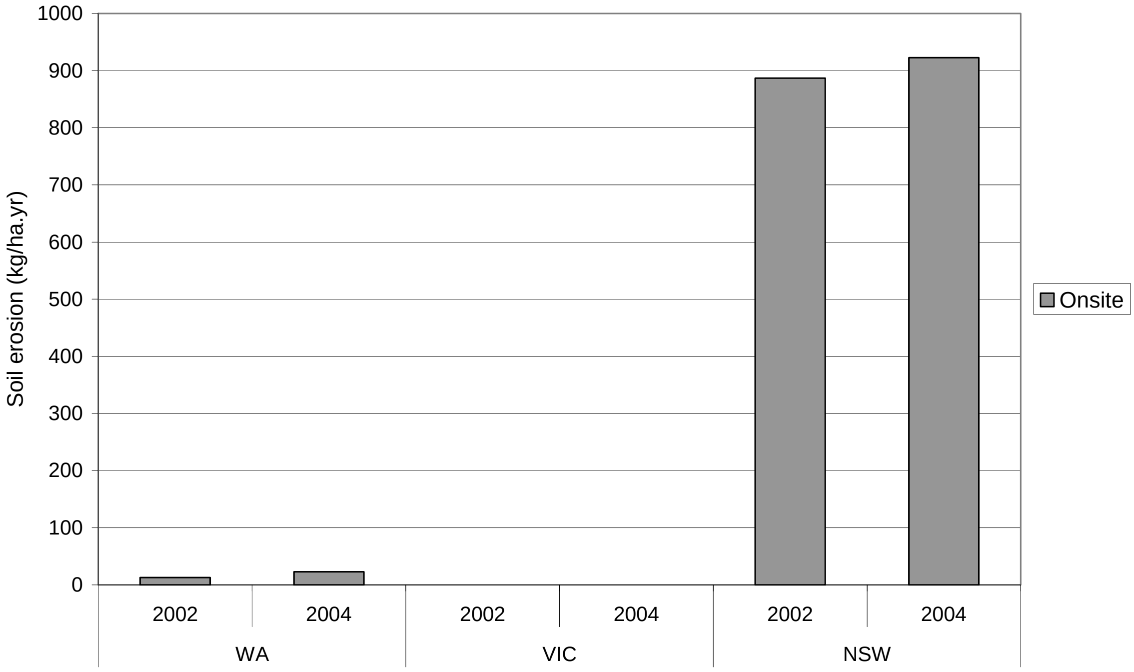


Figure 33: Soil erosion at the grazing properties (per ha.yr)

5.3 Sensitivity Analyses

5.3.1 Greenhouse gas comparison of grain and grass-fed beef

The research team was asked to identify the influence of lot-feeding on greenhouse gas emissions. In the NSW supply chain, some cattle are finished on pasture while others go to a feedlot. In Table 23, we identify the greenhouse gas emissions from different stages of the NSW supply chain when the grass-finished and grain-finished components of that supply chain are considered separately.[5]

In this case, the total greenhouse gas emission per head of cattle is higher for the grain-finished (feedlot) beef, but this is completely offset by the higher weight achieved in the grain-finished cattle. Consequently, the greenhouse gas burden associated with grain-finished cattle is lower than that of grass-finished cattle, on a per kg HSCW basis. This is consistent with expectations.

Table 23: Comparison of grass and grain finished beef

Calculations for NSW supply chain, 2004	Unit	Grain-finished	Grass-finished
HSCW gain per head at the grazing property	kg HSCW/head	217	280
HSCW gain per head at the feedlot	kg HSCW/head	146	0
Total HSCW per head at the processor gate	kg HSCW/head	363	280
GWP at the grazing property, per kg HSCW at the processor	kg CO_2-e/kg HSCW	6.4	10.4
GWP at the feedlot, per kg HSCW at the processor	kg CO_2-e/kg HSCW	2.2	-
GWP per kg HSCW at the processor	kg CO_2-e/kg HSCW	1.4	1.4
Total GWP per head	kg CO_2-e/head	3,602	3,365
Total GWP per kg HSCW	**kg CO_2-e/kg HSCW**	**9.9**	**12.0**

5.3.2 Parameter variation

To assess the sensitivity of the model to changes in assumptions and input parameters, we varied them and examined the influence on the final result. This was carried out for the NSW supply chain for 2004 to illustrate the kinds of changes that might be expected in any of the supply chains. The results of a 10% increase in the 15 input parameters exerting the largest influence on the final result are listed in Table 24.

These results indicate that the GWP model is most sensitive to the dressing percentage on the grazing property (negatively related) and the enteric methane production on the feedlot (positively related).

[5] We therein assume that the NSW supply chain could produce its current HSCW output either by avoiding any direct transfers to the meat processor and increasing the number of cattle sent to the feedlot, or by selling a larger number of cattle direct to the processor.

The principle contributor to GWP (i.e. enteric methane emissions on the grazing property) was estimated using the AGO (2004) methodology described in Section 4.2.1. The results of this methodology are influenced by a large number of parameters. It may therefore be valuable to dedicate some weeks to a sensitivity analysis of the AGO methodology. Overall, this analysis suggests that our model is robust with respect to the input parameters.

Table 24: Parameter sensitivity analysis of the NSW supply chain in 2004

	GWP (kg CO2-e/kg HSCW)		
	Results	**Absolute change**	**Percentage change**
Base case results	10.19	0.00	0.00%
Grazing property parameters varied			
MAP	10.19	0.00	0.02%
Pivot 15	10.19	0.00	0.01%
Single Super	10.19	0.00	0.02%
All chemicals (fert + pest)	10.20	0.01	0.07%
Diesel	10.20	0.01	0.05%
Electricity	10.19	0.00	0.00%
Production only (e.g. dressing percentage)	9.57	-0.62	-6.11%
Production and on-farm GHGs (not wool)	10.18	-0.01	-0.12%
Feedlot parameters varied			
LPG	10.19	0.00	0.02%
Wheat	10.24	0.05	0.50%
Methane	10.26	0.07	0.65%
Processing parameters varied			
Coal	10.20	0.01	0.07%
LPG	10.29	0.10	0.95%
Electricity	10.21	0.02	0.22%
Manure	10.20	0.01	0.08%

5.4 Comparison with published literature

The process of reviewing life cycle assessments (LCA) of red meat production involved comparing 11 studies published between 1999 and 2008. The respective research projects were conducted in a range of different countries or regions and covered different production types of lamb and beef meat including conventional and organic farming principles, feedlot and pastoral production as well as intensive and extensive livestock farming.

There are other studies available that analyse environmental effects related to red meat production, however, only the above mentioned 11 studies provide results of greenhouse gas (GHG) emissions associated with the full cradle-to-farmgate life cycle impact. Other studies only cover emissions from selected substances such as methane, ammonia or nitrous oxide (Loh et al. 2008, Ellis et al. 2007, Kebreab et al. 2008, Harper et al. 1999), deal with mitigation or management approaches of individual emissions (McGrabb 2005, Tedeschi et al. 2003, Page 2003, Woodbury et al. 2001, Hegarty 2002, 2001, 1999), assess GHG emissions for specific processes within the cradle-to-farmgate life cycle (Hao et al. 2001), or are not based on primary data (Fiala 2008). There were additional studies identified to enhance the LCI analysis of energy and GHG emissions of cattle grazing properties by giving statistical data (IPPC 1997, NGGIC 2002(2003), AGO 2004, NGGIC 2004, ABS 2005 and QDPI&F 2005)(2005), or are more than 13 years old and predate ISO14040 (Lipper et al. 1976, Sweeten & McDonald 1979), Schake et al. (1981), Sweeten et al. (1986), Casada & Safley (1990), Sweeten (1990), Johnson & Johnson (1995), Steed & Hashimoto (1995)).

For most of the studies the system boundaries included all farming processes, i.e. breeding, feed production and related fertiliser production and transport, farm electricity use, heating, farm field work and waste management ('cradle-to-farm gate'). Two studies also included the environmental burdens associated with the processing and distribution stages of the meat life cycle (Nemry et al. 2001, Schlich and Fleissner 2005). All studies except for Verge (2008) exclude the environmental impacts associated with capital goods.

Global warming potential (GWP) is the most commonly evaluated impact category: 10 of the 11 studies provide this indicator. While primary energy use (PE) is assessed in seven of the 11 studies, results for other impact categories such as eutrophication potential (EP) or acidification potential (AP) are rarely presented. Only one study takes different toxicity potentials into account (Chassot et al. 2005), another study relates to pesticide use and abiotic resource consumption (Williams et al. 2006). In our comparisons we focus on GWP and PE as the characterisation factors for the other models represent an unknown variable.

5.4.1 Allocation issues

Allocation refers to the principle of partitioning input and/or output flows of a process or product system between the product system under study and one or more other product systems (ISO 2006). Many studies focus entirely on the meat production process and claim that allocation can be avoided. We believe this is inaccurate from an economic allocation perspective and worse from a mass allocation perspective – you cannot produce meat without producing useful byproducts like hides and tallow. Two of the studies under investigation included milk production (Williams et al. 2006, Cederberg and Stadig 2003) and the environmental burdens had to be allocated to each product in a certain way. Whereas Cederberg and Stadig (2003) analysed the effects of different allocation methods (i.e. no allocation, economic and 'biological' allocation, system expansion) on the results, Williams et al. (2006) applied economic allocation. Nemry et al. (2001) used a complex dynamic economic allocation model (MARKAL[6]) to evaluate the GHG emissions associated with a range of different kinds of meat from production to consumption. To compare the results of different studies, we make comparisions on the basis of unallocated burdens (no allocation to useful carcase byproducts) except with respect to the grain and wool products. The sheep farms in the literature use economic allocation to consider wool byproducts so we present our results on the same basis for comparison.

[6] MARKAL (MARKet Allocation) is a dynamic technico-economic energy system optimisation model developed in the framework of the "Energy Technology Systems Analysis Programme" (ETSAP) of the International Energy Agency (IEA).

5.4.2 System analytical matters

When comparing the results it is important to be aware of the different functional units used in the studies. The live weight of an animal is the body mass of the animal immediately before slaughter. The carcase weight, also referred to as hot standard carcase weight (HSCW) or dressed weight, is the live weight multiplied by the dressing percentage which takes into account the body parts of an animal that don't become saleable meat, i.e. the hide or fleece and the contents of the gastrointestinal tract (Warris 2000). Boneless, retail or saleable meet is the premium meat that is sold at the retail outlets. Similarly to the dressing percentage, other parts of the animal are removed, such as bones or fat tissues, to get what ends up on the supermarket shelves. For more detailed information, refer to Jarrige (1992) and Warriss (2000). To compare the results of different studies, we make our comparisions on the basis of paddock to farm-gate burdens.

Table 25: Dressing percentage and saleable meat percentage from literature

Conversion percentages	Default value	Min	Max	Source (default)	Source (min, max)
Dressing % (beef)	53%	50%	62%	Warriss 2000	Jarrige 1992
Saleable meat % (beef)	70%	65%	75%	assumed	Jarrige 1992
Dressing % (lamb)	47%	44%	50%	Kinsella 2008	AFBI 2007, Warriss 2000
Saleable meat % (lamb)	70%	-	-	Marriott 2000	

The values for the dressing percentage and the saleable meat percentage vary between different countries; ages, conditions and breeds of animals, etc. Table 25 shows the default values we used for the conversion as well as other minimum and maximum values obtained from literature.

5.4.3 Global warming potential

The results as illustrated in Figure 34 show a great variation in the results. According to the data evaluated, beef meat produced in Africa in a Sahelian pastoral system has the lowest carbon footprint with 5.9 or 8.4 kg CO_2-eq / kg HSCW – it was unclear whether the published result is retail or HSCW beef so the lower value optimistically assumes the former while the latter assumes HSCW. Beef produced in Japan scores may be four times more greenhouse-intense. Although converting the results to a common functional unit should allow for a comparison between beef and lamb meat production in different countries, these results have to be considered with great caution since many other variables play a major role (see Chapter 5.4.5).

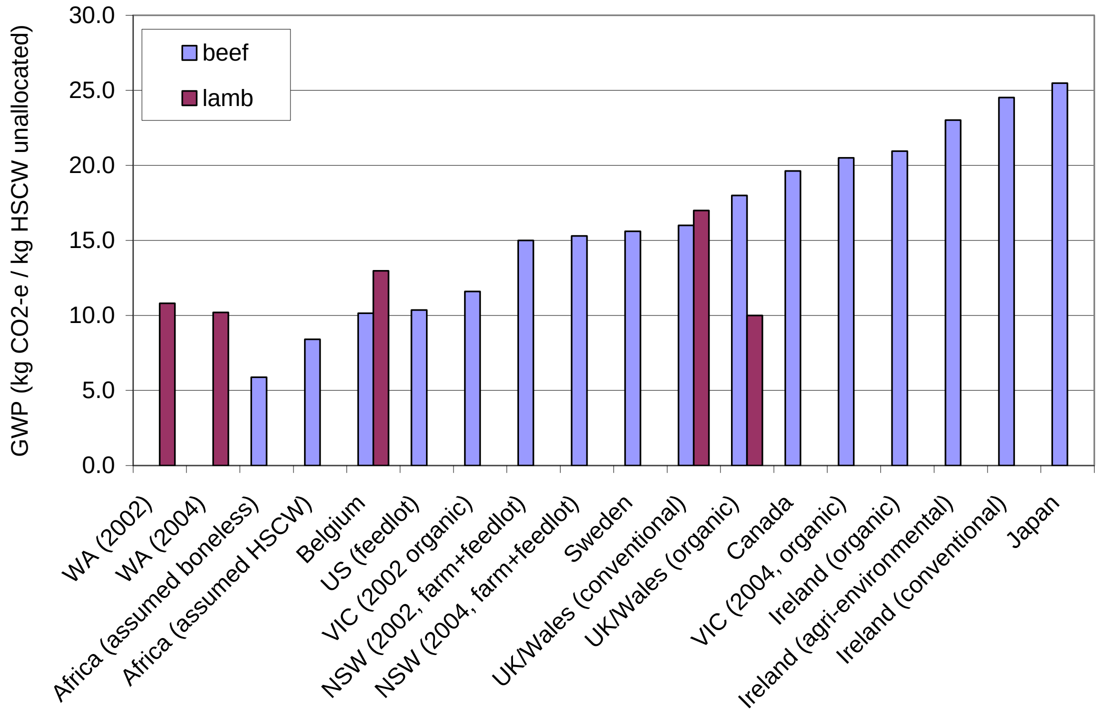


Figure 34: GWP for beef and lamb production (unallocated farm gate kg CO2-e/kg HSCW)

5.4.4 Primary energy demand

A comparison of primary energy demands was achieved by using the same conversion factors for dressing and saleable meat percentages as shown in Table 25. The results as illustrated in Figure 35 show that primary energy use also varies significantly in the different countries and among different production types. Williams et al. (2006) showed that high primary energy demands arise from the production of feed (grass or concentrate feeds). This observation is consistent with the relatively high energy consumption of the WA farm examined in this study, and its on-farm processing of feeds for final fattening of sheep and lambs. The WA farm is nevertheless at the same order of magnitude as the other sheep meat farms and an order of magnitude more efficient than Japanese beef. Verge (2008) also refers to the high fossil fuel energy demand associated with ammonia production which is the basis for N-fertiliser.

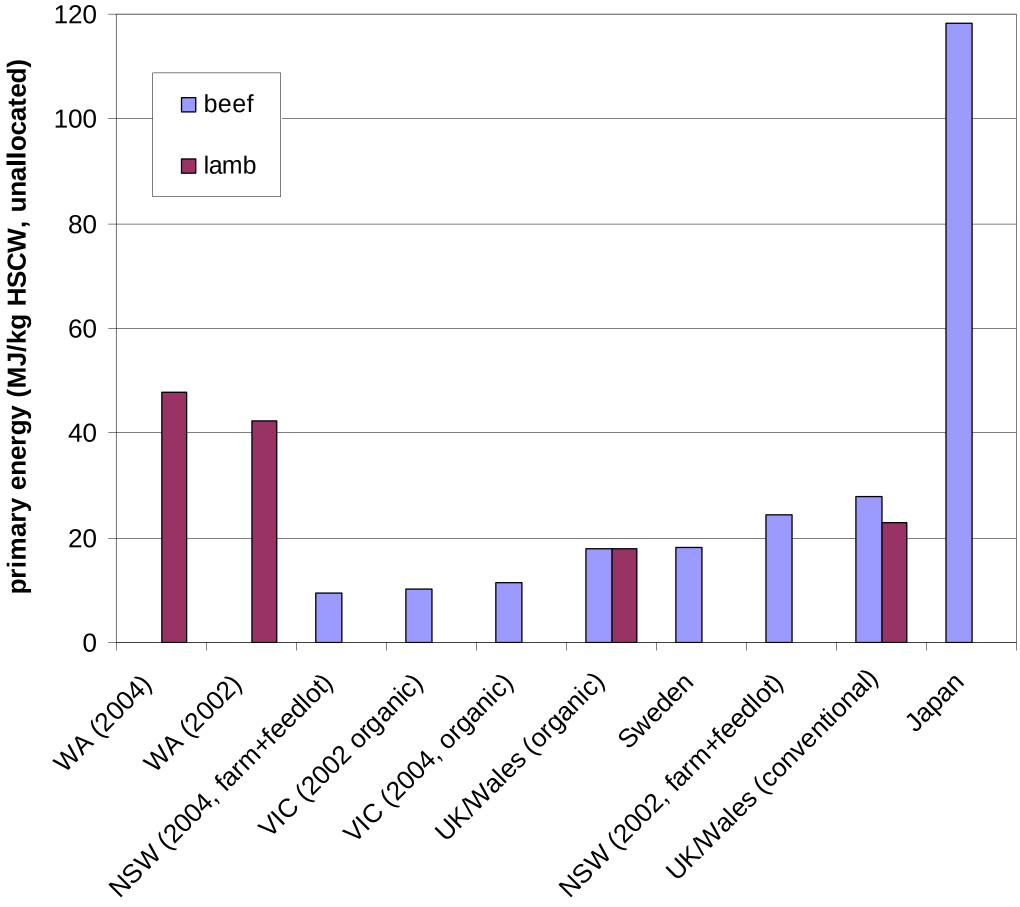


Figure 35: Primary energy (unallocated farm gate MJ/kg HSCW)

5.4.5 Data issues

Besides the allocation and system analytical issues addressed above there are many other variables that can influence the results of these published studies, for which it is not feasible for us to account. With GWP being the impact category assessed in most research projects, the interpretation of the results focuses on this environmental indicator. The most important factors are described briefly below:

- ***Farm operations:*** Farm operations can significantly influence the environmental performance of red meat production. We have previously described the variability in the performance of farms depending on whether they manage the whole lifespan of all cattle and sheep, or engage in trading enterprises. Additionally, our data suggest organic production may use less energy than conventional farming, but typically results in higher GWP.
- ***Type of feed:*** The type of feed varies with the different production types, the phases in an animal's life and the seasons of the year. Emission factors for enteric fermentation depend on feed digestibility, the percentage of gross energy intake that is metabolised and the animal's weight (Verge et al. 2008, Boadi et al. 2004). In general terms, because beef and sheep can digest grain more easily

than forage, animals in feedlots tend to emit less methane than animals of the same weight on pasture (IPCC 2006). Harper et al. (1999) calculated that a highly digestible high grain diet can reduce enteric methane emissions by about 70%. Whether the reduced enteric methane emissions from a grain diet can provide greater GHG savings than caused by the production of the grain feed will depend on the production system.

- ***Methods to determine enteric methane emissions:*** With methane from enteric fermentation being the most significant contributor to GHG in the production of red meat, the method by which the respective amounts are determined is of great importance. Most studies either use IPCC standard values or apply the corresponding methodology (IPCC 1996, 2006). Ogino et al. (2004) follow a quadratic regression equation which is based on the dry matter intake (Shibata et al. 1993), whereas Casey and Holden (2006) used a nutrition software package called RUMNUT which is based on protein systems (RUMNUT 2004)
- ***Lifetime of animals:*** The lifetime of animals until they are slaughtered varies significantly in the studies under comparison. For example, feedlot or forage cattle in the US can be slaughtered at an age of 13 months, whereas in Japan, due to the preference for fattier meat, beef cows are slaughtered after 28 months. In the African nomadic farming system, animals can reach an age of 33 months. Ogino et al. (2004) found out that shortening the feeding lengths of Japanese cattle (production type: feedlot) by one months reduces the environmental impacts in GWP, EP, AP and energy use by approximately 4%.
- ***Type of manure management:*** Manure management varies and methane and nitrous oxide emissions differ between methods. For more details see Casey and Holden (2006)
- ***Different IPCC conversion factors:*** Depending on the year of the research project, different IPCC conversion factors for the main greenhouse gases (i.e. methane, nitrouse oxide and carbon dioxide) applied.
- ***Inclusion of land use change:*** The recently published PAS 2050[7] methodology specifies the requirements for assessing the life cycle GHG emissions of goods and services (PAS 2008). It recommends the inclusion of direct land use change from 1 January 1990 whereby direct land use change refers to the conversion of non-agricultural land to agricultural land as a consequence of producing an agricultural product. Most studies do not include emissions resulting from land use change. Subak (1999) takes into account the carbon storage potential foregone on land appropriated for raising livestock. She reports that the land use change for the Amercian feedlot production system accounts for over 38% of the total GHG emissions.
- ***Country specific impacts from energy production:*** For example, the GHG emissions from Australian vs. Japanese electricity production reveals a value twice as high for Australia (GaBi 2008). This can mainly be attributed to the proportion of nuclear power generation in Japan and the minimal GHG emissions associated with this form of electricity production. Hence, country or region specific electricity mixes play an important role regarding GHG emissions in energy intensive processes such as fertiliser production.

[7] The Publicly Available Specification (PAS) 2050 is an initiative from the British Standards Institution (BSi) and was co-sponsored by the Carbon Trust and the Department for Environment, Food and Rural Affairs (Defra).

- ***Type of animal breed:*** Different methane conversion factors exist for different animal breeds. For more detailed information see Van der Horning et al. (1981) and Blaxter (1989).

6 Conclusions

This study is the first detailed environmental life cycle assessment of red meat production in Australia. It presents the outcome of detailed process-based LCA complemented with input-output analysis to provide a more accurate and complete picture of the environmental profile of supply chains than is feasible using either process LCA or input-output analysis in isolation.

While greenhouse gas emissions associated with red meat production may be increased on a per head basis by feedlot operations, the total emissions are lower when considered on a per kilogram HSCW basis. This is despite the additional energy requirements and associated greenhouse emissions related to the production and transportation of grain and other feeds to the feedlot. So, from a GWP perspective, the increased proportion of lot feeding in Australian beef production is not a concern.

Consistent with expectations, enteric methane dominates the greenhouse gas emissions. The potential value of research activities into the use of cysteine or other dietary additives to reduce this emission source (e.g. Takahashi 2001; Eckard et al. 2008) is clearly supported by this LCA.

This work pushes the development of LCIA further, by demonstrating the feasibility of calculating novel indicators for natural resource management issues relevant to agricultural LCA. Where existing methodologies were followed, the results are consistent with other work in agricultural LCA. Where new indicators were developed, this project presents work that can be benchmarked against other production systems as the application of these indicators progresses. They also offer insights into the variability of the three case study red meat production systems in different states.

It is clear that different supply chains have different potentials for erosive soil loss. Detailed recommendations about the management of the grazing property soils most at risk in this respect are the province of local soil science studies. What is noticeable in this LCA is the large amount of organic waste material produced downstream at the meat processor (around 50 g/kg HSCW). While it may not be cost effective to send this material back to the grazing property to maintain soils, this study suggests that this is an open material loop which could be beneficially closed from the perspective of two of the study's indicators.

7 Recommendations

The main source of variation in the results of this LCA is the actual underlying difference between the three supply chains, particularly the grazing property components. Accordingly, we strongly recommend against the use of a single figure to represent Australian beef production based on the three supply chains examined. It is more appropriate to talk about ranges. Such ranges can play a significant role in discussions about environmental performance of red meat production, particularly considering the common use of overseas data in the media. Another consequence of this observation is the desirability of extending this work by evaluating further grazing properties. There is also a very strong case for the evaluation of several northern supply chains on the same basis as the three supply chains considered here. This would allow comparison between the results, and also ensure that the main source of Australian beef is included in the results. Northern production systems may perform quite differently to the three chains examined here.

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9 Appendices

APPENDIX A: LCI DATA FOR THE GRAZING PROPERTIES

By agreement with the MLA project manager, this data was removed from the report to MLA before delivery to provide maximum anonymity and protection of intellectual property to the three participating grazing properties.

APPENDIX B: LCI DATA FOR THE FEEDLOT

By agreement with the MLA project manager, this data was removed from the report to MLA before delivery to provide maximum anonymity and protection of intellectual property to the participating feedlot.

APPENDIX C: INDUSTRY SECTOR CLASSIFICATION IN THE HYBRID MODEL (106 SECTORS)

Code	Description
1 Agriculture; hunting and trapping	
0101	Sheep
0102	Grains
0103	Beef cattle
0104	Dairy cattle
0105	Pigs
0106	Poultry
0107	Other agriculture
0200	Services to agriculture; hunting & trapping
2 Forestry and fishing	
0300	Forestry and logging
0400	Commercial fishing
3 Mining	
1100	Coal; oil and gas
1301	Iron ores
1302	Non-ferrous metal ores
1400	Other mining
1500	Services to mining
4 Meat and dairy products	
2101	Meat and meat products
2102	Dairy products
5 Other food products	
2103	Fruit and vegetable products
2104	Oils and fats
2105	Flour mill products and cereal foods
2106	Bakery products
2107	Confectionery
2108	Other food products
6 Beverages and tobacco products	
2109	Soft drinks, cordials and syrups
2110	Beer and malt
2111	Wine and spirits
2112	Tobacco products
7 Textiles	
2201	Textile fibres, yarns and woven fabrics
2202	Textile products
2203	Knitting mill products
8 Clothing and footwear	
2204	Clothing
2205	Footwear
2206	Leather and leather products
9 Wood and wood products	
2301	Sawmill products
2302	Other wood products
10 Paper and paper products; printing and publishing	
2303	Pulp, paper and paperboard
2304	Paperboard containers; paper bags and sacks
2401	Printing and services to printing
2402	Publishing; recorded media and publishing
11 Petroleum and coal products	
2501	Petroleum and coal products
12 Chemicals	
2502	Basic chemicals
2503	Paints
2504	Medicinal and pharmaceutical products; pesticides
2505	Soap and detergents
2506	Cosmetic and toiletry preparations
2507	Other chemical products
13 Rubber and plastic products	
2508	Rubber products
2509	Plastic products
14 Non-metallic mineral products	
2601	Glass and glass products
2602	Ceramic products
2603	Cement, lime and concrete slurry
2604	Plaster and other concrete products
2605	Other non-metallic mineral products
15 Basic metals and products	
2701	Iron and steel
2702	Basic non-ferrous metals and products
16 Fabricated metal products	
2703	Structural metal products
2704	Sheet metal products
2705	Fabricated metal products

Code	Description
17 Transport equipment	
2801	Motor vehicles and parts; other transport equipment
2802	Ships and boats
2803	Railway equipment
2804	Aircraft
18 Other machinery and equipment	
2805	Photographic and scientific equipment
2806	Electronic equipment
2807	Household appliances
2808	Other electrical equipment
2809	Agricultural, mining and construction machinery; lifting and material handling equipment
2810	Other machinery and equipment
19 Miscellaneous manufacturing	
2901	Prefabricated buildings
2902	Furniture
2903	Other manufacturing
20 Electricity, gas and water	
3601	Electricity supply
3602	Gas supply
3701	Water supply; sewerage and drainage services
21 Construction	
4101	Residential building construction
4102	Other construction
22 Wholesale trade	
4501	Wholesale trade
23 Retail trade	
5101	Retail trade
24 Repairs	
5401	Mechanical repairs
5402	Other repairs
25 Accommodation, cafes and restaurants	
5701	Accommodation, cafes and restaurants

Code	Description
26 Transport and storage	
6101	Road transport
6201	Rail, pipeline and other transport
6301	Water transport
6401	Air and space transport
6601	Services to transport; storage
27 Communication services	
7101	Communication services
28 Finance and insurance	
7301	Banking
7302	Non-bank finance
7401	Insurance
7501	Services to finance, investment and insurance
29 Ownership of dwellings	
7701	Ownership of dwellings
30 Property and business services	
7702	Other property services
7801	Scientific research, technical and computer services
7802	Legal, accounting, marketing and business management services
7803	Other business services
31 Government administration and defence	
8101	Government administration
8201	Defence
32 Education	
8401	Education
33 Health and community services	
8601	Health services
8701	Community services
34 Cultural and recreational services	
9101	Motion picture, radio and television services
9201	Libraries, museums and the arts
9301	Sport, gambling and recreational services
35 Personal and other services	
9501	Personal services
9601	Other services

Source: ABS (2004)

APPENDIX D: LCA RESULTS

NSW supply chain

Results: not allocated

Indicator	Unit	2002	2004
Energy use	MJ / kg HSCW	55.82432	170.5384
GWP	kg CO2-e / kg HSCW	16.89934	34.8326
Water quality (EP)	kg O2 depl. / kg HSCW	2.900408	0.289949
Solid waste generation	kg / kg HSCW	0.095753	0.095714
Solid waste excl. manure	kg / kg HSCW	0.048753	0.048714
Nutrient management	kg N / kg HSCW	-0.07299	1.87E-01
	kg P / kg HSCW	0.0438	0.020828
	kg K / kg HSCW	-0.00641	-0.00977
Soil acidification	kg CaCO3-e / kg HSCW	-0.3604	-0.67121
	kg CaCO3-e / ha.yr	-24.5382	-56.5
Soil erosion	kg / kg HSCW	33.35618	26.90149
	kg / ha.yr	2271.062	2271.062

Results: allocated on a mass basis

Indicator	Unit	2002	2004
Energy use	MJ / kg HSCW	29.50378	27.6005
GWP	kg CO2-e / kg HSCW	9.660519	9.786071
Water quality (EP)	kg O2 depl. / kg HSCW	1.155443	0.945673
Solid waste generation	kg / kg HSCW	0.056322	0.056066
Solid waste excl. manure	kg / kg HSCW	0.028644	0.028516
Nutrient management	kg N / kg HSCW	-0.02849	7.6E-02
	kg P / kg HSCW	0.017098	0.008461
	kg K / kg HSCW	-0.0025	-0.00397
Soil acidification	kg CaCO3-e / kg HSCW	-0.14069	-0.27265
	kg CaCO3-e / ha.yr	-9.57895	-22.9512
Soil erosion	kg / kg HSCW	13.02123	10.92779
	kg / ha.yr	886.5529	922.5397

Results: allocated on an economic basis

Indicator	Unit	2002	2004
Energy use	MJ / kg HSCW	41.26884	40.36705
GWP	kg CO2-e / kg HSCW	14.36646	14.93268
Water quality (EP)	kg O2 depl. / kg HSCW	1.174204	1.141899
Solid waste generation	kg / kg HSCW	0.085473	0.085519
Solid waste excl. manure	kg / kg HSCW	0.043436	0.043482
Nutrient management	kg N / kg HSCW	-0.02805	0.089971
	kg P / kg HSCW	0.016831	0.01001
	kg K / kg HSCW	-0.00246	-0.0047
Soil acidification	kg CaCO3-e / kg HSCW	-0.13849	-0.32257
	kg CaCO3-e / ha.yr	-9.4294	-27.1531
Soil erosion	kg / kg HSCW	12.81794	12.9285
	kg / ha.yr	872.7119	1091.442

WA supply chain

Results: not allocated

Indicator	Unit	2002	2004
Energy use	MJ / kg HSCW	173.468	117.5951
GWP	kg CO2-e / kg HSCW	27.07484	19.7938
Water quality (EP)	kg O2 depl. / kg HSCW	0.293675	0.207557
Solid waste generation	kg / kg HSCW	0.105089	0.101134
Solid waste excl. manure	kg / kg HSCW	0.058089	0.054134
Nutrient management	kg N / kg HSCW	1.315491	1.04E+00
	kg P / kg HSCW	0.191722	0.11296
	kg K / kg HSCW	0.142791	0.055069
Soil acidification	kg CaCO3-e / kg HSCW	-2.40492	-0.96531
	kg CaCO3-e / ha.yr	-62.082	-44.0579
Soil erosion	kg / kg HSCW	5.316485	3.021711
	kg / ha.yr	137.2426	137.9141

Results: allocated on a mass basis

Indicator	Unit	2002	2004
Energy use	MJ / kg HSCW	27.01563	28.08735
GWP	kg CO2-e / kg HSCW	7.739019	6.771705
Water quality (EP)	kg O2 depl. / kg HSCW	0.128705	0.128864
Solid waste generation	kg / kg HSCW	0.042255	0.042725
Solid waste excl. manure	kg / kg HSCW	0.021347	0.021713
Nutrient management	kg N / kg HSCW	0.123645	1.7E-01
	kg P / kg HSCW	0.01802	0.018735
	kg K / kg HSCW	0.013421	0.009133
Soil acidification	kg CaCO3-e / kg HSCW	-0.22604	-0.1601
	kg CaCO3-e / ha.yr	-5.83518	-7.30705
Soil erosion	kg / kg HSCW	0.499705	0.501154
	kg / ha.yr	12.89966	22.87321

Results: allocated on an economic basis

Indicator	Unit	2002	2004
Energy use	MJ / kg HSCW	75.23119	69.53558
GWP	kg CO2-e / kg HSCW	11.82275	11.32037
Water quality (EP)	kg O2 depl. / kg HSCW	0.390975	0.33623
Solid waste generation	kg / kg HSCW	0.086833	0.086832
Solid waste excl. manure	kg / kg HSCW	0.044795	0.044795
Nutrient management	kg N / kg HSCW	0.441068	0.502997
	kg P / kg HSCW	0.064282	0.054792
	kg K / kg HSCW	0.047876	0.026711
Soil acidification	kg CaCO3-e / kg HSCW	-0.80634	-0.46823
	kg CaCO3-e / ha.yr	-20.8153	-21.3705
Soil erosion	kg / kg HSCW	1.782553	1.465696
	kg / ha.yr	46.01579	66.89593

Victorian supply chain

Results: not allocated

Indicator	Unit	2002	2004
Energy use	MJ / kg HSCW	41.12777	51.29909
GWP	kg CO2-e / kg HSCW	12.97863	20.01035
Water quality (EP)	kg O2 depl. / kg HSCW	0.108695	0.137047
Solid waste generation	kg / kg HSCW	0.102334	0.11607
Solid waste excl. manure	kg / kg HSCW	0.055334	0.06907
Nutrient management	kg N / kg HSCW	0.035573	1.03E-01
	kg P / kg HSCW	-0.00862	-0.007
	kg K / kg HSCW	0.035942	0.169167
Soil acidification	kg CaCO3-e / kg HSCW	2.051069	-0.49208
	kg CaCO3-e / ha.yr	1067	-108.578
Soil erosion	kg / kg HSCW	0	0
	kg / ha.yr	0	0

Results: allocated on a mass basis

Indicator	Unit	2002	2004
Energy use	MJ / kg HSCW	24.26539	28.82985
GWP	kg CO2-e / kg HSCW	7.657392	11.24572
Water quality (EP)	kg O2 depl. / kg HSCW	0.487753	1.028189
Solid waste generation	kg / kg HSCW	0.060377	0.065231
Solid waste excl. manure	kg / kg HSCW	0.032647	0.038817
Nutrient management	kg N / kg HSCW	0.020988	5.8E-02
	kg P / kg HSCW	-0.00508	-0.00394
	kg K / kg HSCW	0.021206	0.095071
Soil acidification	kg CaCO3-e / kg HSCW	1.210131	-0.27655
	kg CaCO3-e / ha.yr	629.53	-61.0205
Soil erosion	kg / kg HSCW	0	0
	kg / ha.yr	0	0

Results: allocated on an economic basis

Indicator	Unit	2002	2004
Energy use	MJ / kg HSCW	35.3705	44.11798
GWP	kg CO2-e / kg HSCW	11.16182	17.2092
Water quality (EP)	kg O2 depl. / kg HSCW	0.710975	1.573426
Solid waste generation	kg / kg HSCW	0.088009	0.099822
Solid waste excl. manure	kg / kg HSCW	0.047588	0.059402
Nutrient management	kg N / kg HSCW	0.030593	0.088843
	kg P / kg HSCW	-0.00741	-0.00602
	kg K / kg HSCW	0.03091	0.145486
Soil acidification	kg CaCO3-e / kg HSCW	1.76395	-0.4232
	kg CaCO3-e / ha.yr	917.636	-93.379
Soil erosion	kg / kg HSCW	0	0
	kg / ha.yr	0	0

APPENDIX E: WATER USE REPORT

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LIFE CYCLE MANAGEMENT

Accounting for water use in Australian red meat production

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Abstract
Background and theory Life cycle assessment (LCA) and life cycle inventory (LCI) practice needs to engage with the debate on water use in agriculture and industry. In the case of the red meat sector, some of the methodologies proposed or in use cannot easily inform the debate because either the results are not denominated in units that are meaningful to the public or the results do not reflect environmental outcomes. This study aims to solve these problems by classifying water use LCI data in the Australian red meat sector in a manner consistent with contemporary definitions of sustainability. We intend to quantify water that is removed from the course it would take in the absence of production or degraded in quality by the production system.
Materials and methods The water used by three red meat supply systems in southern Australia was estimated using hybrid LCA. Detailed process data incorporating actual growth rates and productivity achieved in two calendar years were complemented by an input–output analysis of goods and services purchased by the properties. Detailed hydrological modelling using a standard agricultural software package was carried out using actual weather data.
Results The model results demonstrated that the major hydrological flows in the system are rainfall and evapotranspiration. Transferred water flows and funds represent small components of the total water inputs to the agricultural enterprise, and the proportion of water degraded is also small relative to the water returned pure to the atmosphere. The results of this study indicate that water used to produce red meat in southern Australia is 18–540 L/kg HSCW, depending on the system, reference year and whether we focus on source or discharge characteristics.
Interpretation Two key factors cause the considerable differences between the water use data presented by different authors: the treatment of rain and the feed production process. Including rain and evapotranspiration in LCI data used in simple environmental discussions is the main cause of disagreement between authors and is questionable from an environmental impact perspective because in the case of some native pastoral systems, these flows may not have changed substantially since the arrival of Europeans. Regarding the second factor, most of the grain and fodder crops used in the three red meat supply chains we studied in Australia are produced by dryland cropping. In other locations where surface water supplies are more readily available, such as the USA, irrigation of cattle fodder is more common. So whereas the treatment of

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rain is a methodological issue relevant to all studies relating water use to the production of red meat, the availability of irrigation water can be characterised as a fundamental difference between the infrastructure of red meat production systems in different locations.

Conclusions Our results are consistent with other published work when the methodological diversity of their work and the approaches we have used are taken into account. We show that for media claims that tens or hundreds of thousands of litres of water are used in the production of red meat to be true, analysts have to ignore the environmental consequences of water use. Such results may nevertheless be interesting if the purpose of their calculations is to focus on calorific or financial gain rather than environmental optimisation.

Recommendations and perspectives Our approach can be applied to other agricultural systems. We would not suggest that our results can be used as industry averages. In particular, we have not examined primary data for northern Australian beef production systems, where the majority of Australia's export beef is produced.

Keywords Beef · Hybrid LCA · Meat · Sheep · Water

1 Background

The amount of water that is used in red meat production influences society's view of its environmental sustainability compared to other protein sources. Life cycle impact assessment schemes for water use are currently under development, but until they have been adequately validated in multicountry, multiproduct trials and an international consensus on them is created, life cycle inventory data will be used in public debates. 'Water use' estimates determined using 'virtual water' and other water estimation methodologies vary widely; some values supported by original published work are shown in Table 1. The differences between such figures, and their absolute size, have caused considerable controversy in the media where they are often reported without any discussion of how they were calculated. We wished to inform the current debate by providing a more detailed inventory analysis built on primary process data from actual agricultural properties.

Reported water use estimates are often based on simple desktop calculations that consider all water inputs to production as water use. This may be appropriate for estimates intended to inform economic policy. For example, if the analyst wishes to identify 'virtual water flows' or 'embedded water' (Allan 1998; Zygmunt 2007) to determine whether a country is obtaining the most financial or calorific gain it can, all water that is an input to red meat production is relevant whether its 'use' causes environmental damage or not. Local primary data for such virtual water calculations is hard to obtain. Most authors taking this approach use literature data on plant requirements ('evaporative water demand'; see Hoekstra and Chapagain 2007) and multiply this by the amount of plant products the livestock typically consume.

However, if the intention is to assess potential environmental damage, the virtual water approach is inappropriate. Instead, the analyst ought to consider whether environmental consequences result from water being an input to the system. In constructing the life cycle inventory, characteristics of the water source, such as whether (1) it is renewable, (2) extraction exceeds the renewal rate and (3) whether the extracted water is returned to the original watercourse in full, are understood to characterise whether water use is sustainable (Owens 2002). In practice, this means identifying water that is extracted from artesian sources or subjected to inter-basin transfer as inputs to a production process[1]. Using these three criteria, in situ use of rain for pasture or dryland cropping is generally excluded because (1) it is renewable, (2) it cannot be used faster than it falls, and (3) it is not extracted from its original watercourse.

1.1 Life cycle inventory

Explaining the frequent absence of water use inventories in many agricultural life cycle assessments (LCAs), Mila i Canals et al. (2008) point out that LCA developed as a tool for industrial analysis in wet countries. Consistent with this, and presumably for practical reasons of data quality, LCA and allied studies of agriculture that do include water use generally exclude rain (Beckett and Oltjen 1993; Johnson 1994; Brent and Hietkamp 2003; Hospido et al. 2003; Brent 2004; Foran et al. 2005; Narayanaswamy et al. 2005; Coltro et al. 2006; Mila i Canals et al. 2006; Wood et al. 2006) and focus on water provided by large engineered systems from surface and groundwater storages. Even estimates of water use in agriculture by the Australian Bureau of Statistics (ABS) have excluded rain (ABS 2005).

Consistent with principles listed by Owens (2002), natural resource inventory theory distinguishes between the use of 'deposits' (which would include groundwater unlikely to replenish on human timescales), 'funds' (including rapidly replenished groundwaters) and 'flows' (Udo de Haes et al. 1999). The concept of flows is described as including 'surface water', which defines this water at a point after runoff has occurred. Reflecting this, some inventories differentiate between 'blue' and 'green' water, which relate to conventional fluvial and groundwater resources, and water

[1] Owens refers to 'watersheds'. This may not be as clear as possible in this context. For example, transfers from part of the 10^6 km^2 Murray-Darling watershed to another part of it might not be considered using this terminology. We think 'watercourses' is clearer

Table 1 Published values of water demand for beef production

Water demand (L/kg beef)	Location	Type and stage	Source
105,400	USA (example)	Not stated	Pimentel et al. 1997
48,000	USA (example)	Not stated	Pimentel and Pimentel 2003
17,112	Australian average	Boneless beef (stage not stated)	Hoekstra and Chapagain 2007
15,497	World average	Boneless beef (stage not stated)	Hoekstra and Chapagain 2007
3,682	USA average	Boneless beef ex-processor	Beckett and Oltjen 1993
209	Australian average	All beef products ex-processor	Foran et al. 2005

vapour and groundwater present in the vadose zone, respectively (Falkenmark and Rockström 2006).

Another key aspect of interest in water use LCA is water quality. While LCA practitioners use midpoint indicators like eutrophication potential and aquatic ecotoxicity potential to characterise the impact of returning ‘wastewater’ to the environment, this degree of contamination also suggests the degree of use to the broader public and (ignoring hydrological parameters) if water is returned to the environment at or close to the quality at which it was extracted that use is considered sustainable (Owens 2002). This is a current problem for LCA; if we want to report meaningful inventory data, it must be informed by water quality issues in parallel with source sustainability issues.

A distinction is made in life cycle inventory (LCI) between ‘attributional’ and ‘consequential’ approaches to systems (Ekvall et al. 2005; Russell et al. 2005). If a pastoralist decides to let a property lie fallow and produce no beef, various systems will not operate. The *consequence* would be that water trough pumps would be switched off, fodder purchases would not occur, and other actions motivating a water flow would cease. However, the main water cycle processes of rainfall, evapotranspiration, runoff and infiltration will continue to occur; their relative scale will be determined by passive landscape features, vegetation and soil characteristics. The situation would be different for production of a flood- irrigated crop such as cotton. If a typical Australian cotton farmer chose not to produce cotton or other products in a particular year and let the property rest, the water budget of the property would be very different to a normal production year. Water control infrastructure (e.g. weirs and pumps) would not be actuated to cause the farm’s fields to flood. Overland flows would take their natural course. Therefore, such changes to fluvial and overland water flows would have to be considered in a consequential LCA of cotton production.

Depending on the purpose of the LCA, different temporal frames of reference may be appropriate. If one chose a frame of reference on the scale of centuries, the main changes in the water cycle would be due to landscape changes like deforestation and wetland destruction, which may have occurred shortly after the arrival of Europeans in Australia. If the frame of reference is a particular year (as in our study), then changes to foreground production systems that occur from year to year are more relevant. Construction of the tiny agricultural dams commonly used in Australia will not occur annually—such dams operate passively for much longer lifespans. There are large areas of northern Australia where agricultural interventions in the landscape are minor, where native pasture grows and cattle graze on that native pasture. Rainfall and evapotranspiration flows, which dominate farm hydrology, may not have changed significantly for a millennium. Can we say such flows are ‘used’ in meat production when they are practically unchanged? Our LCI approaches need to recognise this issue and report these flows separately.

Additionally, in systems where they have changed, associating the changed flow with a functional unit (production of 1 kg of red meat) seems difficult when any relevant landscape change (e.g. deforestation) occurred some decades ago and the land may have been used for a large number of different cropping and grazing activities since then. This change may or may not have been originally made for the purposes of livestock grazing. Moreover, in mixed farming regions, the maintenance of land in a cleared state may be driven more by other operations that use the land in rotation (e.g. cropping) rather than for livestock production per se. Notwithstanding this, livestock production does contribute to maintaining land in a cleared state in some instances, and in some cases, this may actually increase the amount of runoff from the system, effectively increasing the flow of blue water and adding complexity to the discussion (Scanlon et al. 2007). In this case, maintaining a hectare of land for red meat production may be a more appropriate functional unit than the provision of a kilogram of red meat. But the dominant cultural dialogue regarding water use in food products is always denominated in terms of the ultimate product units. Therefore this approach is unhelpful for analysts wishing to engage in that dialogue.

1.2 Life cycle impact assessment

Recent life cycle impact assessment (LCIA) proposals on water use suggest assessing consideration of the lifetime of available reserves (Heuvelmans et al. 2005) or the energy required to return water inputs to their original functionality (Stewart and Weidema 2005). The latter approach appeals for its consistency with assessment methods for other resources. Both methods consider the removal of water from its original location as part of the definition of use, while the latter also incorporates water quality issues. Leaving aside the practical difficulties that may arise in dealing with a distributed inland resource like rain, a key communication problem here is that, whether it is the most theoretically elegant denominator or not, volumetric units are the currency of the public water use debate, so LCI or LCIA intended to inform the debate needs to report their results in litres rather than energy demand (or 'kilograms of antimony equivalent' included among suggestions by Mila i Canals et al. 2008).

Recently, the *ratio of water use to renewable water resource* was proposed as a characterisation factor for scaling water obtained from different sources over a product life cycle and reporting a screening-level water use midpoint indicator in litres (Mila i Canals et al. 2008; Pfister et al. 2009). This would avoid this communication problem but, as recognised by its proponents, is dependent on the scale of the normalising renewable water resource datum, which may not be known for background system products and might be unclear even for the foreground system depending on the extent of centralised infrastructure available to supply the water to it. Additionally, many Australian river systems exhibit extremely variable flow rate distributions, and this variability rather than the average flow may be critical for endemic species, so basing sustainability assessment on such averages could overlook the key aspects of water use which threaten biodiversity. Nevertheless, the use of such an approach promises to provide a bridge to eventual use of midpoint indicators for the protection of human health, the biotic environment and resources (Bayart et al. 2010; Pfister et al. 2009).

2 Materials and methods

2.1 Scope of the LCA

The functional unit of this LCA is defined as 'the delivery of 1 kg of HSCW meat to the meat processing works product gate for wholesale distribution'. Three supply systems were considered:

- An organic beef supplier in Victoria. This is a relatively small operation (500 ha) on gently undulating coastal land with a long-term average annual rainfall of 940 mm. The property does not require irrigation supplies so the main use of potable water is at the meat processing works.
- An export beef supplier in New South Wales (NSW). This is a large property (2,800 ha) of mostly hilly land running both sheep and cattle, with some cropping on alluvial soils to provide fodder. The long-term average rainfall is 590 mm but supplies are bolstered by the availability of groundwater, a potable water network and an irrigation canal.
- A sheep-meat supplier in Western Australia (WA). This is a sheep grazing property (1,100 ha) on gentle hills, which supplements its income by producing barley and wheat for sale. It receives a long-term average of 460 mm of rain supplemented by a potable water network and groundwater supplies.

The production of red meat during the years 2002 and 2004 was estimated based on farm-specific production data. A portion of the NSW product was grown in a feedlot. Detailed growth estimates for the farms and feedlot were based on process data from site visits, dialogue with property managers and interrogation of farm and feedlot management information systems. In the case of the meat processing works, local published data were used (MLA 2002). For the NSW supply system, the data were aggregated by considering the proportion of the product made at the farm and the feedlot, and the product flow directly from the farm to the meat processing works relative to the product flow via the feedlot. In that case, as in the other two states, the kilogram HSCW denominator refers to the meat leaving the meat processing works gate, rather than the amount leaving the farm. The water inputs and outputs were allocated to red meat production in accordance with the relative mass of the red meat and its by-products.

Input–output analysis was subsequently used to complement the system modelling, taking into account purchased inputs to the farming enterprises for which primary LCI data were unavailable. This applied a recently developed Australian hybrid LCA model (Rowley et al. 2009). Further detail on the overall model is provided in Peters et al. (2010).

The flows into agricultural operations were classified according to a scheme based on matters raised in previous work (Udo de Haes et al. 1999; Owens 2002; Stewart and Weidema 2005; Bayart et al. 2010). We identify in situ rainfall as the most sustainable water source for agricultural use and list it as a unique local 'flow resource'. Non-passive surface water transfers (or 'diversions') of 'flow' resources (Udo de Haes et al. 1999), which reduce natural water flows in their original watercourses, are grouped by a separate set of shaded cells. These include agricultural irrigation supplies, water which had been transferred from another source by importation of animals or feed and reticulated town water supplies. We also separately inventoried bore water use as a 'fund' in Udo de Haes' sense of the term. Whether the aquifers are deep or shallow was not identified in this study, so this is an environmentally conservative use estimate for this type of source. We subsequently group transferred flows and funds as 'transferred water'—a collective LCI category for reporting water use where the water of source is not as sustainable as local precipitation. This definition is similar in effect to that of the ABS. Reflecting Owens (2002) concern that output quality also defines the degree of environmental impact, we non-quantitatively classified output flows as 'high quality' (evaporated water from fields and animals), 'moderate quality' (deep drainage and runoff, which would be less pure than the original rain), 'low quality' (excreted water and discharges to sewer) and 'alienated' water (water removed from the environment in the product). We subsequently group moderate quality, low quality and alienated flows as 'net use'—a collective LCI category for reporting water use where the discharge quality is not as high as water vapour.

2.2 Hydrological modelling

To obtain more accurate estimates of water use in beef production than is typically available to LCA practitioners, we used a hydrological model based on MEDLI, a model for analysing effluent reuse systems. A 51-year (1957–2007) climate file for each site was obtained from the Australian Bureau of Meteorology. This includes daily meteorological data for rainfall, evaporation, solar radiation, minimum and maximum temperatures. Soil parameters were based on broadscale soil and landscape information contained in the Digital Atlas of Australian Soils and from information supplied by each property manager. The modelling used USDA runoff curves based on the dominant soil type for each property and the topography, with curve numbers ranging from 74 for pastures on sandy soils to 83 for cereal crops on duplex soils.

Modelling was undertaken for native pastures, improved pastures, wheat, barley and oats. Grazing was simulated in the model by harvesting when pasture yield reached 1,000–1,500 kg DM/ha and by reducing nutrient removal to simulate the low net export of nutrients from a grazing system. In the irrigated hay runs, the pastures are periodically cut, harvested and removed from the site. For the cereal crops, the grain and straw are harvested and removed at the end of the cropping cycle. The irrigation model inputs include irrigator type, irrigation area size and irrigation scheduling rules. We modelled a low-pressure travelling irrigator with scheduling based on a soil water deficit. The volume of irrigation water available was limited to the amounts used by each property manager. The effluent inflow to the holding pond for the feedlot model was estimated to be 50 ML in 2002 and 48 ML in 2004. The model was calibrated for nitrogen, phosphorus and salinity concentrations typical for a feedlot of similar size and configuration, for which primary data were available. Due to the below average rainfall for the 2 years of interest, the volume of effluent irrigated was also low (~0.75 ML/ha). Each model run was performed for the entire 51-year period. The rainfall, evapotranspiration, runoff, deep drainage and plant yield were then extracted for the years 2002 and 2004. The rainfall measured on each property for the study years was sometimes different from the rainfall data used in the modelling but in most cases, this was not significant.

3 Inventory results

The inventory of inflows and outflows from the systems under study are shown in Table 2 and, of these data, Fig. 1 shows the water flows for the Victorian farm in 2004 (excluding flows at the meat processing works) as a Sankey diagram. It is striking how the water exchanges between the atmosphere and the farm (rain and evapotranspiration) dominate the overall water budget. The dominance of these two flows is even more extreme for the other five cases, where deep drainage is less important.

As can be seen in Table 2 from the relative errors in the data, the level of agreement between the estimates of total inputs and outputs is quite good with a maximum relative total error of 6.3%. The most significant flows in the table are the rainfall, evapotranspiration, deep drainage and runoff. These are all supplied by the MEDLI model, and the mass balance on the output of this modelling tool does not always close completely. This is primarily in response to the relationship between plant water usage and soil moisture. The primary water input to the properties is rainfall during the calendar year. In some cases, the sum of evapotranspiration, drainage and runoff is greater than total rainfall because the program also estimates stored soil moisture from the previous year. In years where a surplus is observed in the water balance, this was usually in the order of 10–20 mm of stored soil moisture across the property, which is considered a relatively minor error. It was difficult to accurately assess soil moisture retrospectively for the supply chain properties, and considering that the error was relatively small, no further adjustment was made.

Readers will recognise variation between properties and years in the figures. The NSW figures show a system that relies on less rainfall than the WA property, but more than the Victorian property. On the other hand, the NSW system relies more on reticulated water because of the feedlot and its use of cotton products for cattle feed.

Table 2 LCA overview of water use (L/kg HSCW) by supply chain and year

			Victoria (farm + processing)		WA (farm + processing)		NSW (farm + feedlot + processing)	
			2002	2004	2002	2004	2002	2004
Input source characterisation								
Local catchment	Rainfall		7,387	21,541	57,634	34,922	17,717	17,684
Transferred or diverted "flows"	Agricultural irrigation supply		0	0	0	0	86	67
	Livestock or irrigated feed		0	0	0	0	233	217
	Reticulated supply		27	40	207	131	170	142
Inter-compartment transfer "funds"	Bore		0	0	7	4	51	37
		Total inputs	**7,414**	**21,581**	**57,848**	**35,058**	**18,257**	**18,147**
Output quality characterisation								
High quality	Evaporation and evapotranspiration		6,664	14,907	59,171	33,177	17,219	16,837
	Animal perspiration & exhalation		21	24	30	24	22	28
Moderate quality	Deep drainage		1,122	6,622	0	0	0	0
	Runoff		29	22	0	0	454	85
Low quality	Animal urination / excretion		42	49	18	14	30	45
	Discharge to sewer		3.67	3.30	3.35	3.33	3.33	3.33
Alienated	Water content of meat products		0.47	0.48	0.51	0.52	0.77	0.67
		Total outputs	**7,881**	**21,629**	**59,222**	**33,219**	**17,729**	**16,998**
Water balance								
Absolute error (total inputs minus total outputs)			**-467**	**-47**	**-1,374**	**1,839**	**529**	**1,149**
Error as a percentage of total inputs			**-6.3%**	**-0.2%**	**-2.4%**	**5.2%**	**2.9%**	**6.3%**

Inter-annual variation is particularly apparent in the rows that relate to rainfall, evapotranspiration, deep drainage and runoff. The main factor is the changes between the type of agricultural business being run at the properties between years, resulting in different intensities of productive activity on the farms. Particular attention is drawn to the Victorian property which in 2002 operated as a finishing enterprise for traded cattle purchased as weaners. Since this type of system excludes breeding stock, which require more water per unit of liveweight gain than non-breeding stock, water usage was expected to be 30–50% lower than a system including these cattle. In fact, the per kilogram HSCW figures are even lower than that, reflecting this and other sources of inter-annual variation including climate (14% less rain fell in 2002). As a proportion of total red meat exports, sheep purchases by the WA property varied significantly between years (zero in 2002 and 80% of exports in 2004). In this case, the climate was relatively consistent between years, and the variation in the per HSCW figures has mostly to do with the variation in agricultural business practice between years. These two cases illustrate the responsiveness of the model to such changes in the primary data of the underlying systems.

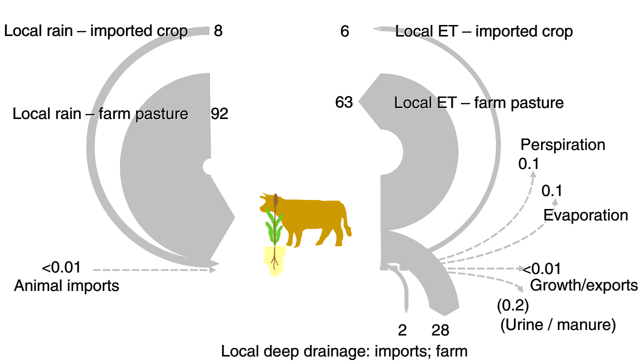

Fig. 1 Annual water flows for the Victorian property in 2004 (percent)

On the other hand, inter-annual variation is less apparent for the engineered water input categories and the lower quality water output categories. This is to be expected because the agricultural system managers are able to control these flows relative to the needs of the production system, compared with the variability of rainfall in Australia.

Table 3 Summary of LCI results

Definition of water use sustainability	Victoria		WA		NSW	
	2002	2004	2002	2004	2002	2004
'Transferred water': input source characterisation=transferred funds and flows	27	40	214	136	540	464
'Net use': output quality characterisation=moderate, low or alienated	46	52	22	18	34	49

The results are summarised in Table 3. This aggregates the water flows in the previous table that are considered less sustainable by virtue of the supply characteristics (transferred flows and funds) or by virtue of the discharge quality (output quality moderate, low or alienated). This reflects the general concerns of LCA theorists and our contention that rain that is an input to pasture whether or not cattle graze on it, and is returned to its source at a high quality, should be addressed separately in LCA studies from other water flows. The table shows that the water flows exist in a relatively small range for both years in the systems without a feedlot: Water use is 18–52 L/kg HSCW under the 'net water use' definition and 27–214 L/kg HSCW for the transferred water definition. The NSW system, with its feedlot and irrigated agriculture at the farm, is estimated to have used around 34 and 540 L/kg HSCW depending on which definition is selected. Most of the difference is due to the purchase of irrigated feeds by the feedlot.

Our results indicate that water used to produce red meat in southern Australia is 18–540 L/kg HSCW, depending on the supply system, reference year and whether we focus on source or discharge characteristics.

4 Comparison with previous studies

Foran et al. (2005), who used a system analysis methodology very different to ours, generated a result within the range of results shown in Table 3. Those authors used an economics-based input–output analysis and the ABS definition of water use (ABS 2005), which excludes rain. By this definition, dryland cropping does not require added water, which is consistent with the published LCA of Australian wheat (Narayanaswamy et al. 2005). Comparison with our work relies on industry-level wholesale pricing: \$3.5/kg beef and \$4.2/kg (beef/sheep/pork/chicken products) calculated from their data. On this basis, they suggest that 209 L/kg is used in the beef industry and 79 L/kg for the other meat products. The masses refer to industry output of all 'meat products after slaughtering'.

Calculating 'water footprints' for various countries, Hoekstra and Chapagain (2007) multiplied the water demand of crops by the amount of crops produced in different countries. No quantitative distinction was made between irrigation supply and rain. For example, an amount of 1,334 kL water per tonne of wheat is cited (compare this with 0.6 kL/t for Australian dryland wheat products; Narayanaswamy et al. 2005). Allocation to multiple products was based on the economic value of the products. Those authors estimated 17,112 L/kg for the production of Australian beef. This is not broken down into its constituents, but the global data are, indicating that roughly 1% of the total is due to 'direct consumption' and the remainder for feed production.

A detailed process analysis of US beef production (Beckett and Oltjen 1993) produced results between ours and those of Hoekstra and Chapagain (2007). Their estimate of 3,682 L/kg is dominated by irrigation of feed supplies. Water use for crops is based on irrigation use, and defined as 'water which is diverted from possible use by humans'. So rain is excluded, but in the USA, 23% of the main feedstuff (alfalfa) is irrigated, and there is a large (two million hectares) area of irrigated pasture. If we substitute data for dryland wheat into this work, and remove the large irrigated pasture, their results are broadly consistent with ours.

Pimentel and Pimentel (2003) estimate that beef production requires 105,400 L/kg. Unfortunately they neither define water use nor describe their methodology in detail in this recent publication, referring instead to Pimentel (1980), who provides some data on fodder and grain consumption but does not divulge the volume of water required to grow fodder and grain. Judging by the data presented, the authors appear to adopt an approach broader than that taken by Hoekstra and Chapagain (2007), that is, one which counts all rain inputs to cropping and pasture as water used, rather than a retrospective estimate of evapotranspiration water used for pasture production. The calculations of Pimentel and Pimentel (2003) are similar to Hoekstra and Chapagain (2007) because they do not distinguish between in situ rain and engineered water supplies. This accounts for the differences between their work and ours.

5 Interpretation

We would like to emphasise that our results only represent three production systems and 2 years. It would be ambitious to take an average of these data or name a particular number as representative of water use by southern red meat producers in Australia—we are more comfortable talking about the range of results. They do nevertheless demonstrate that, from an environmental perspective, the use of water by red meat production in Australia is less than 1,000 L/kg HSCW, and several orders of magnitude lower than some authors have suggested.

Two key factors cause the considerable differences between the data presented by different authors: the treatment of rain and the feed production process. The first factor is often assumed to be a simple matter of exclusion or inclusion by many authors, but in fact deserves careful definition. While we argue that this flow may not be relevant to consequential environmental analysis, it should be noted that the hydrology-based approach we used to estimate rain inputs used here may provide a better estimate of the water use values used in 'virtual water studies' than the metabolic calculations typically in use because they include water needed for the maintenance of vegetation which maintains soil structure and prevents erosion, rather than just the metabolic needs of livestock. It could be argued that in studies which aim to optimise economic or calorific outcomes using attributive analysis, water needed for landscape maintenance is relevant to the ability to produce the functional unit. Regarding the second factor, most of the grain and fodder crops used in the three red meat supply chains we studied in Australia are produced by dryland cropping. In other locations where surface water supplies are more readily available, such as the USA, irrigation of cattle fodder is more common. So whereas the treatment of rain is a methodological issue relevant to all studies relating water use to the production of red meat, the availability of irrigation water can be characterised as a fundamental difference between the infrastructure of red meat production systems in different locations.

Grazing properties are open systems, so rain on a property is a special kind of dispersed renewable resource, which, like oxygen gas, is supplied by natural processes and is present no matter how the property is operated. When we consider this issue, and the differences between foreign farming systems and Australian ones, the differences between higher and lower water use calculations which have been published become clear. We have examined the literature with regard to normal LCA practice and aspects of the methodological basis for estimating water use in the production of red meat. This indicates that, for environmental assessment, rainfall is generally excluded from calculations on account of methodological and practical considerations. To allow us to nevertheless examine three southern red meat production systems from a variety of accounting perspectives, we have applied a standard agricultural hydrological modelling tool (MEDLI) to provide us with an assessment of the behaviour of rainfall at the properties participating in this study. This modelling has demonstrated that when rain is included in the accounts, the results of our assessments are similar to those of other authors reporting high water use in red meat production. However, when we consider the use of water in red meat production from a sustainability perspective, we should identify the kinds of processes used to intervene in the water cycle in obtaining water, and the quality of the water when it is returned from the production system under study. Taking either of these perspectives independently, the amount of water used in the production of red meat in the southern supply systems we studied is several orders of magnitude lower.

One of the benefits of doing detailed hydrological modelling of a foreground agricultural system is the relative certainty with which it allows analysts to use LCIA processes such as that outlined recently by Pfister et al. (2009), which necessitates geographical identification of the production system. For the future application of this kind of method to multicomponent manufactured goods (e.g. pre-mixed foods with fibre-based packaging), more detailed LCI databases will be needed in order to allow LCA tools to identify the location of water uses in background systems on a watershed scale.

Another aspect of LCI methodology which we may increasingly need to consider if we wish to understand the environmental impacts of water use is the potential for environmental damages to non-freshwater systems. Hitherto, the focus of methodological developments has understandably been driven by agricultural use of freshwater, and it is difficult to imagine estuarine or ocean waters being depleted by human uses. However, as noted previously (Peters and Rowley 2009), there is potential for environmental damage associated with filtration processes and changes in temperature and salinity when these water sources are used. We therefore consider that in addition to the classifications used here, people engaged in LCI development should include estuarine and ocean water demands as separate flows in their inventories.

6 Recommendations and perspectives

Whether or not a litre of water is used is related in the public mind and in theory, not only just to the extent to which it is physically removed from natural systems but also to the quality of the water when it is returned to the environment from the production system. We argue that the approach to reporting life cycle inventory data in policy discussions must be mindful of the needs of the data user. Where the focus is on economics and the water transactions between nations, it may be appropriate to include rain in virtual water. Where the focus is on the reduction of environmental burdens, we believe that approach is inappropriate because it fails to consider the environmental significance of water use.

In order to develop estimates that reflect those characteristics, we determined that property-scale hydrological modelling would be a worthwhile approach, with the aim of producing a rich data set. In this study, we report and group our results on the basis of several definitions of water use, including one that is consistent with normal LCA practice and the work of the ABS. Given that both the source of the water used in agriculture and the quality at which it is discharged are relevant in discussions about environmental sustainability, we suggest that analysts who are asked to contribute to public discussions ought to calculate the amount of water used in production by aggregating transferred funds and flows, and aggregating flows of water discharged at reduced quality, and report either the higher of the two figures or preferably the range.

There are many points in the process of designing a method for assessing water use in agricultural production at which value judgements may arise. The more complex the systems and environmental issues we address in LCA, the more unavoidable this becomes. Some alternatives have been proposed for the purpose of environmental assessment, but are yet to be fully validated in case studies. The key, as always, is to ensure that the goal of the study, its informational context and the assumptions made are clear. One can only hope that if more emphasis is placed on this by analysts in discussion with the media, their work will be interpreted more appropriately.

Considering that the majority of Australian beef production comes from northern Australia, it would be worthwhile to extend this work to an assessment of the water used in red meat production in that region.

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