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Undertaking a Life Cycle Assessment for the Livestock Export Trade

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GLOSSARY

AE: Adult equivalent. One AE is a 455 kg beast at maintenance, that is, not growing.

Carbon footprint: The term ‘carbon footprint’ has become a common expression for summarising the quantity of greenhouse gases that are emitted during the production, use and disposal of a product, commencing with the raw ingredients drawn from nature through to end-of-life waste flows back to the environment.

CFI: Carbon Farming Initiative. The proposed CFI is a voluntary scheme whereby Australian land holders can undertake abatement activities that will generate offsets that can be registered and traded in a carbon market.

CH_4: Methane. Methane is the principal component of natural gas and is produced as a by-product of coal mining. Methane is also produced by microbes (methanogens) which operate in the rumen of livestock and in anaerobic decomposition of organic matter (manure ponds and landfill).

CO_2-*e*: Carbon dioxide equivalents. CO_2-*e* is a measure for describing how much global warming a given type and amount of greenhouse gas may cause, using equivalent amount or concentration of carbon dioxide (CO_2) as the reference. Each greenhouse gas is converted to units of CO_2-*e* by multiplying its weight by the global warming potential for the individual gas. The global warming potential of CO_2 is 1, while the global warming potential (over a 100 year time frame) for methane is 21 and for nitrous oxide is 310. That is, a kilogram of methane has 21 times the warming effect compared to a kilogram of CO_2 in the atmosphere.

CPRS: Carbon Pollution Reduction Scheme. The CPRS is a domestic emissions trading scheme proposed by the Australian government in 2008, with a proposed start date of 2011. However the introduction of the CPRS was delayed, due to lack of bipartisan support for the legislation. In October 2010, the Government established a Multi-Party Climate Change Committee to explore options for the implementation of a carbon price for the Australian economy, and the Committee’s deliberation will assist in shaping future policy.

ETS: Emissions trading scheme. Emissions trading (also known as cap and trade) is a market-based approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants.

GHG: Greenhouse gas. A greenhouse gas is a gas that absorbs thermal radiation (heat) and re-radiates the heat in the atmosphere. As a consequence of higher greenhouse gas concentrations in the atmosphere, more of the sun’s radiation is retained as heat in the earth’s atmosphere. The most common GHGs are water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_20) and ozone. Refrigerant gases are also potent GHGs.

IPCC: Intergovernmental Panel on Climate Change. The Intergovernmental Panel on Climate Change (IPCC) is a scientific intergovernmental body tasked with reviewing and assessing the most recent scientific, technical and socio-economic information that is relevant to the understanding of climate change.

ISO: International Organization for Standardization. ISO is an international standard-setting body composed of representatives from various national standards organisations. The organisation promulgates worldwide proprietary industrial and commercial standards.

LCA: Life cycle assessment. A life cycle assessment is a technique to assess each and every impact associated with all the stages of a process from-cradle-to-grave (i.e., from raw materials through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling).

LCI: Life cycle inventory. LCI is the underpinning data required to perform a Life Cycle Assessment. It describes the inputs and associated reference flows (e.g. CO_2-*e* or water) required to produce a product or service.

N_2O: Nitrous oxide. N_2O is a product of the nitrogen cycle and is produced when nitrates are denitrified in the soil by bacteria.

NGGI: National Greenhouse Gas Inventory. Account prepared each year by the Australian government to track emissions from each sector of the economy.

PAS 2050: Publicly Available Standard 2050 that describes the specifications for the assessment of the life cycle greenhouse gas emissions of goods and services.

WUE: Water use efficiency. Describes the evapo-transpiration requirements for producing the crops and pastures.

ABSTRACT

The purpose of the study was to undertake a Life Cycle Assessment for Australian live sheep and cattle export supply chains, to provide benchmarks for global warming, water and energy use, and eutrophication. The two supply chains studied were sheep exported from Fremantle to the Middle East and cattle exported from Darwin to Indonesia. All sectors of the supply chain were covered, from on-farm production, pre-shipping export yards, shipping and feed lotting in the destination country through to delivery of the live animal at the abattoir. Producing one wether ready for slaughter in the Middle East contributed an estimated 353 kg CO_2-*e* to the atmosphere, used an estimated 305,400 L rainwater, 2,220 L reticulated water, but no irrigation water, used an estimated 1,640 MJ of energy and produced estimated nutrient flows linked to eutrophication of 1.05 kg PO_4--- e. Producing one steer ready for slaughter in Indonesia contributed an estimated 12,300 kg CO_2-*e* to the atmosphere, used an estimated 23,510,500 L rainwater, 50,400 L reticulated water, and 9,100 L irrigation water, used an estimated 10,700 MJ of energy and produced estimated nutrient flows linked to eutrophication of 5.82 kg PO_4--- e. The study provides the live export industry with a comprehensive benchmark of its environmental performance. The report delivers scientifically rigorous and detailed information on the contribution of the whole supply chain, each sector of the supply chain, each feedstuff used in each sector, and the management practices applied in each sector, allowing the industry to respond in confidence to claims made by others about their environmental performance. But more powerfully, it enables the industry to explore options for improving their environmental impact, and it allows the industry to investigate the environmental outcome of alternate commercial scenarios for supplying markets.

1. EXECUTIVE SUMMARY

1.1 Issues under study

Australian agriculture is facing a number of imperatives in terms of reducing adverse environmental impacts and resource use. Amongst these is the need to mitigate greenhouse gas (GHG) emissions, use scarce resources such as water and energy in an efficient manner, and reduce the contribution of nutrient flows to eutrophication in the environment. These issues intersect; water scarcity and quality are being exacerbated by climate change (BOM and CSIRO 2010) and the price of fossil fuels is under pressure from a potential carbon market.

Although there exists uncertainty about the policy mechanism by which GHG abatement might be achieved in the Australian economy, there is a high level of certainty that the agricultural sector will need to play a role in reducing emissions, as it currently contributes 15% of Australia's national emissions and is largely responsible for an additional 7% of emissions related to land clearing (DCCEE 2011). In addition, when looking across the options for storing carbon in the landscape, carbon forestry is the option most ready for implementation and will interact with use of land for agricultural production as carbon markets begin to function (Eady *et al.* 2009).

The mainstream farming community is in the process of building its understanding of the potential impact a global carbon economy will have on farming systems. As there is little published data on farm-level sinks and sources of GHG emissions, the first step in this process is for the agricultural sector to quantify and benchmark GHG emissions and begin to investigate ways for mitigation. Along side this sits the use of scarce water resources for agricultural production and carbon storage, and the environmental impact of intensification of agriculture on freshwater and marine ecosystems.

The purpose of the project, funded by LiveCorp/MLA on behalf of live export industry members, was to undertake a Life Cycle Assessment (LCA) for Australian live sheep and cattle export supply chains, to provide benchmarks for global warming, water and energy use, and eutrophication. The two supply chains chosen for the study were sheep exported from Fremantle to the Middle East and cattle exported from Darwin to Indonesia. The study covered the animals through all sectors of the supply chain from on-farm production, pre-shipping export yards, shipping and feed lotting in the destination country through to delivery of the live animal at the abattoir.

1.2 The approach used

A Life Cycle Assessment takes into account all of the environmental impacts that occur from 'cradle-to-grave', that is from resource extraction, production, use and disposal of a product, commencing with the raw ingredients drawn from nature through to end-of-life waste flows back to the environment. For this study much of this information exists in Life Cycle Inventories which were used for inputs such as electricity and fuel. However, much of the information had to be collected specifically for the supply chains examined. This foreground data was obtained from three sheep enterprises exporting wethers from WA and four cattle enterprises exporting feeder steers from the Northern Territory, four export and shipping feed suppliers, three pre-shipping export yards, one feedlot in the Middle East and five Indonesian feedlots. This data was based on written records and the business accounting system in some instances, while in others, data was collected from face to face meetings with the business managers. These records covered inputs such as number of livestock, fodder purchases, health treatments, area of crops/fodder planted, machinery operation, use of fertilizer and pesticide, fuel and electricity inputs, and general business services (e.g. insurance, accounting fees, repairs and maintenance). Data for the eight ships servicing Fremantle Port and the 23 ships serving Darwin Port were obtained from public sources such as Lloyds Register and the relevant Port Authorities.

1.3 Key results

The key result for the study is the benchmark of greenhouse gas (GHG) emissions, water and energy use and nutrient flows of nitrogen and phosphorus linked to eutrophication, for the two supply chains as shown in Table 1.

Producing one wether ready for slaughter in the Middle East contributed an estimated 353 kg CO_2-*e* to the atmosphere, used an estimated 305,400 L rainwater, 2,220 L reticulated water, but no irrigation water, used an estimated 1,640 MJ of energy and produced an estimated nutrient flow linked to eutrophication of 1.05 kg PO_4--- e.

Producing one steer ready for slaughter in Indonesia contributed an estimated 12,300 kg CO_2-*e* to the atmosphere, used an estimated 23,510,500 L rainwater, 50,400 L reticulated water, and 9,100 L irrigation water, used an estimated 10,700 MJ of energy and produced an estimated nutrient flow linked to eutrophication of 5.82 kg PO_4--- e.

The breakdown of how each sector in the supply chain contributed to the GHG emissions is shown in Figure 1, with the on-farm sector being the largest contributor, 72% for the sheep and 85% for the cattle supply chain. The relative contribution of each sector to water and energy use and nutrient flows liked to eutrophication can be found in the full report; but generally water use was largely from the on-farm sector, energy use was dominated by the shipping sector for the sheep supply chain and the feed lotting sector in Indonesia for the cattle supply chain, while nutrient flows linked to eutrophication occurred largely during the shipping sector in the sheep supply chain and the feed lotting sector in Indonesia for the cattle supply chain.

In comparison with other sheep production systems, the GHG emissions of sheep meat from the sheep supply chain to the Middle East (7.4 kg CO_2-*e* /kg live weight for 48 kg wether) is higher than that of wethers produced southern systems where published estimates of GHG emissions range from 3 to 5 kg CO_2-*e* /kg live weight for sheep (Peters *et al.* 2010; Eady *et al.* 2011). This is largely due to the additional input that shipping makes to the carbon foot print of live export sheep, contributing 1.8 kg CO_2-*e*/kg live weight. Compared to export lamb, shipped frozen to the UK from New Zealand (Ledgard *et al.* 2010), with a GHG emissions of 7.5 kg CO_2-*e* /kg (accounting for on-farm and shipping processes), Australian live export wethers had a similar GHG emissions of 7.4 kg CO_2-e/kg live weight, albeit the split between on-farm and shipping being quite different (75:25 for export wethers) and (94:5 for NZ lamb). Energy use estimates were similar to other estimates in the literature for Australian sheep.

Table 1. The GHG emissions, water and energy use and nutrient flows linked to eutrophication for the whole supply chain from ‘cradle-to-grave’ for live export sheep from Western Australia to the Middle East and live export cattle from the Northern Territory to Indonesia.

Live animal delivered to abattoir	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**				**Energy use (MJ)**	**Eutrophication (PO_4---*e*)**
		Green water	**Blue water on-farm**	**Blue water off-farm**	**Blue water irrigation**		
Total for one 48 kg wether	**353**	**305,400**	**1,360**	**860**	**0**	**1,640**	**1.05**
Total for one 470 kg beast	**12,300**	**23,510,500**	**39,400**	**11,000**	**9,100**	**10,700**	**5.82**

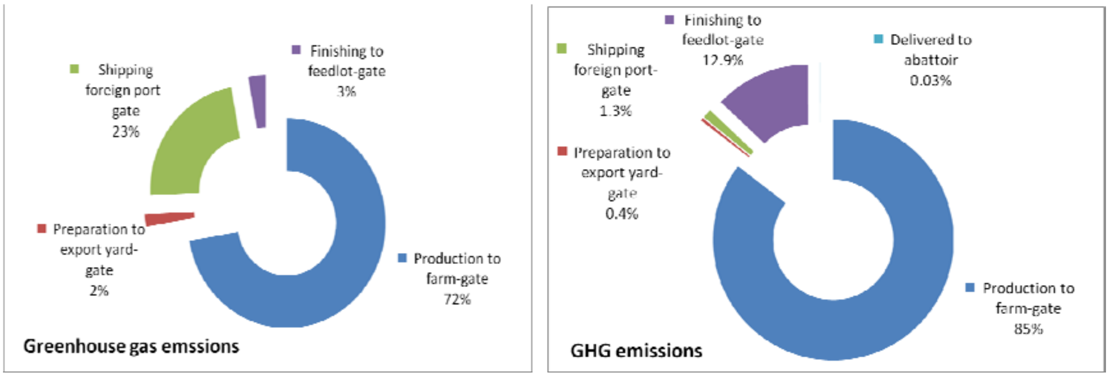


Figure 1. Relative contribution from each sector of the sheep supply chain (left) and cattle supply chain (right) for GHG emissions.

In comparison with other beef production systems, the GHG emissions of beef from the cattle supply chain to Indonesia (26 kg CO_2-*e* /kg live weight for 470 kg steer) is higher than beef produced in southern systems where published estimates of GHG emissions range from 5.4 to 14.5 kg CO_2-*e* /kg live weight for finished steers (Peters *et al.* 2010; Eady *et al.* 2011b submitted). This is largely due to herds in the southern systems having a higher reproduction rate, faster turn-off, no savanna burning emissions and lower methane emissions per unit of feed intake. Energy use estimates for this study were in the order of two-fold higher than other published figures for Australian cattle production.

There is a sparsity of published data for water use and eutrophication for ruminant livestock, either in Australia or overseas.

1.4 Industry benefits and recommendations

The study provides the live export industry with a comprehensive benchmark of its environmental performance for four key impact categories. The report delivers scientifically rigorous and detailed information on the contribution of the whole supply chain, each sector of the supply chain, each feedstuff used in each sector, and the management practices applied in each sector. This will allow the industry to respond in confidence to claims made by others about the environmental performance of the industry. But more powerfully, it will enable the industry to explore options for improving their environmental impact, and it will allow the industry to investigate the environmental outcome of alternate commercial scenarios for supplying markets.

Consideration has been given to options that could be explored to moderate environmental impacts (specifically global warming) along the two supply chains. These cover a range of options - improvements in on-farm productivity, the contribution of legume based pastures, savanna burning and land clearing, varying feed ingredients for the export yard and feedlot sectors, minimising transport distances for feeds and management of livestock effluent.

Along with opportunities for mitigation of GHG emissions (and other environmental impacts) there are a number of industry-based issues that may benefit from comparing scenarios. Scenarios that may be worth investigating to provide the industry with a concrete environmental assessment are:

- a comparison of frozen boxed meat (both sheep and beef) with live export of animals to target regions
- a comparison of southern Australian-based feedlot finishing for store steers with live export of feeder steers
- a comparison of disposal of culled cattle via interstate slaughter markets with live export of slaughter cattle to Asia

2. INTRODUCTION

2.1 Background

Australian agriculture is facing a number of imperatives in terms of reducing adverse environmental impacts and resource use. Amongst these is the need to mitigate greenhouse gas (GHG) emissions, use scarce resources such as water and energy in an efficient manner, and reduce the contribution of nutrient flows to eutrophication in the environment. These issues intersect; water scarcity and quality are being exacerbated by climate change (BOM and CSIRO 2010) and the price of fossil fuels is under pressure from a potential carbon market.

Although there exists uncertainty about the policy mechanism by which GHG abatement might be achieved in the Australian economy, there is a high level of certainty that the agricultural sector will need to play a role in reducing emissions, as it currently contributes 15% of Australia's national emissions and is largely responsible for an additional 7% of emissions related to land clearing (DCCEE 2011). In addition, when looking across the options for storing carbon in the landscape, carbon forestry is the option most ready for implementation and will interact with use of land for agricultural production as carbon markets begin to function (Eady *et al.* 2009).

The mainstream farming community is in the process of building its understanding of the potential impact a global carbon economy will have on farming systems. As there is little published data on farm-level sinks and sources of GHG emissions, the first step in this process is for the agricultural sector to quantify and benchmark GHG emissions and begin to investigate ways for mitigation. Along side this sits the use of scarce water resources for agricultural production and carbon storage, and the environmental impact of intensification of agriculture on freshwater and marine ecosystems.

A significant contributor to environmental impacts for food products is the agricultural sector where the basic ingredients are grown. However, there are other operations along the value chain that can significantly influence the final impact. In the case of live export of cattle and sheep these include shipping, feeding and handling at destination. For cattle this often includes a significant period of time in a local feedlot where feedstuff supply can be quite different to Australian feedlots.

The purpose of the project, funded by LiveCorp/MLA on behalf of live export industry members, was to undertake a Life Cycle Assessment (LCA) for Australian live sheep and cattle export supply chains, to provide benchmarks for global warming, water and energy use, and eutrophication. The goal was to produce a science-based, transparent assessment of these environmental impacts and flows for live cattle and sheep exports. The LCA covers all parts of the supply chain from on-farm production, pre-shipping export yards, shipping, and feed lotting in the destination country.

2.2 Global Warming and policy response

Australian agriculture is facing a number of imperatives – water scarcity and the need for greenhouse gas (GHG) abatement, to mitigate global warming, being amongst them. A summary of how the Australian climate has changed (Figure 2) can be found in the joint Bureau of Meteorology and CSIRO publication – 'The State of the Climate' (BOM and CSIRO 2010).

The science community has examined many hypotheses to explain global changes in climate and have arrived at the position that it is human induced changes in the level of greenhouse gases that is the predominant force driving these changes. Figure 3 demonstrates the change in carbon dioxide (CO_2) and methane that has occurred since pre-industrial times. Based on scientific evidence from research agencies across the world, there is very high confidence (9 out of 10) that human activities, which have accelerated the release of greenhouse gases into the atmosphere, are responsible for climate change (IPCC 2007a).

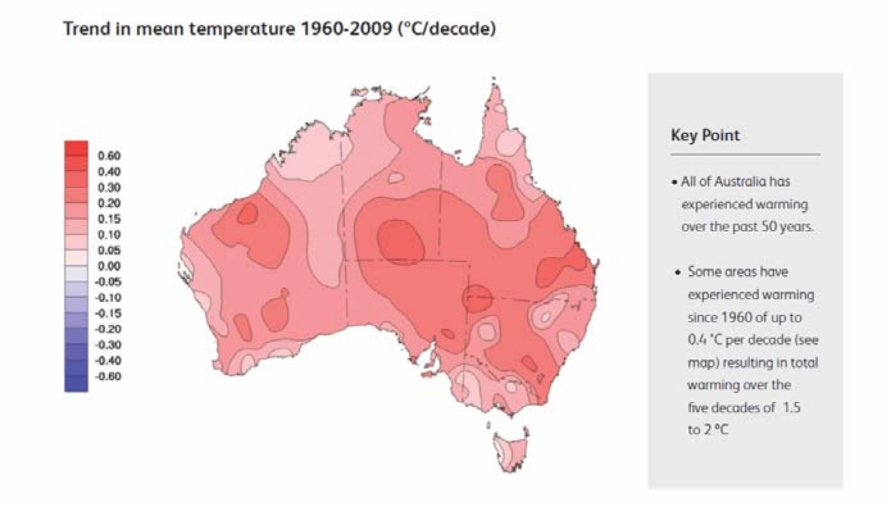
The predicted impact of global warming on the climate in Australia is to see general warming across the continent, a change in geographic distribution in rainfall (particularly a decease in winter rainfall in parts of southern Australia) and an increase in extreme weather events such as droughts, floods, coastal storm surges and high risk fire conditions (IPCC 2007b).

Various legislative frameworks have been developed to mitigate GHG emissions, such as the European Emissions Trading Scheme (ETS), the New Zealand ETS, and state-based schemes in the US (on the east coast, the Regional Greenhouse Gas Initiative, and on the west coast, the Western Climate Initiative) and the NSW Greenhouse Gas Reduction Scheme.

Emissions trading schemes are being introduced to assist countries in meeting their emissions reduction commitments under international agreements such as the Kyoto Protocol. An ETS creates an economic incentive for emissions reduction: it allows those emitters who can reduce their emissions at low cost to trade emissions rights with others who can only do so at a higher cost, and thus it allows the market to identify and implement practices that achieve mitigation at least overall cost (Cowie *et al.* 2011).

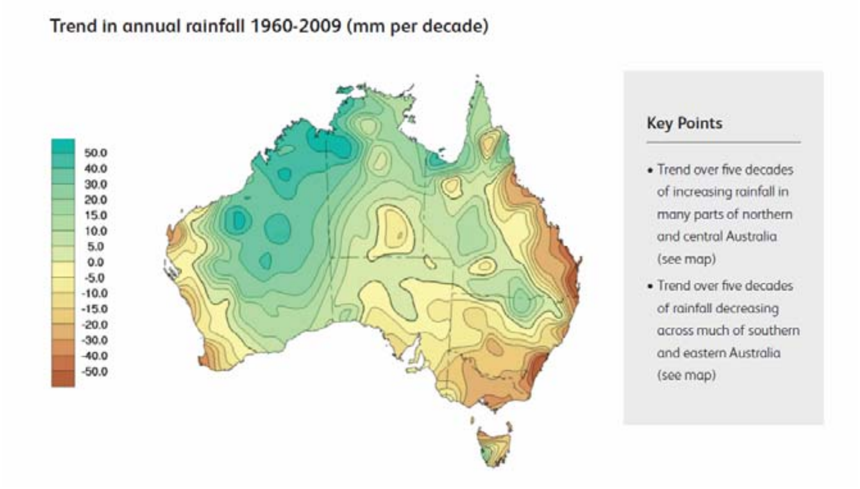
The Australian government has proposed a domestic ETS, the Carbon Pollution Reduction Scheme (CPRS), which was due to commence in 2011. The decision to exclude agricultural emissions from the trading scheme was made in late 2009. There is no current proposal in Australia for agricultural emissions in general to be included or 'covered' under a future ETS or carbon tax. The introduction of the CPRS was delayed, due to lack of bipartisan support for the legislation. In October 2010, the government established a Multi-Party Climate Change Committee to explore options for the implementation of a carbon price for the Australian economy and it is anticipated that this Committee will deliver its recommendations in late 2011.

The mainstream farming community is in the process of building its understanding of the potential impact that a global carbon economy will have on farming systems. As there is little data on farm-level sinks and sources of GHG emissions, the first step in this process is for the agricultural sector to quantify and benchmark GHG emissions. Along side this sits the issue of the use of water for agricultural production and carbon storage.



Key Point

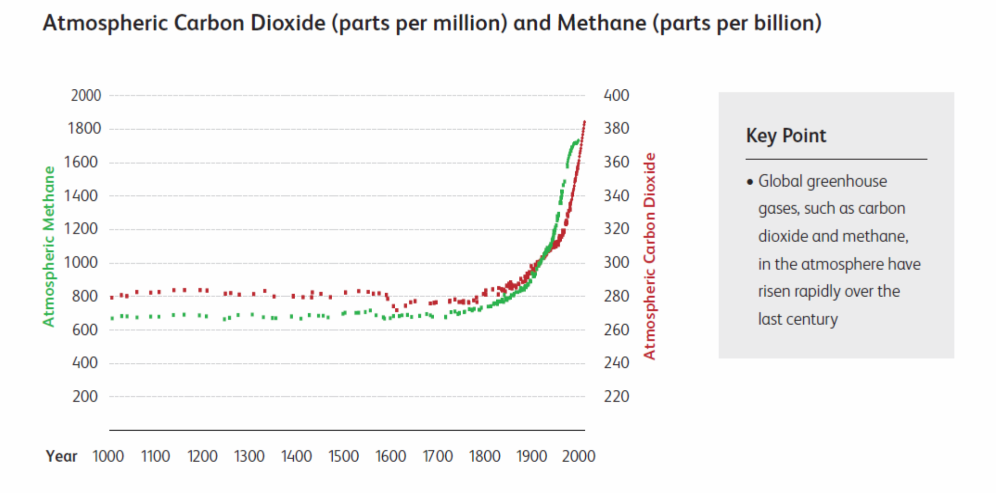
- All of Australia has experienced warming over the past 50 years.
- Some areas have experienced warming since 1960 of up to 0.4 °C per decade (see map) resulting in total warming over the five decades of 1.5 to 2 °C



Key Points

- Trend over five decades of increasing rainfall in many parts of northern and central Australia (see map)
- Trend over five decades of rainfall decreasing across much of southern and eastern Australia (see map)

Figure 2. Trend in mean temperature and rainfall for Australia since 1960. Source: Bureau of Meteorology 2010.



Atmospheric Carbon Dioxide (parts per million) and Methane (parts per billion)

Key Point

- Global greenhouse gases, such as carbon dioxide and methane, in the atmosphere have risen rapidly over the last century

Figure 3. Concentration of greenhouse gases (CO_2 and methane) in the atmosphere. Source: Bureau of Meteorology 2010.

2.2.1 Carbon accounting frameworks relevant to Australian agriculture

A number of overlapping frameworks for ‘accounting’ for carbon have developed in response to climate change. The following description seeks to explain the intersections and overlaps between them from an agricultural perspective.

National Greenhouse Gas Inventory (NGGI)

These accounts are used at the national scale to monitor Australia’s greenhouse gas (GHG) emissions (DCCEE 2011). Emissions are attributed to sectors in the economy, of which the most relevant for primary production are agriculture and land use change, followed to a lesser extent by transport and energy. These accounts are used to prepare the National Greenhouse Gas Inventory (NGGI) each year to meet Australia’s accounting requirements under international agreements, such as the Kyoto Protocol.

Offset projects – Carbon Farming Initiative

Offset projects are designed to abate GHG emissions by undertaking an additional activity outside of ‘business-as-usual’ (DCCEE 2010). For the land sector, the Carbon Farming Initiative (CFI) will provide a voluntary scheme whereby land holders can undertake abatement activities that will generate offsets which can be registered and traded in a carbon market. This policy is designed to enable carbon sinks to be built in the landscape and for reductions in agricultural emissions to be rewarded.

Carbon footprint

The term ‘carbon footprint’ has become a common expression for summarising the quantity of GHGs that are emitted during the resource extraction, production, use and disposal of a product, commencing with the raw ingredients drawn from nature through to end-of-life waste flows back to the environment. The ‘rules’ for how to undertake the estimation, and what emissions are to be included for a carbon footprint, are set out in internationally agreed standards (ISO 2006) with a particular standard for carbon footprinting currently under development (ISO 2010). British Standards (2008) have also developed a Publicly Available Standard (PAS 2050) for carbon footprinting which is widely used in retailing. The use of such standards gives consistency between assessments. The analytical technique used to determine the carbon footprint is a Life Cycle Assessment (LCA).

'Carbon footprint' is a colloquial term applied to a LCA that examines the global warming impact of a product, organisation or event. It is calculated as the quantity of GHG emitted, less GHG sequestered, and is expressed in units of CO_2 equivalents (CO_2-e).

A carbon footprint for food and fibre production typically includes the upstream emissions from manufacturing fertiliser and other inputs, from fuel used in farming operations, from transport, processing and packaging, distribution to consumers, electricity use in refrigeration and food preparation, and waste disposal. The GHGs considered include non-biogenic CO_2 (from burning fossil fuels), methane and nitrous oxide (and precursors of N_2O such as ammonia and NOx). Each of these GHGs has a different warming potential, with initial estimates for methane and nitrous oxide being 21 and 310 times the warming effect of CO_2, respectively, when considered over 100 years. These figures were updated in 2007 to 25 and 298 times the warming effect of CO_2, respectively, when considered over 100 years (Forster *et al.* 2007). However, the original figures will be used for Australian greenhouse gas inventory until the end of the current Kyoto accounting period in 2012, to enable consistency across years in the national accounts and carbon offset programs.

Using the global warming potential, emissions of these gases are converted to CO_2-e units for ease of comparison. Hydro-carbons used as refrigerants are also included. Biogenic CO_2 emissions are only included when they result in a decline in biomass or soil carbon stock, for example, felling a forest to plant crops. Otherwise biogenic carbon is assumed to cycle between the atmosphere and plant, soil and animal matter in a balanced manner.

Already in Australia product manufacturers have undertaken carbon footprinting. For example, a pet food manufacturer has undertaken a carbon footprint for two of their products to help identify the key parts of the supply chain that contribute to global warming, enabling them to investigate ways of reducing this impact. A New Zealand sportswear provider that uses Australian Merino wool is undertaking a carbon footprint so that they know how much carbon they need to offset to be able to produce 'carbon-neutral' garments.

A carbon footprint ***does not*** represent the quantity of carbon that would need to be covered by permits under an ETS or a carbon tax, should agriculture be included in the future. However, it does represent the amount of carbon that would need to be offset if a business was to voluntarily claim its product is 'carbon neutral'.

How do these three accounting frameworks differ?

A carbon footprint from a LCA is the most comprehensive framework, accounting for GHG emissions from ‘cradle-to-grave’ (see Figure 4) so let’s compare the frameworks, working down from the carbon footprint perspective.

Carbon footprint differs from national accounts for GHG emissions, as the inputs from nature in a LCA are not constrained by geographical boundaries, as are the national accounts. For example, the carbon footprint for French cheese imported into Australia will include emissions from the dairy livestock in France as well as the transport to Australia. These values are not included in Australia’s national accounts even though the cheese is consumed here. What will be included in the Australian national accounts is the transport and refrigeration from the Australian entry port to a wholesaler, then retailer, then consumer. Any GHG emissions associated with disposing of the packaging and spoiled cheese will also be included. Emissions from the production phase in France will be part of the French national accounts and the emissions during international transport don’t ‘belong’ to any country at this stage.

Carbon footprint also differs from project scale offsets, which can be used to generate carbon credits under schemes such as the Carbon Farming Initiative. Offset projects for agriculture will cover primarily those GHG sinks or sources that occur in the agriculture and land use sectors – such as livestock methane, carbon stored in trees or soil and emissions from savannah burning. Offset projects will also include direct inputs from other sectors, such as electricity and diesel, but not a full ‘cradle-to-grave’ inventory of emissions associated with a particular product or practice being applied in the offset project. Hence, offset projects are currently somewhat of a hybrid between the national accounts and a carbon footprint.

However, much of the same information is needed to arrive at our national accounts, establish an offset project or calculate a carbon footprint. It is how the pieces of information are combined that differs. This is because each has a different purpose.

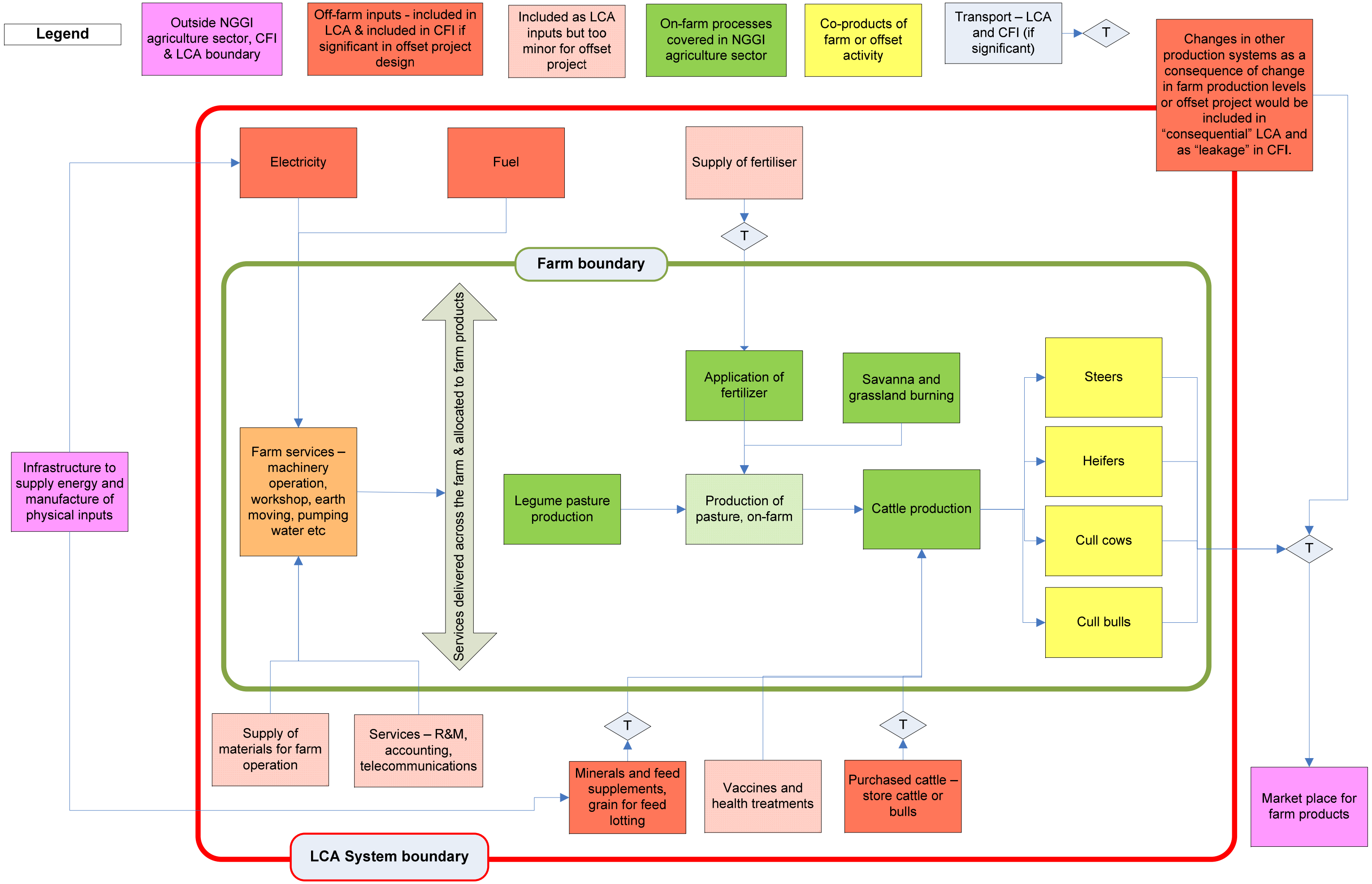


Figure 4. Diagrammatic representation of a farm or Carbon Farming Initiative (CFI) offset project for livestock production showing those processes included in the National Greenhouse Gas Inventory (NGGI) accounts for agriculture (dark green boxes), an offset project under the CFI (orange boxes) and a 'cradle-to-farm gate' Life Cycle Assessment (LCA) (every process within the red boundary).

2.3 Water scarcity and policy response

The Australian continent has a highly variable rainfall which results in equally variable water flows through our major rivers systems such as the Murray-Darling (Chartres and Williams 2006). Over extraction in the Murray-Darling catchment has been exacerbated over the last decade by generally declining rainfall in southern Australia, which has had a significant impact on both agriculture and urban water users. Consequently the amount of water required to produce a service or product is an important environmental consideration. There are a number of different approaches to assessing this water requirement, which have been well summarised in a review by Wiedmann and McGahan (2010).

The approach taken in this study is to assess the virtual water required to produce a product, including both rain water and reticulated water. Profiling the different categories of water use to produce a product or service is one tool in assessing the relative demand for water for the activity. However, it is not an end point; it is a preliminary step in understanding the water demands for different agricultural products. It does not inform the issues of environmental impact nor does it suggest priorities for water use. For example, a crop such as safflower has a low water use efficiency per unit of grain compared to wheat but because of its deep taproot, the crop can be strategically used to assist in lowering water tables to reduce salinity in the soil. Hence, water policy and market instruments to optimise water use are much more complex than for climate change, where the national GHG emissions targets and product ‘carbon footprint’ are relatively simple and straight forward tools for driving mitigation.

Water policy in Australia is determined under the framework of the National Water Initiative, an intergovernmental agreement negotiated within the Council of Australian Governments in 2004, with the last of the states joining the agreement in 2006 (National Water Commission 2011a). The agreement covers the preparation of water plans, with provisions for the environment, that deal with the over-allocation of water in drainage systems, introduces registers of water rights and standards for water accounting, facilitates trade in water and manages the urban demands for water. The overall objective of the National Water Initiative is “to achieve a nationally compatible market, regulatory and planning based system of managing surface and groundwater resources for rural and urban use that optimises economic, social and environmental outcomes.”

Legislative and administrative arrangements are now in place in every state (exception of ACT and the Northern Territory). In many areas of Australia, water use is managed through the granting of water access entitlements and water allocations (National Water Commission 2005). A water access entitlement, such as a water licence, refers to an ongoing entitlement to exclusively access a share of water. A water allocation refers to the specific volume of water that is allocated to water access entitlements in a given season. Water trading is the process of buying, selling, leasing or otherwise exchanging water access entitlements (permanent trade) or water allocations (temporary trade).

Water markets starting trading in Australia in 2007 (National Water Commission 2011b), with 618 GL of entitlement trades in the Murray-Darling Basin (920 GL nationally), and 1,237 GL of allocation trades in the Murray-Darling Basin (1,594 GL nationally). In 2009 these figures grew to 1,818 GL of entitlement trades in the Murray-Darling Basin (1,949 GL nationally) and 2,301 GL of allocation trades (2,495 GL nationally). On-going policy issues, such as the target for allocations to the environment, are under negotiation as water plans are developed.

2.4 Energy use and policy response

Energy inputs to agriculture make up a significant portion of on-farm costs and steadily increasing energy costs have an impact on our agricultural terms of trade. Energy efficiency in the agricultural sector has been largely left to the market to drive, with increasing energy costs seeing improvements in machinery efficiency both on-farm and for transport.

2.5 Eutrophication and policy response

The two major contributors to eutrophication from agricultural systems are nitrogen (N) and phosphorus (P) nutrient flows in to fresh water and marine environments. Although these nutrients are essential for agricultural production, they can be accompanied by adverse environmental effects when they enter waterways, lakes and coastal marine environments, such as the Barrier Reef (see review by Drewry *et al.* 2006). The most common manifestation that the general pubic sees is an algal bloom that can deoxygenate water causing fish to die and vegetation and algae to rot.

In Australia, eutrophication has been studied in a limited range of environments were algal blooms have occurred with some frequency, and in sensitive ecosystems such as the Great Barrier Reef. To date there has been little policy response in terms of regulations or legislation to control the flow of nutrients, compared to other regions of the world such Europe (Jakobsson *et al.* 2002). However, there is a policy program in place to facilitate “best management practice” in the Queensland sugar industry (URS 2008).

2.6 Description of the live export industry

Australia leads the world in the export of commercial livestock, exporting 2.97 million sheep, 0.88 million beef cattle, 77,200 dairy cattle and 77,400 goats in 2010 (ABS 2010). The business opportunity to export livestock arises due to the scarcity and relatively high cost of production of livestock in the overseas countries that are being supplied from Australia. Australia is a relatively cost efficient producer of livestock, especially extensively grazed sheep and cattle, and combined with our favourable animal health status, positions Australia as a competitive supplier.

The live sheep export industry has developed in response to demand for animals in the Middle Eastern market, a market where sheep and goats are the traditional sources of meat. Live animals have best suited the local marketing system, where fresh meat is purchased on a daily basis from a ‘wet market’ as domestic refrigeration has been limited. There is also a demand for live animals for ritual slaughter as a part of religious ceremonies. The main driver for importing live animals is the ability to hold stock in feedlots for periods of 2-3 weeks to enable a regular supply of fresh meat to the market.

Sheep exports to each country and sheep exports from the Australian state of origin are shown in Figure 5.

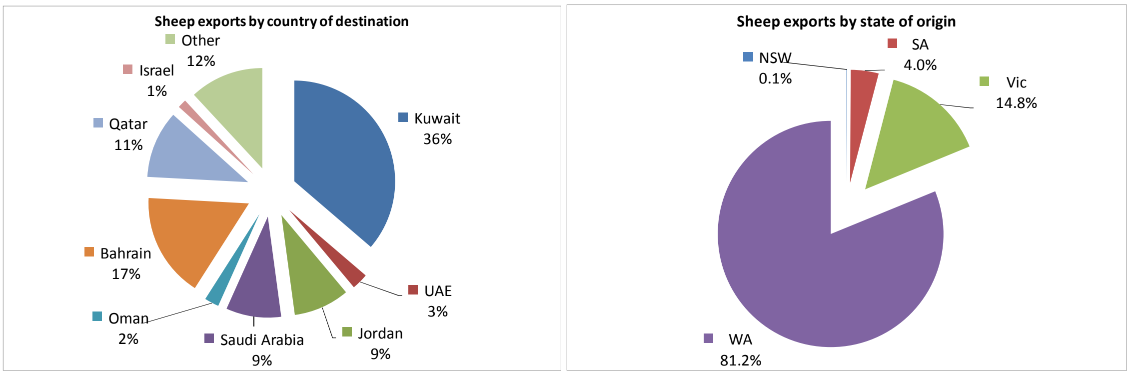


Figure 5. Australian live sheep exports by destination country (left) and state of origin (right) for 2010 (Source: ABS 2010).

Western Australia was chosen for the study as the source of sheep from this state comprised more than 80% of national live sheep exports in 2010 (ABS 2010). Within Western Australia the bulk of the sheep for export are sourced from the mixed sheep/wheat farming systems in the south west of the state (David Jarvie and Kevin Bell, pers. comm.). Bahrain was chosen as the representative destination country for the Middle East as this country received a significant proportion of sheep exports in 2009 (17%), is in close geographical proximity to the major importer Kuwait, and Meat & Livestock Australia has staff in Bahrain who could provide reliable data on local operations.

The live export of beef cattle is dominated by exports to Indonesia (520,987 head or 59% of national exports in 2010; Figure 6) predominantly from Western Australia and the Northern Territory. Store cattle are exported to Indonesia where they typically spend 80-100 days in a local feedlot before slaughter. This provides local and regional markets in Indonesia with a supply of fresh beef, purchased daily from a 'wet market', while also supporting economic development through growth of the local feedlot industry. The decision was made to use supply chain for Northern Territory cattle exports to Indonesia for the study, as the majority of cattle (42% of national exports in 2009; Norris and Norman 2010) shipped to south-east Asia leave from the Port of Darwin. Within the Northern Territory the major regions from which cattle are sourced are the Victoria River District, Sturt Plateau and Katherine and the Adelaide River and Gulf regions (Adam Hill pers. comm.).

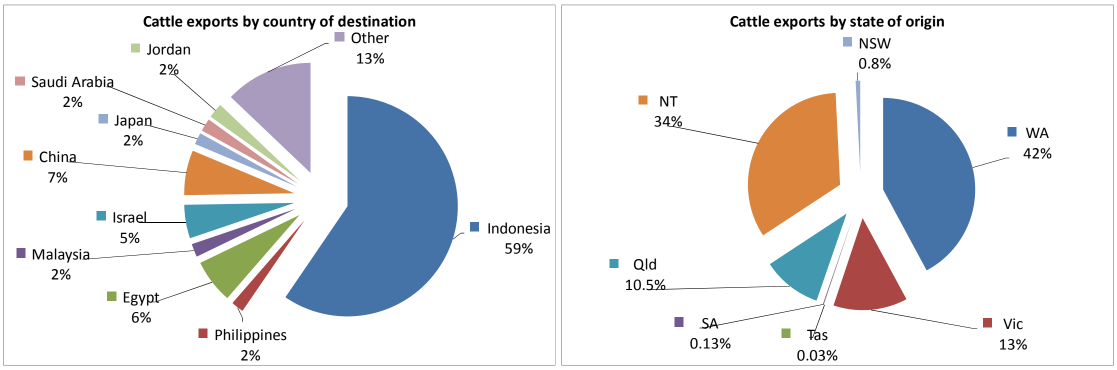


Figure 6. Cattle exports by destination country (left) and state of origin (right) for 2010 (Source: ABS 2010).

3. GOAL OF THE STUDY

The live export industry recognises the need to benchmark their environmental impacts, firstly to understand the magnitude of the impact and secondly to investigate means of reducing the impact.

The goal of the study was to deliver a:

- Life Cycle Assessment (LCA) detailing the total GHG emissions, energy and water use, and nutrient discharges associated with the live export of feeder cattle to SE Asia and sheep to the Middle East. The report will cover both the on-farm and the post-farm gate supply chain.
- documented library of Life Cycle Inventory (LCI) that MLA can use in subsequent investigations.

The LCA was undertaken in a manner consistent with:

- the methodology proposed in the AusLCI Data Guidelines for Agricultural LCI (July 2008)
- the framework developed by the RIRDC Project – Methodology for Agricultural LCA in Australia (Harris and Narayanaswamy 2009)
- the methodology outlined in the LCA standards ISO14040:2006 and ISO14044:2006
- and GHG emissions will be consistent with emission factors used by the National Greenhouse Gas Inventory.

LCA is a method that has been developed to quantify the environmental impact of a product or service during its life, from ‘cradle-to-grave’. It takes into account all the ‘whole of life’ impact of resource extraction, production, use and end of life disposal. This allows a transparent, robust and standardised evaluation framework to be established, which means that products can be benchmarked for environmental performance; participants in the supply chain can identify the parts of the production system that are contributing the most to the environmental impact of the product; and new scenarios can be investigated to identify ways of improving environmental performance.

LCA is used in a range of applications:

- to label a product with environmental information such as carbon footprint for marketing purposes
- to compare two products and the consequences of shifting from one to the other
- to analyse the contribution that a life cycle stage makes to the overall environmental load so that product and processes can be improved.

Standard methods have been developed for LCA by the International Standards Organisation (ISO 2006), and are being devised specifically for global warming impact (e.g. PAS 2050:2008, developed by British Standards; ISO 14067 under development by ISO; product accounting and reporting standard under development by GHG Protocol). These standards set out the 'rules' when determining the environmental impact for a product or service, so as to give a consistent approach across businesses and applications.

4. SCOPE OF THE STUDY

4.1 Audience

The LCA is being undertaken by the Meat & Livestock Australia/LiveCorp joint program and CSIRO, to allow the live export industry to benchmark the environmental impact of their product. This is the first work in this area that has been undertaken by live exporters, so the primary goal for this audience is to build an understanding of the types of impact that the live export trade has on the environment, quantify the impact in a scientifically rigorous manner and identify potential areas for improvement.

4.2 Functional Unit

The main function that is delivered by supplying sheep meat into the Middle East and cattle meat to Indonesia is a regular and consistent supply of quality meat for the mass market.

The animals shipped to the Middle East are predominantly Merino wethers between 12 to 18 months of age. Sheep are purchased from Australian farms using a strict criteria of weight range and condition score, hence the product delivered to the Middle East is good quality (in terms of tenderness and taste) and consistent.

Cattle shipped to Indonesia are predominantly *Bos indicus* (Brahman and Brahman cross) steers between 18-30 months of age. Cattle are purchased from Australian properties using strict criteria of weigh range and level of *Bos indicus* genes.

The functional unit chosen for the sheep supply chains was one Australian Merino sheep (shipped at 46kg live weight) delivered to the abattoir in the Middle East (slaughtered at 48 kg live weight). For the cattle supply chain the functional unit was one Australian *Bos indicus* breed steer (shipped at 333 kg live weight) delivered to the abattoir in Indonesia (slaughtered at 470 kg live weight).

An assessment of the obligatory properties and positioning properties for the functional unit assists with scenario testing that may arise from the original benchmarking LCA. For an alternate product to be considered (not within the scope of this study) it must deliver the same obligatory properties whereas positioning properties are desirable but not essential.

For both sheep meat in the Middle East and beef in Indonesia the main obligatory property for the functional unit is that the animals can be slaughtered in a manner that is consistent with Islamic law; conforming foods are commonly referred to as ‘halal’. The production of halal meat involves slaughtering the animals using ‘dhabiĥa’ method which consists of a swift, deep incision with a sharp knife on the neck, cutting the jugular veins and carotid arteries of both sides but leaving the spinal cord intact. This ensures that the animal is well bled before death, as it is the consumption of blood that is inconsistent with Islamic law.

A second obligatory property for the functional unit is that value of the meat delivered to the local market is relatively low in international markets, as the product is servicing a mass market in a developing country rather than a niche market for value-added product.

A third strong property, but probably not obligatory in both markets, is that the product is presented at the point of wholesale in a fresh form such that it can be split into locally accepted cuts of meat of varying portion sizes. There is evidence that the sheep meat market will not substitute ‘boxed’ meat from Australia if the supply of live sheep is reduced (MLA 2008). (Boxed meat is the term used to describe meat processed into cuts, packed into 20 kg cartons and shipped chilled or frozen to the destination market). However, recent restrictions on live cattle exports to Indonesia have seen the level of boxed meat imports to Indonesia rise (Adam Hill pers. comm.).

Another important property that is not obligatory but helps position the product in the market is the health status of the country of origin. If the health status of the country of origin is such that it is free of important diseases, then livestock from that source will be favoured. However, the Middle East and Indonesia do not have a firm import ban on livestock, such as exercised in Australia. Globally the major livestock diseases of concern are foot and mouth disease , Bovine Spongioform Encephalopathy, Contagious bovine pleuro-pneumonia, Rift valley Fever and Brucellosis (FAO 2009). Australia is free of these diseases.

Although the overall functional unit for the whole supply chain is one wether or one beast delivered to the abattoir, the analysis for each sector uses a functional unit that best represents the way in which products are traded in that sector. For example the functional unit at the farm gate is one wether, but in the sector providing livestock feed the functional unit used for the analysis of this sector is one tonne of feed. For the feed lotting sector the functional unit is a kilo of live weight gain while in the feedlot. For other sectors such as shipping the functional unit for the analysis is one wether or beast moved to the destination country.

4.3 System boundary

The system boundary for the LCA is shown in Figure 7 and covers the on-farm production of animals (including feed grown on other farms), the preparation of animals in an export yard prior to shipping, the shipping, the holding of animals in a feedlot in the destination country, and delivery to the abattoir gate. Treatment of waste from export yard and feedlot were also included. Transport between processes was included.

Construction of infrastructure was not included in the system boundary. Processes explicitly associated with the ships crew, such as transport to the vessel, services such as meals and laundry, and waste treatment for domestic waste and sewerage, were not included in the system boundary. The on-farm component of the sheep system is shown in more detail in Figure 8, which describes the interconnections between the individual crop and livestock products for a mixed farming system. Crop stubble is used for pasture for three months of the year, all the lupins/oats and some of the cereal is fed to sheep, and the sheep impart nutrient and weed control benefits to the crops.

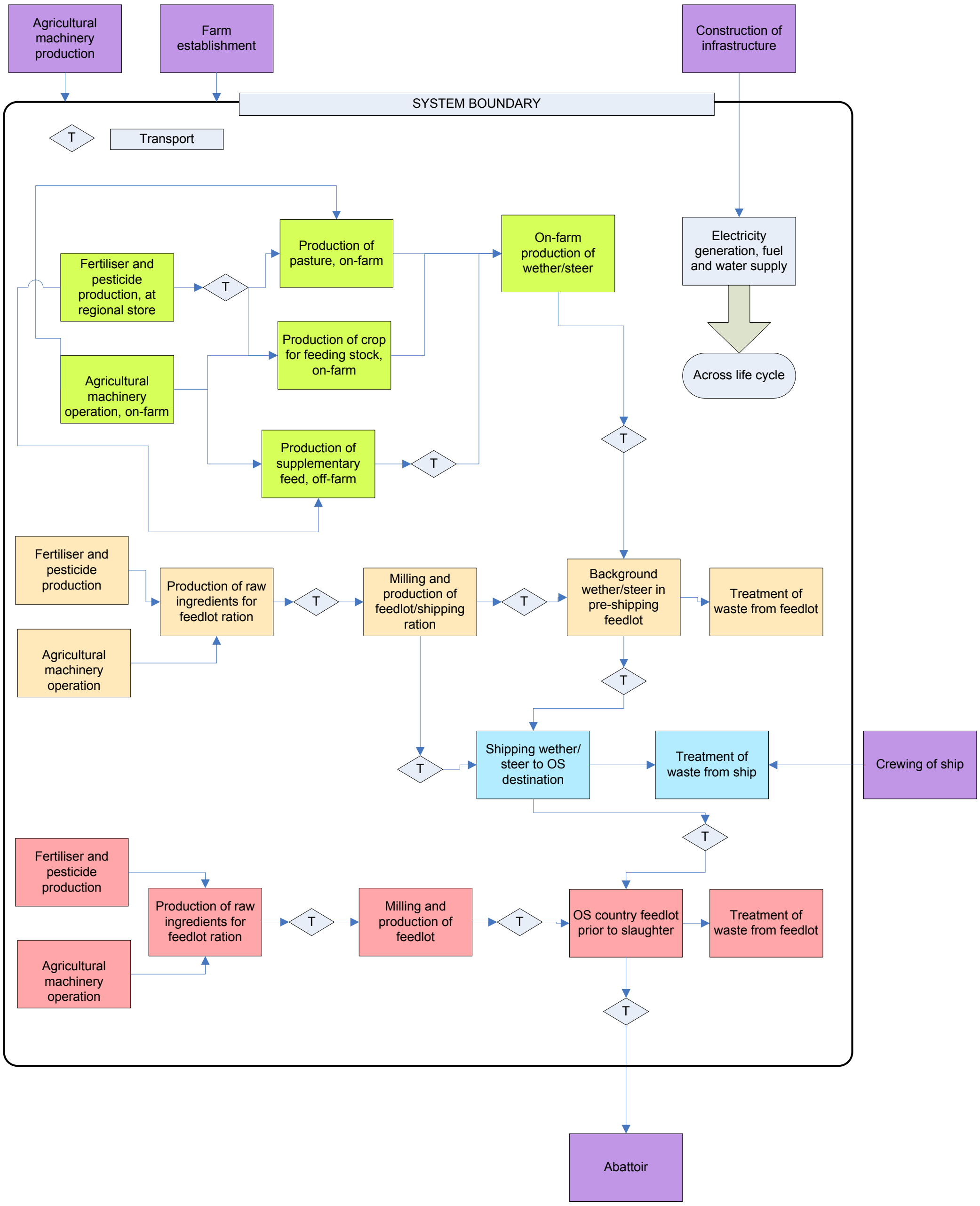


Figure 7. System boundary for life cycle assessment of live export sheep to the Middle East and cattle to Indonesia

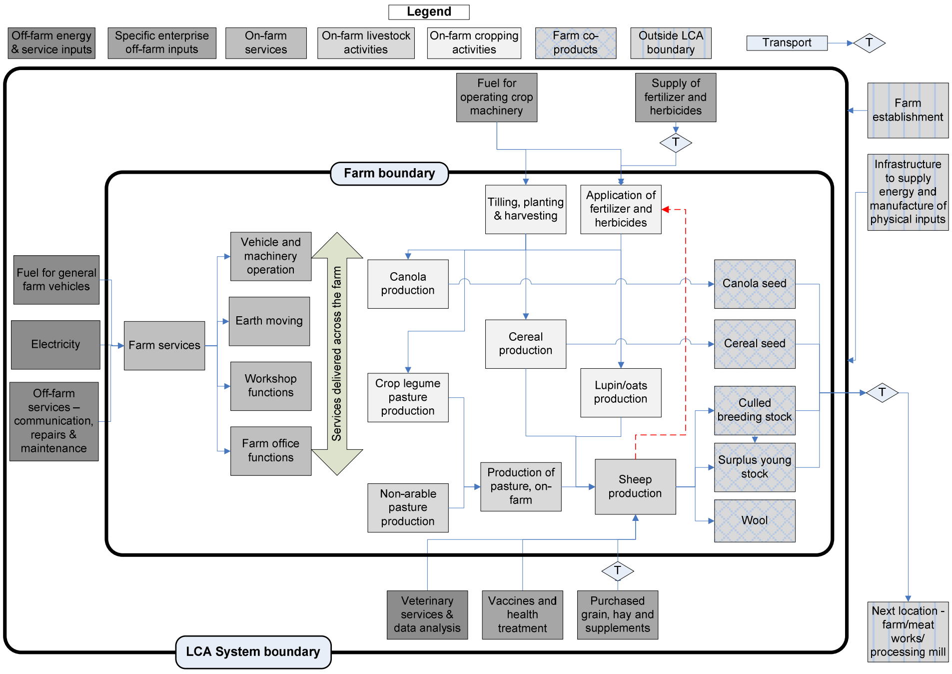


Figure 8. System boundary for the on-farm component of the sheep supply chain showing crop and livestock co-products from the mixed farming system.

The cattle production system (Figure 9) is simpler in that there are fewer co-products and interactions between different activities on the property. In most instances any arable activity is confined to small areas of fodder crops that are consumed by cattle on the property.

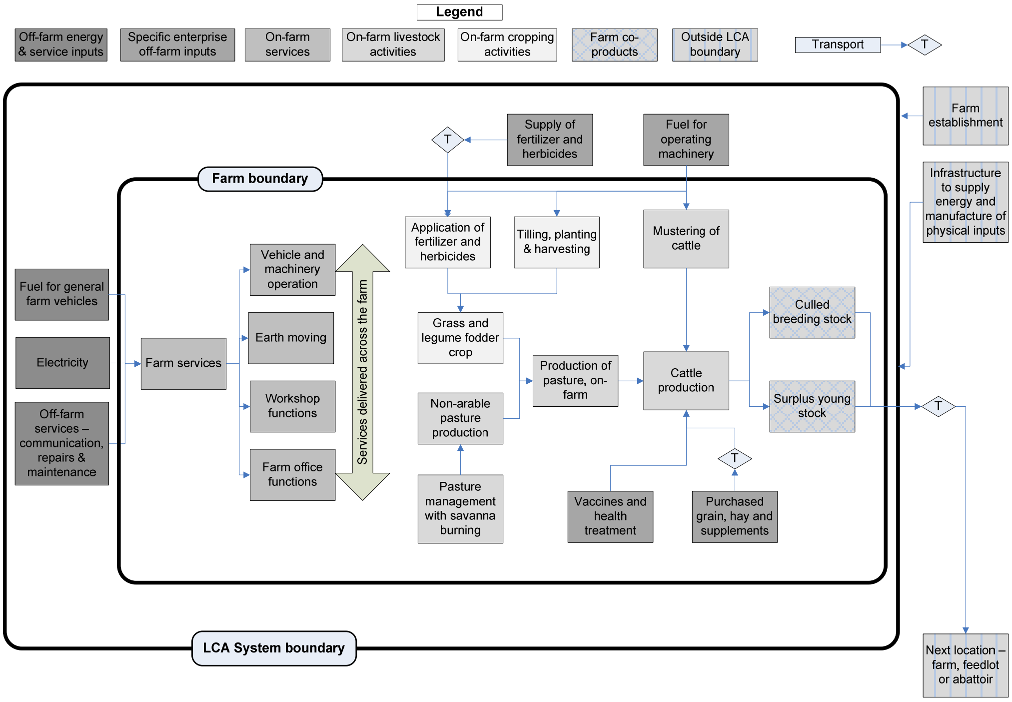


Figure 9. System boundary for the on-farm component of the cattle chain showing livestock co-products from the beef enterprise.

4.4 Cut-off criteria applied

For ease of visualisation, the system boundary diagram shows the key processes in the supply chain. The LCA modelling of processes breaks these key processes down into small individual processes. Many of the processes for agricultural production, shipping of livestock and feed lotting did not exist in current published LCI and have been modelled from foreground data and published literature. The approach taken was to model all inputs and outputs that can be clearly identified for the supply chain regardless of size, as until these inputs were characterised, a decision as to whether to include them or not could not be made.

4.5 Data quality requirements

Data quality can be characterised using the following criteria:

- reliability i.e. is data based on measurement or derived from theory?
- completeness i.e. does it represent all sites?
- temporal relationship i.e. is the data recent of from the past?
- geographical relationship i.e. is the data from the area under study or a distinctly different area?
- technological relationship i.e. is the data from a process that uses representative technology, in terms of scale and sophistication?
- sample size i.e. is the data an average of >100 values or <3?

The general quality of the data overall is summarised below for the key components of the live export supply chains.

The data for GHG emissions, water and energy use from the Australian components of the supply chain can generally be described as good quality as it was derived from measurement of geographically representative sites, using data collected within the last five years from businesses that are using current business scale technology. However, in some cases it represents a sub-set of sites of agricultural production and post-farm processing, and sometimes sample size was small.

The live export shipping data comprehensively covers the fleet servicing the two ports for the period under study but the reliability of the fuel consumption data is not high as it was based on engine specifications and general operating conditions rather than recorded fuel use from voyage reports.

Overseas the data for the sheep supply chain was less certain, as data was largely based on informed estimates from MLA staff in Bahrain, rather than direct measurement. However, the sheep only spend a relatively short period in the destination country feedlot before slaughter.

Data for feedlots in Indonesia was collected directly but in most instances was based on informed estimates, rather than measurement. It was not possible to get open access to the business records for all the feedlots, as was the case for the majority of Australian businesses.

With regard to the different environmental impacts, data for GHG emissions and energy use was generally available, data on water use was more sparse but a number of modelling tools (APSIM, GRASP) were used, and data on nutrient flows (N and P) was very sparse and in most instances was calculated from theory rather than based on field measurement.

Table 2 and Table 3 give a listing of data sources and a qualitative assessment of data quality, key elements for each component and if these were adequately covered by the data inventory collected. The quality rating was from 1 to 5, with 1=poor and 5=excellent.

The uncertainty analysis undertaken for the LCA used the data quality characteristics described above to define the level of variability to attach to reference flows; the level of variability assigned to data that rated poorly was higher than that assigned to good quality data.

Table 2. Data sources and quality assessment for sectors of the sheep export supply chain

Sector of the sheep supply chain	**Number of case studies**	**Supplementary data**	**Quality rating**	**What are the key elements for the impact categories?**	**Key elements covered?**
On-farm sheep production	3 farms in south western WA	APSIM crop modelling; farm management publications; published literature; industry publications	3.5	Enteric methane	✓✓✓
				Fertilizer and fuel use	✓✓✓
				WUE of crops and pastures	✓✓
				Nutrient runoff	✓
Operation of sheep export yards	1 facility near Fremantle	Published literature and industry publications	3	Enteric methane	✓✓✓
				Manure waste management	✓✓
				Nutrient runoff	✓
Feed for export yards and shipping	1 case study recipe	Validated as representative for the industry using published literature and industry publications	3	Energy input for milling	✓✓✓
				Crop fertilizer and fuel use	✓✓✓
				WUE of crops	✓✓✓
				Nutrient runoff from farms	✓
Shipping	8 ships departing Fremantle	Lloyd's Register for ship engine specification; consultant Marine Engineer for auxiliary engines and water use; Port Authorities for ship movements.	2	Fuel oil and diesel use	✓
				Enteric methane	✓✓✓
				Nutrient runoff	✓✓✓
Destination country feedlot	1 case study in Bahrain	MLA in-country staff for Bahrain; European Life Cycle Inventory for feed ingredients	2	Enteric methane	✓✓✓
				Nutrient runoff	✓✓
				Feed ingredients	✓
Feed for Bahrain feedlot	1 case study recipes from Bahrain	Published literature and industry publications; European Life Cycle Inventory for some feed ingredients	2	Energy input for milling	✓✓
				Crop fertilizer and fuel use	✓✓
				WUE of crops	✓
				Nutrient runoff from farms	✓

Table 3. Data sources and quality assessment for sectors of the cattle export supply chain

Component of the cattle supply chain	**Number of case studies**	**Supplementary data**	**Quality rating**	**What are the key elements for the impact categories?**	**Key elements covered?**
On-farm cattle production	4 properties in NT	APSIM crop modelling; GRASP for northern pasture modelling; Breedcow Gross Margin Templates for Beef CRC; published literature; industry publications	4	Enteric methane	✓✓✓
				Savanna burning	✓✓✓
				Fuel use	✓✓✓
				WUE of crops and pastures	✓✓✓
				Nutrient runoff	✓
Operation of cattle export yards	2 facilities near Darwin	Industry publications and sources such as NT LEA	4	Enteric methane	✓✓✓
				Manure waste management	✓✓
				Nutrient runoff	✓
Feed for export yards and shipping	3 case study recipes, 2 produced in NT and 1 from SA	Industry publications and sources such as NT LEA; Australian agricultural LCI for some ingredients	4	Energy input for milling	✓✓✓
				Crop fertilizer and fuel use	✓✓✓
				Post-1990 land clearing	✓✓
				WUE of crops	✓✓
				Nutrient runoff from farms	✓
Shipping	21 ships departing Darwin	Lloyd’s Register for ship engine specification; consultant Marine Engineer for auxiliary engines and water use	2	Fuel oil and diesel use	✓
				Enteric methane	✓✓✓
				Nutrient runoff	✓✓✓
Operation of Indonesian feedlot	4 case studies in Indonesia	NT LEA, MLA in-country staff for Indonesia	4	Enteric methane	✓✓✓
				Nutrient runoff	✓
				Manure management	✓
Feed for Indonesian feedlot	4 case study recipes from Indonesia	Published literature and industry publications; European Life Cycle Inventory for some feed ingredients	3	Energy input for milling	✓✓
				Crop fertilizer and fuel use	✓✓
				Post-1990 land clearing	✓
				WUE of crops	✓✓
				Nutrient runoff from farms	✓

4.6 Allocation

The issue of how to allocate inputs to the various outputs generated from a process arises when there are multifunction processes, that is, the enterprise produces interrelated products. In this study there are a number of examples: the sheep enterprise produces a number of interrelated sheep products (wool, live export wethers, other surplus livestock); likewise the cattle enterprise produces young stock and culled breeding animals; general farm services need to be allocated to all the farm products, including crops.

The ISO recommendation for allocation (ISO 14044:2006) is to first avoid allocation altogether, if possible, by dividing the multifunction process into sub-processes or expanding the system so as to include functions related to all the products. Where allocation cannot be avoided, the next preference is to use an underlying physical cause-effect relationship to allocate inputs to products. The last resort is to use other relationships (such as economic returns) to allocate inputs. Because of the complexity of agricultural production, economic allocation is often used as the default (Kanyarushoki *et al.* 2008; Peters *et al.* 2010).

Amongst LCA practitioners (Finnveden *et al.* 2009) there is some consensus that an attributional modelling approach is appropriate when the goal of the LCA is to describe the product, whereas a consequential approach is more appropriate when the goal is to investigate a change in production. For this study, an attributional approach was largely used as the goal was to benchmark the farm products, that is, to arrive at a carbon footprint that could be used to describe the impact of the product. However, this was only after farms were split into multi-functional processes and co-products that could easily be modelled as avoided products were dealt with in a consequential manner.

In this instance the mixed sheep/cropping system was divided into sub-processes - cropping and sheep activities, with specific inputs identified for each. Not separating cropping and livestock processes, and instead allocating all farm inputs to farm outputs, can distort results (Kanyarushoki *et al.* 2008).

After dividing the farm activities into sub-processes, there were still three areas where allocation may be required. The first arises with the sheep activity which produced a number of interrelated products – wool, wethers, stud rams and cull livestock. An alternative to allocation is system expansion which allocates 100% of the environmental impacts to the primary product, in this case wool. With this approach, the co-products (young wethers, stud rams, cull ewes and the agronomic benefits provided to the crop by sheep grazing) would be modelled in terms of avoided products that would substitute for these co-products.

To do this requires a comprehensive understanding of supply and demand for a range of possible substitutes, for instance, cull ewes would most likely go to the lower-value processed meat sector and substitutes could be culled cattle or pigs. However, culled cattle and pigs are going to be secondary products in their own production system and would also be modelled as an avoided product. To use system expansion it is necessary to substitute a ‘primary’ product from another system and this becomes more complex, for instance, what would be the avoided product for stud rams? A LCA that uses a consequential modelling approach needs to model not just sheep but also the production of cattle or pigs, allowing the 'consequence' of a change in wool production to be assessed.

There was no clear way forward to resolving the complexities of substitution in this instance for most of the sheep co-products, a point that might be argued amongst LCA practioners, but in practice the tools/resources needed to model substitution within an agricultural system (with any certainty) are not readily available. However, the last co-product (agronomic benefits provided to the crop by sheep grazing) can be easily modelled in a consequential manner, simply as an avoided product of nitrogen fertilizer and herbicide for weed control, and this approach was used.

With regards to allocation for the remaining sheep co-products, an attributional approach was used based on relative economic value of each co-product. For the on-farm component of sheep production a comparison was made between economic allocation and allocation based on resource use, to allocate GHG emissions to each co-product to investigate the impact of choice of allocation method. Relative resource use was based on the nutrient requirement of each class of stock, the additional nutrients required to rear surplus stock and the relative nutrient requirement for wool versus body maintenance and live weight gain (Liu *et al*. 2003, NSW I&I 2005a). This additional investigation was only undertaken for sheep production but was felt to be informative given the complex nature of co-production from mixed farming systems. A full description of this investigation was published by Eady *et al.* (2010).

The second instance of co-production is where crops produce both grain and stubble, where 20% of the stubble (Roberts 2006) forms a component of feed for livestock and the remainder is retained to enhance soil organic matter or is lost to the system. Crop stubble substitutes for pasture in this farming system, and could be modelled in a consequential manner as avoided pasture production, if crop production was considered in isolation. However, when it comes to defining inputs into the sheep production process, the sheep are actually eating crop stubble, not more pasture, and treating stubble and pasture equivalently does not make sense given the differing environmental impact of these two sources of sheep feed.

Therefore, within the farming system an attributional approach was also taken to crop co-production. Likewise, a comparison was made between economic allocation and allocation based on resource use, to assign reference flows to each crop co-product. Economic allocation uses grain prices and an assumed on-farm value of $60/tonne for lupin and $45/tonne for canola/cereal stubble. Resource use is determined by the relative energy content of grain and stubble (NSW I&I 2005b).

The third case for allocation deals with the attribution of general farm services such as vehicle use, farm office, repairs and maintenance, inputs that cannot be specifically identified as applying to a particular crop or the livestock activity. These inputs can be allocated on an economic basis in proportion to the farm income earned by each product or on a more direct resource use basis, such as farm area utilised, and both were investigated (Eady *et al.* 2010).

Cattle production is a much simpler system as there is only one activity on the property (breeding livestock) and all of the inputs to the business are specifically for producing sale animals. The issue of co-production of young surplus stock and older culled breeding stock was dealt with in a similar manner to sheep co-products, and allocation was made on economic basis.

Where there were multi-function processes in the remaining components of the supply chain, allocation of environmental impacts was made on an economic allocation basis. These mainly included the production of feed ingredients for livestock.

5. METHODOLOGIES FOR EACH IMPACT CATEGORY

5.1 Methodologies for GHG emissions

The methodology for identifying and quantifying GHG emissions followed the international standards for estimating the carbon footprint for a product, PAS2050 (British Standards 2008) which is widely used in Europe and by international retailers and ISO 14067 (ISO 2010) which is currently under development. These standards describe which emissions are to be included.

5.1.1 Livestock GHG emissions

GHG emissions that occur from livestock production are:

- methane (CH_4) from enteric fermentation (digestion) of pasture
- methane (CH_4) from manure
- direct nitrous oxide (N_2O) emissions from dung and urine
- and indirect N_2O emissions as the N_2O moves through the land system and N from ammonia emissions are deposited in soils and re-emitted as N_2O .

The overall emissions for livestock are estimated using information on the quantity and quality of feed consumed by the animals. The equations describing these relationships are defined in the National Greenhouse Gas Inventory for Australia (NGGI 2006) and are based on Australian research for sheep and cattle, for southern regions with *Bos taurus* cattle and northern Australia with *Bos indicus* cattle.

The Sheep and Beef GHG Calculator (Eckard 2010) and FarmGAS (Australian Farm Institute 2009) apply these equations to calculate emissions for a given flock/herd structure, animal growth rate, and reproduction rate for each state/territory and both of these models were used to estimate livestock emissions.

Data for flock structure for sheep in Western Australia was drawn from the case study properties where records of sheep numbers are reasonable accurate. For NT cattle production herd structure, reproduction rate, growth rate and turn-off weights were drawn from the Beef CRC Gross Margin Templates in Breedcow (Holmes *et al*. 2010), which was informed by the case study properties, but not based on their data due to high levels of uncertainty as to actual counts of animals given the extensive nature of the production landscape.

5.1.2 Agricultural and land use GHG emissions

In addition to livestock emissions, accountable GHG emissions also occur when:

- nitrogen fertiliser is used, releasing N_2O
- legume based pastures release N_2O as plant residues, that remain after grazing, break down
- crop residue burning occurs to remove excess biomass before replanting, releasing CH_4, N_2O and NO_x (which converts to deposited N in the soil, part of which is emitted as N_2O)
- savanna burning occurs for woody weed control and pasture management, releasing CH_4, N_2O and NO_x (which converts to deposited N in the soil, part of which is emitted as N_2O)
- land is cleared of vegetation for the establishment of crops or pasture (post-1990 clearing)

The National Greenhouse Gas Inventory (NGGI) methodology (NGGI 2006) was used for estimating emissions from fertiliser legume-based pastures and crop residue and savanna burning. FullCAM (Richards *et al.* 2005) was used to estimating emissions from cleared vegetation biomass in Australia.

In Indonesia the proportion of post-1990 cleared land producing green forage, copra and palm kernel was estimated to be 43%, based on the national report submitted to the UNFCC by the Indonesian Government (1994) which reported emissions from deforestation. The carbon stored in tree biomass was assumed to be 562 t CO_2-e, an average value for seasonal tropical forest (Gibbs *et al.* 2007).

For savanna burning, the assumed NGGI fuel load and burning efficiency was adjusted to more closely reflect open woodland in pastoral districts of the Northern Territory. Savanna woodland burning in the NGGI uses a fuel load of 12.7 t/ha and burning efficiency of 0.4 (NGGI 2006). For the case study properties the fuel load was assumed to be 5.9 t/ha comprising fine, coarse and shrub material that would be characteristic of open eucalypt woodland that is regularly burnt. The assumed burning efficiency was 0.38 for an early season burn and 0.69 for a late season burn (Meyer 2004).

Using these assumptions, the emissions for early season burning are estimated to be 0.16 t CO_2-e/ha and for late season burning are estimated to be 0.29 t CO_2-e/ha. The Northern Australia Fire Information website (NAFI 2011) was used to obtain areas of land burnt in each season.

Carbon in annual growth cycles is not included as it is assumed that carbon cycles in a balanced way – that is, vegetation grows each year accumulating carbon, and then it is eaten or decomposes releasing the carbon.

Change in carbon stores in tree/shrub cover is included in the carbon footprint if it is likely to act as a long term store (> 100 years) and is a direct result of grazing or active management intervention. The level of carbon storage in woody vegetation can increase through vegetation thickening or it can decrease through land clearing. Whether it is included in the carbon footprint depends on the causal relationship between the thickening or clearing activity and the production of the target product (i.e. cattle for live export). (This is where a carbon footprint differs from a whole farm carbon balance, where the latter recognises the carbon storage in woody vegetation regardless of the cause.)

The assumption was made the agricultural land in Western Australia was largely cleared prior to 1990, and the there is no vegetation thickening on cropping and pasture land.

Even though there may be signs of increased woody vegetation in northern Australian, there is little evidence that grazing itself increases woody vegetation (Alchin *et al.* 2010) in these systems. Conversely, the purpose of land clearing on a pastoral holding is to increase pasture production for cattle. However, the carbon footprint standards specify that it is only emissions from land cleared within the last 20 years (PAS 2050) or since 1990 (ISO 14067) that needs to be included. These are amortised over 20 years.

The proportion of post-1990 cleared land producing hay for live export cattle feed was estimated to be 12%, based on figures for land clearing published by NT government (Hosking 2002). The carbon stored in tree biomass was estimated to be 113 t CO_2-*e*, using FullCAM (Richards *et al.* 2005) for the Douglas Daly district, a major hay producing area where there has been land clearing since 1990.

5.1.3 Industrial, energy and transport GHG emissions

GHG emissions associated with the resource extraction and production of inputs to the businesses along the supply chain (such as electricity, fuel, fertilisers, pesticides) were included in the Life Cycle Inventory and used to provide background data. Background data were sourced from Life Cycle Inventory (LCI) libraries incorporated into LCA software, SimaPro® (Pré Consultants 2007), and included the Australian Unit Process LCI (2010), Ecoinvent 2.0 unit processes (2007), and LCA Food DK Library. Where new processes were required (e.g. fuel use during shipping) emissions were calculated based on NGGI methodologies.

5.2 Methodologies for water use

Water flows were defined into two categories as conceptualised by Falkenmark and Rockström (2006):

- Green water - water in soil that flows back to the atmosphere through transpiration and evaporation by pasture plants, constituting consumptive water-use by the plant to produce pasture or crops. Green water use does not include run-off or water that is used by other vegetation that is not eaten by livestock.

- Blue water - freshwater in aquifers, lakes, wetlands, dams and storage tanks that is used for industrial processes, production of feed, consumed directly by livestock or used for cleaning.

5.2.1 Green water

Green water, that is water used to grow crops and pastures, was estimated using published data and modelling estimates for water use efficiency (evapo-transpiration demands) for the particular biomass. APSIM (Keating *et al.* 2002) was used to model crop, fodder and southern pastures water use efficiency. This model has been well validated across a number of crops and regions in Australia.

The model used for pastures in the Northern Territory was GRASP, a deterministic, point-based model of soil water, grass growth and animal production (McKeon *et al*. 1990, 2000; Littleboy and McKeon 1997). This model has been validated using Northern Territory sites (Cobiac 2006; Robyn Cowley, unpublished data). Soil water is simulated from daily inputs of rainfall, temperature, evaporation, vapour pressure and solar radiation. Plant growth is calculated from transpiration, but includes the effects of vapour pressure deficit, soil water availability, temperature, radiation interception, nitrogen availability and grass basal area.

Given the large geographical areas represented by each case study property, additional work was undertaken (Robyn Cowley, NT DPI) to set up the model parameters based on the specific property attributes. Each property was divided into distinct land systems (based on soil and vegetation classifications) to model pasture production and water use efficiency. Daily weather data from 1889 to 2009 was obtained from SILO climate data sets (Jeffrey *et al.* 2001) which includes records collected at the closest BOM registered rain and climate stations, which in some instances was the weather station on the case study property itself.

The subsequent allocation of green water to animal production was based on the physical quantities of plant material eaten by livestock (not the total pasture grown), as estimated within the Sheep and Beef GHG Calculator (Eckard 2010) and adjusted for hay and supplementary feed consumption.

5.2.2 Blue water irrigation

The assumption was made that there was no use of irrigation in any of the sheep, cropping or cattle enterprises, which was generally consistent with the regions from which the majority of agricultural products were drawn. There were three exceptions to this. The first was molasses, where a portion of the Queensland sugar industry uses irrigation, the second was specialised fodder production in the Douglas Daly region of the northern Territory (ABS 2006), and the third was palm kernel production in south East Asia.

5.2.3 Blue water on-farm

All water stored in farm dams or reticulated was classified as blue water but was identified separately from blue water originating from an off-farm reticulated supply.

The assumption was made that all water for farm activities such as pesticide spraying and drinking water for grazing livestock was reticulated from an on-farm storage facility. Estimates of drinking water for grazing stock were based on dry matter intake (3.7 L of water per kg DM intake) and validated on-property measurement where available. This method gives average daily water intake of approximately 4.6 L for a 50 kg sheep (one dry sheep equivalent) and 42L for a 455 kg beast (one adult equivalent).

5.2.4 Blue water off-farm

Water use associated with the resource extraction and production of inputs to the businesses along the supply chain (such as electricity, fuel, fertilisers, and pesticides) were included in the Life Cycle Inventory used to provide background data. Background data were sourced from Life Cycle Inventory (LCI) libraries incorporated into LCA software, SimaPro® (Pré Consultants 2007), and included the Australian Unit Process LCI (2010), Ecoinvent 2.0 unit processes (2007), and LCA Food DK Library.

5.2.5 Blue water on-board ship

Drinking water for livestock on-board ship was classified as blue water and was assumed to be either from the mainland reticulated system at port of departure or from desalination of sea water during the voyage. Water for cleaning of waste from pens on the ship was assumed to be untreated sea water and was not included in the water use inventory.

5.3 Methodologies for energy use

Energy use for this study was analysed as the “embodied energy” or cumulative energy demand to produce a product or service. Lower heating values (also know as net heating values) are used, i.e. the amount of energy available from combustion of a fuel without recovering energy associated with water condensation during the combustion process, from moisture in the fuel and water produced as a result of combustion. All energy sources are included – both from fossil fuel, nuclear, renewables and biomass. Energy use is built in to the Ecoinvent and Australasian Unit Processes for electricity and liquid fuels. New processes that required the combustion of fuels, i.e. shipping processes, used the NGGI assumptions for energy content (and estimation of GHG emissions).

5.4 Methodologies for eutrophication

The two major contributors to eutrophication from agricultural systems are soluble nitrogen (N) and phosphorus (P) nutrient flows in to fresh water and marine environments. Northern Hemisphere studies show that P tends to be the main limiting nutrient in freshwater systems in agricultural areas due to the relatively high levels of N in the water, while N tends to limit growth in marine systems where N concentration is lower (UNEP 2011). However in Australian river systems, N is found at much lower levels and tends to be the limiting nutrient for algal blooms in fresh water systems (Harris 2001).

Nutrient flows are built into the Ecoinvent and Australasian Unit Processes for external inputs to the agricultural business (electricity, fuel, fertilizer manufacture). Nutrient flows from runoff to surface water and leaching to ground water were estimated for key processes in the two livestock supply chains, where there was published evidence of N and P emissions to water.

The sparseness of data on some agricultural systems (i.e. NT cattle production) precluded a complete coverage of all processes, and the nutrient flows for many systems were not well characterised, resulting in default values being used for similar but not identical systems. Other sources of nutrients such as atmospheric deposition of N resulting from volatilisation of ammonia (from urine and dung) and N_2O emissions to the atmosphere (from fertilizer use and savanna burning) were not included.

An analysis of the source and likelihood of N and P emissions to water (fresh and marine) was made for important agricultural systems that contributed to the sheep and cattle supply chains, and for the shipping and feedlot sectors and is summarised in Table 4 . The scale for an assessment of the likelihood of N and P reaching water ways ranged from unlikely to certain.

The quality of data to describe the flows is also assessed in terms of availability and how well it matched the system in the study.

The scoring system for production system match was characterised as:

1 = different region, different technology, similar but not the same product

2= different region, different technology, same product

3= similar region, different technology, same product

4= same region, different technology, same product

5= same region, same technology, same product

For example, the goodness of match was 3 where data on annual cropping systems was generally available but not specifically for the south west of Western Australia.

The values and assumptions used to calculate flow for each of the systems are detailed in Table 4 . The nutrient flows have been adjusted to reflect the additional flows from the farming activity, that is, flows over and above natural nutrient flows of undisturbed land or found in open ocean.

Table 4. Source and likelihood of nitrogen and phosphorus emissions to fresh water and marine environments, an assessment of the availability of data to describe the flows and the estimate of the flow used in the life cycle inventory.

Agricultural system	**Source of N and P**	**Likelihood of flows to waterways**	**Availability of system specific data**	**Match to system**	**Method of calculation**	**Estimate of nutrient flow**
Crop production in south western WA	Synthetic fertilizer	Probably	Drewry et al. 2006	3	Based on Drewry *et al.* 2006	3.3 kg N/ha/year 0.3 kg P/ha/year
Sheep production in south western WA	Urine and faeces Fertilizer application to pastures	Probably	Drewry et al. 2006	3	Based on Drewry *et al.* 2006	2 kg N/ha/year 0.53 kg P/ha/year
Cattle production in NT	Urine and faeces Mineral licks	Unlikely	Nil[a]; only P flows estimated	1	P based on 10% flow (Hunt and Patterson 2004) from quantity of P in cattle licks; N ignored due to likely high volatilisation losses.	0.42 kg P/steer
Fodder production in NT	Synthetic fertilizer	Probably	Nil[a]	1	Based on Drewry *et al.* 2006	16.3 kg N/ha/year 4 kg P/ha/year
Export yards –	Manure management	Likely	Davis and Watts (2006)	3	Based on quantity of manure, concentration of N and P, and assumed flow of	0.007 kg N and P/wether prepared

	systems				4% and 10% for N and P (Drewry *et al.* 2006, Hunt and Patterson 2004) to waterways, respectively.	0.012 kg N and P/steer prepared
Livestock ships	Manure management	Certain	Landline Consulting (2003)	5	Based on quantity of manure, concentration of N and P, and assumed for of 100% to ocean.	0.05 kg N and 0.19 kg P/wether shipped 0.97 kg N and 0.32 kg P/steer shipped
Middle Eastern feedlots	Manure management	Probably	Nil[a]	2	Based on quantity of manure, concentration of N and P (Drewry *et al.* 2006, Hunt and Patterson 2004), and assumed flow of 4% and 10% for N and P to waterways, respectively.	0.011 kg N and P/wether finished
Indonesian feedlots	Manure management	Certain	Nil[a]	3	Based on quantity of manure, concentration of N and P (Drewry *et al.* 2006, Hunt and Patterson 2004), and assumed flow of 4% and 10% for N and P to waterways, respectively.	0.50 kg N and P/ steer finished

Crop production in Middle Eastern region	Synthetic fertilizer	Probably	Nil[a]	2	Based on Drewry *et al.* 2006	3.3 kg N/ha/year 0.3 kg P/ha/year
Crop production in Indonesia	Synthetic and manure fertilizer	Highly likely	Nil[a]	1	Based on Drewry *et al.* 2006	16.3 kg N/ha/year 4 kg P/ha/year

[a] Where there was no system specific data available default values were used from Australian based studies that best matched the system.

6. IMPACT ASSESSMENT

6.1 Global warming

The audience for this study is the live export industry in Australia, so the choice of impact assessment method for global warming was the Australian Impact Method with normalisation using Australian annual figures for GHG emissions. This will assist the stakeholders in interpretation of the magnitude and relevance of the results in a national context. The on-farm results for GHG emissions from the study are also set in the context of overall agricultural emissions, at the national, state and industry level.

6.2 Water use

With regards to water use, the environmental impact is dependent on location; water extracted from an environment where there is scarcity has a far different impact to its extraction in an environment of abundance. Therefore, it is difficult to ascribe an environmental impact without local parameterisation of a water impact assessment model. There is also a case for treating green and blue water differently – with the use of green water ascribed to land use rather than considered as direct water use (Ridoutt & Pfister 2009). Impact assessment models for water and land use are under development for Australia. Hence, the figures for green and blue water use in this report are not totalled to give an overall water ‘footprint’ but are presented as a life cycle inventory analysis result, cataloguing the flow crossing the system boundary, which can subsequently be used as a starting point for life cycle impact assessment.

6.3 Energy use

A mid-point indicator of embodied energy (MJ) is used to present the impact of energy use.

6.4 Eutrophication

Eutrophication occurs when there is rapid growth of plants and algae in nutrient rich water to such an extent that the water is depleted of oxygen, causing the die-off of other organisms. This typically occurs when there is run-off of macronutrients such as nitrogen and phosphorus from fertiliser and animal waste. The eutrophication impact category covers all impacts due to excessive levels of macronutrients in the environment caused by emissions of nutrients to air, water and soil. It is expressed in units of PO_4---e, which uses the Redfield molecular ratio of carbon, nitrogen and phosphorus in plankton (Redfield *et al.* 1963) to convert a range of nutrients to a common base, a similar concept to that of converting all GHGs to CO_2-*e*.

Like water use, the environmental impact of nutrient flows (N and P) from the system to the natural environment has not been described for Australia or for livestock shipping (Landline Consulting 2003). Eutrophication causes environmental damage when it occurs in both freshwater and marine systems, and while present to some extent in

Australia's inland water ways, the incidence and impact of eutrophication is largely unknown. Therefore, a similar approach was taken to water use, whereby the flows of N and P into water ways were estimated and presented as a life cycle inventory analysis result, cataloguing the flow crossing the system boundary, which can subsequently be used as a starting point for life cycle impact assessment.

7. GENERAL LIFE CYCLE INVENTORIES

The inventories of data for the two supply chains were drawn from a variety of sources. Foreground data was obtained from three sheep and four cattle enterprises, four export and shipping feed suppliers, three pre-shipping export yards and five Indonesian feedlots. This data was based on written records and the business accounting system in some instances, while in others data was collected from face to face meetings with the business managers. These records covered inputs such as number of livestock, fodder purchases, health treatments, area of crops/fodder planted, machinery operation, use of fertilizer and pesticide, fuel and electricity inputs, and general business services (e.g. insurance, accounting fees, repairs and maintenance).

For the on-farm sector of the supply chain three years (2007-2010) of detailed business records were used to collect data on:

- Flock/herd structure and turnoff of sale animals
- Inputs such as diesel, avgas, petrol, mineral licks, herbicides, health treatments and fodder
- Service inputs such as insurance, accounting fees, repairs and maintenance and communications

Three years of data is the period recommended for livestock farming systems to enable some estimate of year to year variation (Eady and Ridoutt 2009).

Estimates of parameters such as crop stubble and pasture dry matter were drawn from the literature and agricultural models such as APSIM (Keating *et al.* 2002) and GRASP (McKeon *et al.* 1990, 2000; Littleboy and McKeon 1997).

For the feed manufactures, export yards and feedlots in the destination country data was based on one years business records, or if coming from the face to face interviews, was a more general description of the business operation.

Where service inputs were identified (largely for the Australian businesses only) they were based on the dollar value expended, and LCI generated from economic input output tables (Rebitzer *et al.* 2002) were used to estimate the impacts associated with the expenditure in each sector. The US Input-Output Tables in SimaPro® were used as technologies in the service sectors. These were assumed to be comparable to Australia. The US Input-Output Tables are also much more disaggregated than the equivalent Australian tables, allowing an estimation of the impacts associated with veterinary services, communications and farm maintenance. This level of detail is not available in the Australian Input-Output Tables. The assumed exchange rate was $A1 per $US.

8. SHEEP LIVE EXPORT CHAIN

8.1 On-farm sheep production

8.1.1 System description

The on-farm component of the sheep supply chain is based on a farming systems in the south western region of Western Australia, producing Merino sheep and crops. This region experiences a 'Mediterranean' style climate of wet winters and dry summers. Crops grown are wheat, barely, oats, canola, field peas and lupins. The Merino sheep activity produces wool, surplus sheep and stud/flock rams. Arable land is cropped in rotations of canola, legume, cereal and sown pasture. Non-arable land is largely improved pasture based on annual legumes and grasses.

While the majority of the grain is sold as a cash crop, significant proportions of cereal and lupins are retained to feed sheep over the dry summer period, when pastures are not adequate to support grazing. Crop stubble is extensively utilised during this period as a source of dry feed. The sheep activity offers benefits to crop production in terms of weed control during the intercropping period and return of nitrogen to the soil via dung and urine deposition. These interdependencies are explicitly modelled in the LCA.

However, the synergies from including a pasture phase or a legume in the crop rotation (nitrogen fixation and pest/disease control) are not explicitly modelled. It was not the goal of the study to drill down to the level of modelling nutrient flows between years in the cropping system as per Deimling *et al.* (2008). The study's goal was to develop methodologies that could be applied to a mixed farming enterprise to bench mark the environmental impact of its products, including live export wethers. Hence, the inputs and yields for crops are premised on the crop rotation system that is used on the farm.

Wethers destined for the live export trade are turned off the farm at 12-15 months of age. In 2009, 1,036,413 adult hoggets were exported from Fremantle (average live weight 47 kg) while 191,031 hogget wethers were exported (average live weight 39 kg). Using these figures as weighting values, the functional unit modelled for sheep to the Middle East was an average wether at 46 kg live weight.

8.1.2 Inventory

Data from the case study farms were averaged to give a value for the region, with each weighted for the live weight category of the wethers being produced for the live export market. Due to the complexity of averaging the whole mixed farming system, only the export wether production was modelled on an average basis, by estimating the share of inputs for the wethers from the co-production model and modelling these separately for a single product process that produces only wethers.

The inputs for producing 1,000 export wethers, with an average live weigh of 46 kg, is given in Table 5. This is the allocation of inputs to wethers produced by the sheep enterprise, taking into account allocation to other co-products from the sheep enterprise such as wool, surplus ewes, rams and lambs. The average allocation to wethers was 17.7% of all sheep specific inputs.

Table 5. Average inputs for producing 1000 export wethers (46 kg live weight) in south western Western Australia from a mixed sheep cropping system after allocation across co-products in sheep system.

Business inputs	**Quantity or level of expenditure**	**Description and source of inventory**
General farm services		
Telecommunications – telephone, internet	$6.03	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4
Insurance	$602	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4
Repairs and maintenance – structures	$1,506	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4
Repairs and maintenance – automotive plant and equipment	$1,510	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4.
Petrol for general services	168 L	Based on Australasian Unit Process for Australian petrol
Diesel for general farm services	210 L	Based on Australasian Unit Process for Australian diesel
Heavy machinery operation (grader, bulldozer, excavator)	49 minutes	Based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Electricity	914 kWh	Based on Australasian Unit Process for WA power supply
Sheep specific inputs		
Drench	22.4 kg	Ecoinvent Unit Process
Dips and pour-ons	26 kg	Ecoinvent Unit Process
Vaccine	1.2 kg	Ecoinvent Unit Process
Selenium pellets	11.7 kg	Based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Ear tags	5.1 kg	Based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Shearing	1.83 days	CSIRO Unit Processes
Wool packs	42.8 kg	Based on combination of Ecoinvent, Australasian and CSIRO Unit Processes

Fleece testing and worm egg counts	$132	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4
Drinking water	1357 kL	CSIRO Unit Processes
Natural pasture intake	131 kg	CSIRO Unit Processes
Pasture in crop rotation	65 kg	Based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Stubble grazing	68 kg	Based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Sheep feed grown on-farm (oats, lupins, silage)	63 kg	Based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Sheep feed purchased off-farm	41 kg	Based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Avoided products due to sheep inputs to cropping system		
Avoided urea fertiliser from manure and urine deposition on arable land	1.26 t	Based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Avoided herbicide from weed control by sheep	131 kg	Based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Avoided tractor use for application of herbicide	131 ha	Based on combination of Ecoinvent, Australasian and CSIRO Unit Processes

8.2 Australian sheep feed production system

8.2.1 System description

Sheep feed is required for feeding in the export yards prior to shipping (3-7 days) and while on-board ship (approximately 14 days). The formulation is a high fibre and low concentrate ration designed to maintain rumen health and encourage intake, rather than maximise live weight gain. Feed used for export sheep from Fremantle is sourced from local feed manufacturers in Western Australia. Road transport is used to deliver all feed ingredients to the mill.

8.2.2 Inventory

One feed manufacturer contributed to the study with general information on:

- Electricity and diesel use in the plant

- Inputs such as pallets, bags and packaging
- Service inputs such as insurance, accounting fees, repairs and maintenance and communications
- Ingredient inputs for the pellets

Additional data was drawn from Australasian Unit Process library, science and industry publications to supplement the case study data. The feed formulation has been simplified and averaged; it does not represent the exact formulation for any one enterprise. The assumed transport distance and an assessment of how well the available life cycle inventory data matched the production systems used to produce the feed ingredient are also presented (

Table 6).

The scoring system for production system match was characterised as:

1 = different region, different technology, similar but not the same product

2= different region, different technology, same product

3= similar region, different technology, same product

4= same region, different technology, same product

5= same region, same technology, same product

A fuller description of the production systems for feed ingredients is given in Table 7, detailing the allocation of reference flows to the feed product, the yield and inputs required to grow the crop and relevant machinery and land use change parameters.

Table 6. Approximate mix of ingredients (and associated transport) for producing feed in Western Australia for export yards in Western Australia and shipping from Fremantle.

Ingredient	**Transport distance to feed mill**	**Proportion in ration**	**Production system match with available inventory**	**Source of inventory**
Cereal stubble	150	54%	5	CSIRO Unit Process
Wheat	200	22%	5	CSIRO Unit Process
Lupins	200	24%	5	CSIRO Unit Process
Road transport in tonnes x km travelled		173		Australasian Unit Process

Table 7. Description of the production systems for feed ingredients used in manufacture of feed in Western Australia for live sheep export.

Ingredient description	**Production parameters**	**Water and fertiliser**	**Land use change, machinery and fuel inputs**
Cereal stubble 5-7% allocation to stubble	Yield: 3.8 - 4.7 t/ha/year	Water: Rain-fed Fertiliser: 49-56 kg N/ha/year as both urea and MAP	All land cleared pre-1990. No till cropping system with annual planting and harvesting.
Wheat grain 93-95% allocation to grain	Yield: 2.2 – 2.6 t/ha/year	Water: Rain-fed Fertiliser: 49-56 kg N/ha/year as both urea and MAP	All land cleared pre-1990. No till cropping system with annual planting and harvesting.
Lupin grain 89% allocation to grain	Yield: 1 t/ha/year	Water: Rain-fed Fertiliser: 100 kg single super/ha/year	All land cleared pre-1990. No till cropping system with annual planting and harvesting.

8.3 Export yards operation

8.3.1 Description of operation

Export yards for marshalling and holding sheep prior to shipping are located within 80 km of the Port of Fremantle. Sheep are transported from property to the yards by road train with travel distances of 100 to 500 km (average 350 km). Sheep spend 3-7 days in the yards (average 4.5 days) where they are accustomed to the shipping feed and inspected by AQIS before shipping.

The feed supplied to sheep in the export yards is comprised of approximately 50% cereal hay fed as large bales in the pens and 50% pelleted feed that is the same as that which is used on-board ship. This helps accustom animals to the feed that they will receive once at sea. The source of the pelleted feed fed in the export yards is assumed to be 100% from Western Australian manufacturers.

Road transport is used to move feed an average distance of 30 km from local manufactures to the export yards and port. Feed is handled in bulk.

8.3.2 Inventory

One export yard contributed case study data with general information on:

- Electricity and diesel use in the yard
- Inputs such as feed and water
- Residence time of the sheep
- Manure management systems

Data from the case study yard combined with data from publications was used to gain an average for inputs per sheep transiting through the yard. These are summarised in

Table 8. This data was used to inform modelling of the total number of wethers departing the Port of Fremantle (approximately 1,227,450 head in 2009) with inputs such as feed and fuel.

Table 8. Sheep and manure management assumptions for Western Australian sheep export yards for one year of operation.

Total head	1,227,450/year
Initial live weight	46 kg
Days on feed	6 days
Average daily live weight gain (kg/head/day)	0 kg/head/day
Mortality	0.1%
Feed intake	1.3 kg/head/day
Water intake	4.5 L/head/day
Manure management system	100% solid storage and dry lot
Diesel use	0.025 L/head
Electricity use	0.006 KWh/head
Transport for feed	2870 tkm/year
Transport for sheep	250 km/head

8.4 Shipping operation

8.4.1 Description of operation

Fremantle is a major port for export of sheep to the Middle East. In 2009/10 the trade to the Middle East was serviced by 8 live export vessels making between one and 8 voyages for the year. Sheep are loaded at Fremantle Port and are brought from the export yard by road train, an average distance of 20 km. Sheep are loaded onto the ships taking about 2 days to complete loading. Unloading in the Middle East takes about 5 days.

While at sea sheep are fed a ration of shipping pellets similar to those fed in the export yards. Daily intake of feed is approximately 2.7% of live weight. Shipping feed is sourced from Western Australian manufacturers. Feed is supplied to the ships in bulk. The sheep gain approximately 2kg/head during the voyage.

Fresh water for livestock is taken on board at the port and is also produced by desalination plants while at sea. Livestock waste is washed into the open sea with salt water once the sheep have disembarked. The assumption is made that the GHG emissions from manure and urine while on-board ship are negligible and are not included.

Some of the ships made repeated return voyages back to Fremantle to collect more sheep while others were deployed to other routes for part of the year. The assumption was made that there was no back-loading of stock and that the required ship time to transport one consignment of sheep to the Middle East was 2 days at port in Fremantle, 12 days loaded at sea, 5 days at port in the Middle East and 11 days for return to Fremantle, a total of 30 days for a return voyage. While the ship is in port the assumption was made that the auxiliary engine provided all services and the main engine was shut down.

8.4.2 Inventory

Feed intake while on board ship for a 46 kg wether was assumed to be 1.3 kg and water intake of 4.5 L/head/day. Feed is sourced from local manufacturers in Western Australia and is transported 30 km to the ship. Sheep are transported 20 km from the export yard to the ship.

The ships servicing the Port of Fremantle in 2009/2010 were identified along with information on the number of voyages to the Middle East (Fremantle Port Authority), the main engine size (Lloyds Register) and an estimate of the auxiliary engine capacity made by a marine engineer.

This publicly available information on the livestock export fleet was used to estimate daily heavy fuel oil use in the main engines and diesel use in the auxiliary engines. Data were estimated with the assistance of a marine engineer and was partly validated by one ship owner covering three of the ships. The information on pen capacity and number of voyages for the year was used to construct an average shipping process for sheep to the Middle East that was weighted by the contribution each ship made to stock movement in 2009/10. All ships were assumed to be fully loaded on the voyage to the Middle East, and fuel consumption was assumed to be the same both loaded and unloaded. The average ship is a modelling construct and does not describe an individual ship in the fleet nor is it the most common description of ships servicing the trade. The parameters for the modelled ship are given in Table 9.

Table 9. Description of modelled ship servicing the Fremantle to Middle East live sheep export trade.

Sheep pen capacity (head)	**Estimate of fuel oil use (t/day)**	**Estimate of diesel use (t/day)**	**Voyage time (days)**	**Backload**
94,100	51.2	20.2	15 loaded 15 empty	0%

8.5 Middle East feedlot operation

8.5.1 Description of operation

The sheep feedlots in the Middle East supply a wide range of local and regional markets within the region with sheep for slaughter, approximately 3,542,600 head during the study period in 2009 (747,800 head for Bahrain). Due to the difficulties in sourcing information directly from feedlots in the Middle East, data from the feedlot in Bahrain, where MLA staff are employed, was used.

Merino wethers were chosen as the ‘functional unit’ for the life cycle assessment as they are the most common class of animal traded. In the absence of specific data on turn-off quantities for each class of livestock (wethers, ewes and rams) and to simplify the analysis, it was assumed that wethers were the only class of animal produced by the feedlot.

Sheep arrive from various ports in Australia with Fremantle, Adelaide and Portland being the major ports. Sheep from Fremantle are delivered to a range of ports in the Middle East (Kuwait, Bahrain, Muscat, Persian Gulf, Shuwaikh, Eilat, Jeddah, Saudi Arabia, Doha, and Adabiya).

In Bahrain the distance between the port and the feedlot approximately 25 km. Sheep are transported to the feedlots on two deck semi trailers made from shipping containers, which accommodate 100 sheep per deck.

Wethers arrive in the Middle East at an average live weight of 48 kg, having gained 2 kg/head during the voyage, and remain in the feedlot for 10-20 days (average 14 days). The animals are fed a maintenance ration of 1 kg/head/day and do not gain weight in the feedlot. The preference is for lean meat. Once sheep leave the feedlot they travel most often a short distance (1km) to an abattoir co-located with the feedlot.

Feedlots operate as a dry lot, where manure is physically removed from pens with machinery and/or manual labour. There was no data available to quantify the amount of manure or accurately describe its management. It was assumed that all manure remained at the feedlot for 12 months and its fate after this period was not considered.

8.5.2 Inventory

One year (2009-2010) of business records or an annual estimation from the feedlot was used to collect data on:

- Electricity and diesel use in the feedlot
- Turnover of the feedlot including starting and finishing live weights for animals
- Ingredient inputs for the ration fed to sheep
- Amounts of feed consumed and average daily live weight gain
- Other business inputs such as pesticides, bedding and health treatments
- Transport for major inputs (sheep, feed)

An average Middle Eastern feedlot was modelled using the parameters in Table 10. The average feedlot reflects the data collected from MLA staff in the Middle East.

Table 10. Sheep and manure management parameters describing Middle Eastern feedlot for live export sheep.

Initial live weight	48 kg
Final live weight	48 kg
Days on feed	14 days
Average daily live weight gain (kg/head/day)	0 kg/head/day
Mortality	0.05%
Feed intake	1 kg/head/day
Water intake	4 L/head/day
Waste feed allowance	25% of feed consumed
Manure management system	100% solid waste and dry lot
Fuel inputs	0.05 L/head

8.6 Middle East feed production system

8.6.1 System description

8.6.2 Inventory

The ingredients for the feedlot ration used in the modelling are an approximate average of that used by the feedlot in Bahrain and are presented in Table 11, along with the assumed transport distance and an assessment of how well available life cycle inventory data matched the production systems used to produce the feed ingredient. Transport inventory was sourced from the Australasian Unit Process library for rigid trucks and sea freight.

The scoring system for production system match was characterised as:

1 = different region, different technology, similar but not the same product

2= different region, different technology, same product

3= similar region, different technology, same product

4= same region, different technology, same product

5= same region, same technology, same product

Cereal hay is soured from countries in the region such as Pakistan, likewise grain by-products such as bran are from grain sourced in the region and processed in the Middle East. Australian shipping pellets are also used in the feedlot; ships are required to carry an additional 3 days fodder allowance on the ship and some of this feed is off loaded into feed bunkers in the region and distributed to feedlots. The crude protein content of the ration is approximately 9% with a dry matter digestibility of 63%. These feed parameters are used to determine the GHG emissions from sheep in the feedlot.

Table 11. List of main feed ingredients used in Middle Eastern feedlots, average travel distance for each ingredient and match between life cycle inventory used and the production systems (1=poor; 5=good).

Ingredient	**Proportion in ration (%)**	**Assumed average transport distance (km)**	**Production system match with available inventory**
Cereal straw	40	1,700[os]	2
Bran	50	120	3
Shipping pellets	10	120	5

[os] Off-shore and transport assumed to be by sea.

9. CATTLE LIVE EXPORT CHAIN

9.1 On-farm cattle production

9.1.1 System description

The on-farm sector of the cattle supply chain is based on beef production systems in the Northern Territory which predominantly supply the live export trade to Indonesia. The regions covered in the study were Victoria River District, Sturt Plateau and Katherine and the Adelaide River and Gulf regions (covered by ABARES Statistical Regions 713 and 714). These regions experience a tropical climate with a distinct December-March wet season. Cattle are grazed under extensive pastoral conditions with stocking rates in the vicinity 10-20 ha per beast depending on the level of property development and vegetation type.

The main business enterprise is self-replacing beef herds of close to 100% Bos *indicus* content (Brahman). The primary product from this system is steers of 1.5 to 2.5 years of age, sold for live export to Indonesia. However, these enterprises also produce significant numbers of cull cows and surplus heifers.

Three years (2007-2010) of detailed business records from 3 properties??? were used to collect data on:

- Herd structure and turnoff of sale animals
- Inputs such as diesel, avgas, petrol, mineral licks, herbicides, health treatments and fodder
- Service inputs such as insurance, accounting fees, repairs and maintenance and communications

Three years of data is the period recommended for livestock farming systems (Eady and Ridoutt 2009) to enable some estimate of year to year variation. The structure of the case study properties was relatively stable over the three years and was taken to be indicative of the region as a whole.

Each case study was assessed against the results for the region based on the Beef CRC Gross Margin Templates prepared in Breedcow software (Holmes *et al.* 2010). The regional templates have been set up with data provided by state and territory Department of Primary Industries staff based on on-property field trials. The four case study properties were average, or above, compared to the regional performance which is not surprising given the volunteers for the study are recognised innovators and early adopters of technology. Hence the decision was made to use the regional values for herd structure, reproduction and mortality rates and turnoff numbers. The case studies were used to add data on business inputs such as fuel and fodder and to estimate averages for management practices such a savanna burning.

9.1.2 Inventory

The data in Table 12 are drawn from the Beef CRC Gross Margin Template for Region 713 and 714 in the Northern Territory (Holmes *et al.* 2010) and describe the key production parameters of breeders, herd structure, reproduction and survival rates.

Table 12. Herd structure, sale and mortality rates assumed for the beef industry in Region 713 and 714 of the Northern Territory

Production parameter	**Region 713 (Victoria River District/Stuart Plateau/Katherine)**	**Region 714 (Top End and Gulf)**
Number of breeding cows > 3 years	274,031	57,064
Number of 1st calf heifers	66,955	15,438
Proportion of bulls (%, number in brackets)	4% (12,161)	3% (1,951)
Calves weaned/cows retained (%)	62%	52%
Mortality rate of heifers >1 (%/year)	2%	5
Mortality rate of heifers >2 (%/year)	8.5%	10
Mortality rate of mature cows (%/year)	3.5%	13%
Cull rate of mature cows (%/year)	5%	0%
Culling age for cows (years)	10-11 years	10-11 years
Sale of unmated heifers (%/year)	23%	9%
Mortality rate weaners <1 (%/year)	2.3%	5
Mortality rate of steers > (%/year)	2%	4
Proportion of homebred bulls	50%	0%
Replacement bulls purchased per year	1033 bulls sourced within an average of 600 km	273 bulls sourced within an average of 300 km

A summary of the classes and number of sale stock is given in Table 13. Sale prices may not reflect current markets but it is the relativity of the assumed prices for each class of livestock that is important rather than the absolute price. The main way in which price is used in the LCA is to apportion environmental impacts/flows in proportion to the percentage of gross income earnt by each class of sale stock.

Table 13. Sale weight and prices for different classes of stock in Region 713 and 714 in the Northern Territory

Class of stock	**Number sold**		**Sale weight (kg live weight)**		**Sale price ($/kg live weight)**
	Region		Region		Both Regions
	713	714	713	714	
Number of feeder steers sold at 1.5 years of age	70,565	1,625	330	300	1.70
Number of feeder steers sold at 2.5 years of age	10,373	11,810	350	340	1.70
Number of steers sold at 3.5 years of age	6,539	1,908	360	350	1.60
Number of surplus heifers sold at 2.5 years of age	36,567	1,387	360	300	1.55
Number of unspayed cull cows sold various ages	11,405	2,853	450	410	1.20
Number of spayed cows sold various ages	24,280	3,237	400	430	1.20
Number of culled bulls	2,067	312	650	600	1.20

The functional units used for enterprise products (at the farm gate) are given in Table 14. The choice of 1 kg of live weight as the functional unit is made because it reflects the most common unit used for trading the product and for market quotation of prices.

The issue of how to allocate inputs, to the outputs generated from a livestock enterprise, arises when there are multifunction processes, that is, the enterprise produces interrelated products. For this example, the breeding enterprise produces a number of interrelated beef products – steers, heifers, cull cows and bulls. A common approach is to allocate inputs based on a mass or economic value basis. This approach is used where attributional modelling of LCA seeks to describe the environmental flows for a particular product. In this case an economic allocation has been used.

Table 14. Functional unit for beef enterprise products, level of production of products leaving the property and allocation (based on economics) of environmental effects to co-products, within the beef enterprise.

Functional Unit at farm gate	**Region 713**		**Region 714**	
	Quantity produced per year (kg live weight/year)	Economic allocation to class of stock (%)	Quantity produced per year (kg live weight/year)	Economic allocation to class of stock (%)
1 kg live weight of feeder steer	29,271,040	62.8	5,170,700	69.2
1 kg live weight surplus heifer	6,026,040	12.1	416,100	4.9
1 kg live weight cull cow	5,132,250	8.0	1,169,730	11.1
1 kg live weight cull spayed cow	9,712,000	15.2	1,391,910	13.2
1 kg live weight cull bull	1,343,550	1.9	187,200	1.6

Business inputs are based on averages from the four case study properties. Inputs that were considered as business overheads were estimated by using an average value of $ spent per breeder; these were inputs such as accounting, business travel, insurance, repairs and maintenance auto, repairs and maintenance structures and telecommunications. Variable operating inputs were estimated by using an average based on quantity per kg of total live weight produced. The total value and quantity of inputs for each region are detailed in Table 15 and

Table 16.

Table 15. Business inputs per year for beef total beef operations in Region 713 Northern Territory

Business inputs	**Quantity or level of expenditure**	**Description and source of inventory**
Telecommunications – telephone, internet	$374,510	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4
Business travel	$390,058	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4
Insurance	$512,073	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4
Accounting	$554,005	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4
Repairs and maintenance – structures	$899,249	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4
Repairs and maintenance – automotive plant and equipment	$2,421,274	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4.
Dry season lick	1,822 t	10% urea and protein meal; based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Dry season lick	3,008 t	30% urea and protein meal, 3.6% phosphorus; based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Molasses	3,824 t	Based on data from University of Queensland for Qld sugar industry.
Wet season phosphorus lick	2,728 t	14% phosphorus; based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Local pasture hay	2,769 t	Pasture hay; based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Super phosphate	287 t	Based on Australasian Unit Process
Cattle pellets	727 t	Based on CSIRO Unit Process
Vaccination and health treatments	340,986 breeders and followers	Vaccination of all breeding animals for botulism and all weaners for botulism and ticks; anthelmintic treatment for weaners; based on combination of

		Ecoinvent, Australasian and CSIRO Unit Processes.
Herbicide	2,294 L	Based on Ecoinvent unit processes
Diesel for machinery and power generation	2,639,007 L	Based on Australasian Unit Process for Australian diesel
Petrol	37,699 L	Based on Australasian Unit Process for Australian petrol
Avgas	480,931 L	Based on Australasian Unit Process for Australian avgas
Electricity	1,082,467 kWh	Based on Australasian Unit Process for NT power supply
Purchased bulls	1,095 head	600 kg bulls from average distance of 600 km; CSIRO Unit Process
Working dog maintenance	308 dogs	Based on dry dog food consumption; CSIRO Unit Process
Transport for lick and blocks	18,575,178 tkm	From various locations – Brisbane, Charters towers and Townsville; based on Australasia Unit Process for articulated truck, 28 tonne load on 30 tonne truck, 90% rural operation
Transport for local hay	250,944 tkm	From various locations over distance of 50-500 km; based on Australasia Unit Process for articulated truck, 22 tonne load on 30 tonne truck, 90% rural operation
Transport for fuel	1,171,083 tkm	From Darwin; based on Australasia Unit Process for articulated truck, 22 tonne load on 30 tonne truck, 90% rural operation
Transport for purchased bulls	657,000 cattle.km	1 cattle.km = 1 head for 1km; CSIRO Unit Process
Transport of cattle for internal transfer between holdings	29,574,179 cattle.km	1 cattle.km = 1 head for 1km; CSIRO Unit Process

Table 16. Business inputs per year for beef total beef operations in Region 714 Northern Territory

Business inputs	Quantity or level of expenditure	Description and source of inventory
Telecommunications – telephone, internet	$78,107	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4
Business travel	$52,248	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4
Insurance	$89,004	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4
Accounting	$115,542	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4
Repairs and maintenance – structures	$187,545	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4
Repairs and maintenance – automotive plant and equipment	$504,974	Based on $ expenditure ($1A = $1US) with associated reference flow from US input-output library in SimaPro 7.2.4.
Dry season lick	295 t	10% urea and protein meal; based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Dry season lick	487 t	30% urea and protein meal, 3.6% phosphorus; based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Molasses	619 t	Based on data from University Queensland for Qld sugar industry.
Wet season phosphorus lick	442 t	14% phosphorus; based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Local pasture hay	448 t	Pasture hay; based on combination of Ecoinvent, Australasian and CSIRO Unit Processes
Super phosphate	47 t	Based on Australasian Unit Process
Cattle pellets	117 t	Based on CSIRO Unit Process
Vaccination and health treatments	71,115 breeders and followers	Vaccination of all breeding animals for botulism and all weaners for botulism and ticks; anthelmintic treatment for weaners; based on combination of Ecoinvent,

		Australasian and CSIRO Unit Processes.
Herbicide	371 L	Based on Ecoinvent unit processes
Diesel for machinery and power generation	427,267 L	Based on Australasian Unit Process for Australian diesel
Petrol	6,104 L	Based on Australasian Unit Process for Australian petrol
Avgas	77,865 L	Based on Australasian Unit Process for Australian avgas
Electricity	175,256 kWh	Based on Australasian Unit Process for NT power supply
Purchased bulls	273 head	600 kg bulls from average distance of 300 km; CSIRO Unit Process
Working dog maintenance	50 dogs	Based on dry dog food consumption; CSIRO Unit Process
Transport for lick and blocks	3,007,407 tkm	From various locations – Brisbane, Charters towers and Townsville; based on Australasia Unit Process for articulated truck, 28 tonne load on 30 tonne truck, 90% rural operation
Transport for local hay	40,629 tkm	From various locations over distance of 50-500 km; based on Australasia Unit Process for articulated truck, 22 tonne load on 30 tonne truck, 90% rural operation
Transport for fuel	189,604 tkm	From Darwin; based on Australasia Unit Process for articulated truck, 22 tonne load on 30 tonne truck, 90% rural operation
Transport for purchased bulls	81,900 cattle.km	1 cattle.km = 1 head for 1km; CSIRO Unit Process
Transport of cattle for internal transfer between holdings	4,788,196 cattle.km	1 cattle.km = 1 head for 1km; CSIRO Unit Process

9.2 Australian cattle feed production system

9.2.1 System description

Cattle feed is required for feeding in the export yards prior to shipping (3-7 days) and while on-board ship (approximately 5 days). The formulation is a high fibre and low concentrate ration designed to maintain rumen health and encourage intake, rather than maximise live weight gain. Feed used for export cattle from Darwin is sourced from both local Northern Territory manufacturers and from southern Australia, with an approximate 70:30 split between locally manufactured and southern manufactured sources. Road transport is used to deliver all feed ingredients to the mill.

9.2.2 Inventory

Three feed manufactures contributed to the study. One year (2009-2010) of business records was used to collect data on:

- Electricity and diesel use in the plant
- Inputs such as pallets, bags and packaging
- Service inputs such as insurance, accounting fees, repairs and maintenance and communications
- Ingredient inputs for the pellets

The feed formulations have been simplified and averaged; they do not represent the exact formulation for any one case study business. The assumed transport distance and an assessment of how well the available life cycle inventory data matched the production systems used to produce the feed ingredient are also presented.

The scoring system for production system match was characterised as:

1 = different region, different technology, similar but not the same product

2= different region, different technology, same product

3= similar region, different technology, same product

4= same region, different technology, same product

5= same region, same technology, same product

The average feed formulation for feeds produced in the Northern Territory are given in Table 17. The production systems for the three major ingredients (forage sorghum, grass and legume hay) are summarised in Table 18. Much of the information for fodder production was provided by Arthur Cameron (Pastoral Practices, NT Department of Resources), Fergal O’Gara (NT Agricultural Association), and local producers growing hay on their properties.

Feed is packaged in bulker bags of approximately 1.2 t or in smaller bags of 35 kg where feed is manually handled on-board ships. In some instances bulker bags are recycled from export yards (not from ships) back to the feed manufacture. Small bags are packed on timber pallets and wrapped in stretch wrap. The average amount of packaging for one tonne of feed produced in the NT is 2 kg polypropylene bags, 0.2 kg of stretch wrap and 0.1 use of a timber pallet.

Table 17. Approximate mix of ingredients (and associated transport) for producing feed in the Northern Territory for export yards in the Northern Territory and shipping from Darwin.

Ingredient	**Transport distance to feed mill**	**Proportion in ration**	**Production system match with available inventory**	**Source of inventory**
Forage sorghum	65	20%	4	CSIRO Unit Process
Perennial grass hay	25	42%	5	CSIRO Unit Process
Legume hay	25	20%	5	CSIRO Unit Process
Grain - sorghum/corn from Kununurra (50%) or Katherine (50%)	250	5%	4	CSIRO Unit Process
Cottonseed meal	3000	4%	4	CSIRO Unit Process
Molasses from Townsville	2200	4%	5	University Qld for Qld sugar
Salt	3000	1.5%	5	Australasian Unit Process
Lime	3000	1.5%	5	Australasian Unit Process
Bentonite	3000	1%	4	Ecoinvent Unit Process
Other plant products	120	1%	4	Australasian Unit Process
Road transport in tonnes x km travelled		374		Australasian Unit Process

Table 18. Description of the production systems for major hay ingredients used in manufacture of feed in the Northern Territory for live cattle export.

Hay description	**Production parameters**	**Water and fertiliser**	**Machinery and fuel inputs**
Forage sorghum	Yield: 12 t/ha/year Cuts: 4/year	Water: Dry season irrigation Fertiliser: 100 kg/ha NPKS at planting and 200 kg/ha urea during growing season annually	Tree clearing, stick-raking and burning – assumed 12% of land used for forage sorghum production cleared post-1990, amortised over 20 years. Annual ploughing, cultivation, planting and 4 cuts of hay.
Perennial grass hay – i.e. Jarra and Gamba grass	Yield: 10 t/ha/year Cuts: 1/year	Water: Rain-fed Fertiliser: 100 kg/ha NPKS and 150 kg/ha urea annually	Tree clearing, stick-raking and burning – assumed 12% of land used for hay production cleared post-1990, amortised over 20 years. Ploughing, cultivation and planting at initial establishment with assumed replanting interval of 50 years. One cut of hay/year.
Cavalcade legume hay	Yield: 7 t/ha/year Cuts: 1/year	Water: Rain-fed Fertiliser: 90 kg DAP/ha annually	Tree clearing, stick-raking and burning – assumed 12% of land used for legume hay production cleared post-1990, amortised over 20 years. Annual ploughing, cultivation, planting and one cut of hay.

The average feed formulation for feeds produced in southern Australia is given in

Table 19. Feed from southern Australia is generally handled in bulk.

Table 19. Approximate mix of ingredients (and associated transport) for producing feed in southern Australia for export yards in the Northern Territory and shipping from Darwin .

Ingredient	Transport distance to feed mill	Proportion in ration	Production system match with available inventory	Source of inventory
Cereal straw	200 km	50%	5	CSIRO Unit Process
Legume straw	200 km	19%	5	CSIRO Unit Process
Cereal by-products	200 km	10%	4	CSIRO Unit Process
Various horticulture by-products	25 km	15%	1	CSIRO Unit Process
Molasses from Townsville	3000 km	3%	5	Uni Qld for Qld sugar
Lime	25 km	2%	5	Australasian Unit Process
Urea	25 km	1%	5	Australasian Unit Process
Road transport in tonnes x km travelled		260		Australasian Unit Process

9.3 Export yards operation

9.3.1 Description of operation

Export yards for marshalling and holding cattle prior to shipping are located within 80 km of the Port of Darwin. Cattle are transported from property to the yards by road train with travel distances of 100 to 1200 km (average 800 km). Cattle spend 3-7 days in the yards (average 4.5 days) where they are accustomed to the shipping feed, treated for ticks and lice, vaccinated against clostridial diseases (if required), and inspected by AQIS before shipping.

The feed supplied to cattle in the export yards is comprised of approximately 50% pasture hay fed as large bales in the pens and 50% cubed or pelleted feed, that is the same as that which is used on-board ship. This helps accustom animals to the feed that they will receive once at sea. The source of the pelleted feed fed in the export yards is assumed to be 75% from Northern Territory manufacturers and 25% from southern Australia.

Road transport is used to move feed an average distance of 250 km from local manufactures to the export yards and port. Where feed is brought from southern

Australia it is moved in bulk by rail over an average distance of 3000 km. Feed is delivered 80 km by road to the originating southern rail head.

9.3.2 Inventory

Two export yards contributed case study data. One year (2009-2010) of business records was used to collect data on:

- Electricity and diesel use in the yard
- Inputs such as feed and water
- Residence time of the cattle
- Manure management systems

The case study yards were used to gain an average for inputs per beast transiting through the yard. This data was used to inform modelling of the total number of cattle departing the Port of Darwin (approximately 348,250 head in 2009) with inputs such as feed and fuel, weighted to their relative contribution across the types of yards operating in the NT (Table 20).

Table 20. Cattle and manure management assumptions for Northern Territory export yards for one year of operation.

Total head	348,250/year
Initial live weight	333 kg
Days on feed	4.4 days
Average daily live weight gain (kg/head/day)	0 kg/head/day
Mortality	0.1%
Feed intake (NT manufacture)	4.2 kg/head/day
Feed intake (southern Aust manufacture)	1.4 kg/head/day
Water intake	40 L/head/day
Manure management system	1% anaerobic lagoon
	99% solid storage and dry lot
Diesel use	0.36 L/head
Cattle transport	800 km/head

9.4 Shipping operation

9.4.1 Description of operation

Darwin is a major port for export of cattle to Indonesia. In 2009/10 the trade to Indonesia was serviced by 21 live export vessels making between one and 22 voyages for the year. Cattle are loaded at East Darwin Port and are brought from the export yard by road train, an average distance of 80 km. Cattle are loaded onto the ships at a rate of approximately 500/hour/ramp. Larger ships will have multiple ramps and most ships are loaded with in half a day.

While at sea cattle are fed a ration of shipping pellets or cubes similar to those fed in the export yards. Daily intake of feed is approximately 2% of live weight. Approximately 68% of shipping feed is sourced from Northern Territory manufacturers with 32% coming from southern Australia. Feed is supplied to the ships in bulk, in 1.2 t bulker bags or in 35 kg small bags, depending on the feed handling equipment employed on the ship.

Fresh water for livestock is taken on board at the port and is also produced by desalination plants while at sea. Livestock waste is washed into the open sea with salt water once the cattle have disembarked. The assumption is made that the GHG emissions from manure and urine while on-board ship are negligible and are not included.

Some of the ships made repeated return voyages back to Darwin to collect more cattle while others were deployed to other routes for part of the year. The assumption was made that there was no back-loading of stock and that the required ship time to transport one consignment of cattle to the Indonesia was 5 days loaded and 5 days for return to port.

9.4.2 Inventory

Feed intake while on board ship for a 333 kg steer was assumed to be 6.7 kg and water intake of 30 L/head/day. Feed is sourced from local manufacturers in the Northern Territory and from southern Australia.

The ships servicing the Port of Darwin in 2009/2010 were identified along with information on the number of voyages to Indonesia (Darwin Port Authority), the main engine size (Lloyds Register) and an estimate of the auxiliary engine capacity made by a marine engineer .

This publicly available information on the livestock export fleet was used to estimate daily heavy fuel oil use in the main engines and diesel use in the auxiliary engines. This data was partly validated by two ship owners covering four of the ships. The information on pen capacity and number of voyages for the year was used to construct an average shipping process for cattle to Indonesia that was weighted by the contribution each ship made to stock movement in 2009/10. All ships were assumed to be fully loaded on the voyage to Indonesia, and fuel consumption was assumed to be the same both loaded and unloaded. The average ship is a modelling construct and does not describe an individual ship in the fleet nor is it the most common description of ships servicing the trade. The parameters for the modelled ship are given in Table 21.

Table 21. Description of modelled ship servicing the Darwin to Indonesia live cattle export trade.

Cattle pen capacity (head)	**Estimate of fuel oil use (t/day)**	**Estimate of diesel use (t/day)**	**Voyage time (days)**	**Backload**
15,700	40.1	11.2	5 loaded 5 empty	0%

9.5 Indonesian feedlot operation

9.5.1 Description of operation

The cattle feedlots in Indonesia supply a wide range of local and regional markets within Indonesia with cattle for slaughter, approximately 760,000 head during the study period in 2009. The level of technology applied across the feedlot sector varies. A sub-sector of the industry (producing 40% of the turn-off) is similar to Australia; large feedlots with a high level of mechanisation, scientific feed formulation and management of cattle health, achieving cattle growth rates in the order of 1.7 kg/head/day. A sub-sector of the industry (35%) is comprised of large feedlots, partly mechanised and with less technologically advanced feed formulation and health care, achieving growth rates in the order of 1.3 kg/head/day. A third sub-sector of the industry (25%) is made up of smaller feedlots that are labour intensive, also achieving growth rates in the order of 1.3 kg/head/day. The figures for growth rates are generalisations drawn from local industry knowledge, with cross-checking using the case study feedlots. These are consistent with figures for average daily gain reported by Perkins *et al.* (2010) for Australian cattle in two feedlots in Indonesia (1.5 – 1.6 kg/head/day).

Given the difference in energy inputs characterising the three sectors of the feedlot industry, each sector was modelled individually and then a combined/average model for the industry was constructed with each sector making a contribution in proportion to the number of head turned off each year.

During the period of the project the trade in cattle was defined into two classes of stock:

- feeder cattle that arrive at approximately 333 kg live weight and are fed for an average of 100 days, and sold at 470 kg live weight. This class is largely comprised of steers of 1.5-2.5 years of age, with some heifers of the same age range.
- slaughter cattle that are >350 kg and are held for only a short period (<14 days) in the feedlot before slaughter. This class is largely comprised of cull cows, older bullocks and bulls.

When purchasing Australian cattle, the feedlot specification (apart from weight) is that the animals have a high *Bos indicus* breed content so that they are able to grow well and remain healthy in the hot humid conditions in Indonesia. The main consumer specification for meat is that it is lean; very little fat is acceptable to consumers.

Feeder steers were chosen as the ‘functional unit’ for the life cycle assessment as they are the most common class of animal traded. In the absence of specific data on turn-off quantities for each class of livestock (steers, heifers and slaughter cattle) and to simplify the analysis, it was assumed that feeder steers was the only class of animal produced by the feedlot.

Since 2009/10 a maximum weight restriction of 350 kg live weight has been enforced by Indonesian authorities, which has had an impact on the class of cattle being shipped and the live weight of animals at arrival. The trade in mature livestock (bullocks, cull cows and bulls) has all but ceased and the average live weight of feeder cattle has dropped, as exporters move to ensure that individual animals do not exceed the 350 kg cap. The data reported here pertains to the period prior to the enforcement of restrictions.

In the study period (2009), approximately 760,000 cattle were shipped to Indonesia and finished in feedlots. The overall capacity of feedlots was estimated to be in the order of 225,000 head. Cattle arrive from various ports in Australia with Darwin, Townsville, Broome, Wyndham and Geraldton being the major ports. Cattle from Darwin are delivered to a range of ports in Indonesia (Jakarta, Panjang, Surabaya , Belawan, Cigading, Cilacap, and Dumai).

From there they travel 40-80 km to feedlots on small stock trucks (7-8 tonne) which can accommodate approximately 12 head of cattle.

Feeder steers arrive in Indonesia at a live weight of 300-350 kg (average of 333 kg) and remain in the feedlot for 75-120 days (average 97 days), after which time they are sold for slaughter at 440-500 kg live weight (average 470 kg). Average daily growth rate is 1.3-1.7 kg/head. This varies by up to 10% over the year with maximum growth rates in September, which is the best month for live weight gain because the local feed commodities are delivered dry, the pens are dry and the cattle are lean, coming out of the Northern Territory later in the dry season. Cattle are fed an introductory ration with higher fibre content or the first 10-21 days in the feedlot. They then transition onto a higher concentrate ration until finishing.

Feedlots operate either as a dry lot, where manure is physically removed from pens with machinery or manual labour, or a wash down lot, where manure is flushed from the pens on a regular basis every 3-4 days. Water use and effluent management is different for the two systems, with liquid waste forming a larger proportion of the manure management system with a wash down system. Estimates from industry participants are that 40% of feedlot facilities are wash down and 60% are dry lot. With dry lot systems there may be additional bedding added in the form of sawdust and coconut husk to improve animal welfare and reduce injuries.

Animals are sold on a per head basis with little monitoring of live weight during the growing period. Once they leave the feedlot they most often travel 10-20 km to a local abattoir but in some instances can travel up to 600 km before slaughter.

A proportion of manure is used as fertiliser to produce fodder and other crops on the feedlot farm, some is sold making a minor contribution to business income (<1%) and a significant quantity is stored as excess product. There was no data available to quantify the amount of manure or accurately describe its management. All feedlots had anaerobic ponds with many reporting that the ponds overflow in the wet season. Based on the type of cleaning system used (wash down or dry lot), assumptions were made on the proportion of manure managed in ponds verses dry lot. It was assumed that all manure remained at the feedlot for 12 months and its fate after this period was not considered.

9.5.2 Inventory

One year (2009-2010) of business records or an annual estimation from the manager of the feedlot was used to collect data on:

- Electricity and diesel use in the feedlot
- Turnover of the feedlot including starting and finishing live weights for animals
- Ingredient inputs for the ration fed to cattle
- Amounts of feed consumed and average daily live weight gain
- Other business inputs such as pesticides, bedding and health treatments
- Transport for major inputs (cattle, feed, bedding)

An average Indonesian feedlot was modelled using the parameters in Table 22. The average feedlot reflects the data collected from the five case studies, weighted by the proportion of the industry using similar technology to the case study feedlots.

Table 22. Cattle and manure management assumptions for average Indonesian feedlot.

Initial live weight	333 kg
Final live weight	469 kg
Days on feed	97 days
Average daily live weight gain (kg/head/day)	1.4 kg/head/day
Mortality	5%
Feed intake	11.5 kg/head/day
Water intake	40 L/head/day
Waste feed allowance	25% of feed consumed
Manure management system	32% anaerobic lagoon 68% solid storage and dry lot

Average inputs for the Indonesian feedlot modelled are given in Table 23. They are expressed in terms of quantity per tonne of live weight gain for the feed lotting period. All are based on a weighted average of the case study data and do not represent any individual business.

Table 23. Inputs for average Indonesian feedlot.

Inputs for average Indonesian feedlot – all are in unit per tonne of live weight gain added in the feedlot		**Source of inventory**
Electricity	18.64 kWh	Australasian Unit process modified for Indonesia brown coal fuel.
Diesel	16.86 L	Australasian Unit Process for diesel
Water for cleaning pens	0.156 kL	Water flow only included; energy inputs for pumping included in energy inputs
Fibrous bedding	1.25 t	No reference flow or emissions assumed for product; weight used to estimate associated transport inputs.
Insecticides	0.18 kg	Ecoinvent Unit Process
Herbicides	0.1 kg	Ecoinvent Unit process
Animal health treatments	0.044 kg	Ecoinvent Unit Process

9.6 Indonesian feed production system

9.6.1 System description

Cattle are typically fed a mixture of roughage and concentrate ingredients based on locally and regionally available products. In some instances a particular local by-product such as rice straw or pineapple skins makes up a significant proportion of the ration while locally produced onggok (a by-product from cassava processing), copra meal and palm kernel meal are common ingredients used by the majority of feedlots. Other ingredients are sourced from the district and region such as molasses, maize and dry cassava chips. Distiller’s grain, pollard, wheat, urea, limestone, dicalcium phosphate and mineral pre-mix are largely sourced from the Austral-Asian region, while soybean meal generally originates from America and Brazil.

The mixing of feed ingredients is done at the feedlot. Smaller feedlot use mixers run by electric motors, dispensing the feed into bags which are taken to the pens on the back of utility vehicles or small trucks. In the large mechanised feedlots, tractor PTO driven mixers or mixing trucks combine the ingredients and deliver them to the pens.

Transport of local and regional ingredients is by rigid truck of 5-15 t size. Ingredients are often bagged in sizes of 30-70kg depending on the product. Ingredients from off-shore were assumed to be transported by sea.

9.6.2 Inventory

The ingredients for the feedlot ration used in the modelling are an approximate average of that used by the case study feedlots and are presented in Much of the information for fodder and feed production was provided by local operators during interviews. This was supplemented with published information where available. Three major local ingredients - green forage, onggok and copra meal, were modelled from local data while data for other ingredients were drawn from existing published sources. The production systems for the three major ingredients (green forages, onggok and copra meal) are summarised in Table 25.

Table 24, along with the assumed transport distance and an assessment of how well available life cycle inventory data matched the production systems used to produce the feed ingredient. Transport inventory was sourced from the Australasian Unit Process library for rigid trucks and sea freight.

The scoring system for production system match was characterised as:

1 = different region, different technology, similar but not the same product

2= different region, different technology, same product

3= similar region, different technology, same product

4= same region, different technology, same product

5= same region, same technology, same product

To determine the GHG emissions from cattle in the feedlot, the plant components of the feed are split into energy concentrate, protein concentrate and roughage, with values for the feedlot ration in Indonesia being 12%, 23% and 65% respectively. The dry matter digestibility was assumed to be 65%. This information is used in the NGGI inventory to estimate emissions.

Much of the information for fodder and feed production was provided by local operators during interviews. This was supplemented with published information where available. Three major local ingredients - green forage, onggok and copra meal, were modelled from local data while data for other ingredients were drawn from existing published sources. The production systems for the three major ingredients (green forages, onggok and copra meal) are summarised in Table 25.

Table 24. List of main feed ingredients used in Indonesian feedlots, average travel distance for each ingredient and match between life cycle inventory used and the production systems (1=poor; 5=good)..

Ingredient	**Proportion (range) in ration (%)**	**Number of the 5 case study feedlots using ingredient**	**Assumed average transport distance (km)**	**Production system match with available inventory**
Green forage	19 (0-38)	4	10	5
Onggok	24 (14-30)	5	40	5
Copra meal	12 (6-16)	5	240	4
Palm kernel meal	9 (3-15)	5	240	4
Cassava chips	2 (0-12)	2	40	5
Molasses	4 (0.1-9)	5	240	2
Dried distiller grain salute	1.6 (0-5)	3	1,000[os]	3
Maize	0.2 (0-1)	2	40	2
Wheat milling by-products	2.5 (0-5)	3	1,000[os]	3
Rice milling by-products	0.5 (0-2.3)	1	240	2
Pineapple skins	9 (0-44)	1	10	1
Rice straw	5 (0-20)	1	10	2
Soybean meal	0.8 (0-3)	2	10,000[os]	4
Other plant by-products	4 (0-6)	2	40	2
Urea, mineral premix, dicalcium phosphate, salt	6 (1-10)	5	1,000[os]	5

[os] Off-shore and transport assumed to be by sea.

Table 25. Description of production systems for major local ingredients used in manufacture of feed for cattle in Indonesian feedlots.

Ingredient description	**Production parameters**	**Water and fertiliser**	**Land use change, machinery and fuel inputs**
Green forages	Yield: 30-35 t/ha/harvest Cuts: 3/year	Water: 5% of production is dry season irrigated rest is rain-fed Fertiliser: No synthetic fertilizer; assume animal manure applied at rate of 100 kg N/ha/year (15-25 t wet manure; Chivenge *et al.* 2004)	Proportion of agricultural land cleared since 1990 assumed to be 43%. Assume annual land preparation is mechanised for 33% of consumption, with the remainder being produced with manual labour.
Onggok	Yield: 25 t/ha/year (Howeler 2006) Crop: 1/year Allocation of 1.3% of flows to onggok	Water: Rain-fed Fertiliser: 100 kg/ha urea, 100 kg/ha super phosphate.	Proportion of agricultural land cleared since 1990 assumed to be 43%. Land preparation done mechanically with remainder of operations undertaken with manual labour. Processing inputs provided in-confidence from business operator.
Copra meal	Yield: 9 t/ha/yr husked nuts (Kasturi et al. 1996; CMIC 2010) Allocation of 6% of flows to copra meal.	Water: Rain-fed Fertilizer: Nil	Proportion of agricultural land cleared since 1990 assumed to be 43%. Nut collection done using tractor and trailer. All other farm operations use manual labour. Milling inputs from Ecoinvent Unit Processes.

10. LIFE CYCLE INVENTORY ANALYSIS

The Life Cycle Assessment is reported in stages so that the impacts associated with different parts of the supply chain can be identified separately. Most detail is provided for global warming due to the topical interest in this impact category, and due to the greater availability of inventory for this impact category.

10.1 Sheep live export supply chain

10.1.1 On-farm sector

On-farm GHG emissions from livestock sources, legume pastures and cropping enterprises for mixed farming system in south western Australia, that were allocated to production of export wethers, are summarised in Table 26. The total GHG emissions associated with production of a wether to the farm gate were 255 kg CO_2-*e*. Livestock emissions contributed 196 kg CO_2-*e* while the other major contribution of 60 kg CO_2-*e* came from the provision of feed (which included emissions associated with fertilizer, pesticides and fuel use).

Table 26. On-farm GHG emissions from livestock, legume pastures and cropping enterprises for mixed farming system in south western Australia.

Emission source	**GHG emissions (kg CO_2-*e*/head)**
CH_4 – Enteric	158
N_2O – Indirect	21.8
N_2O - Dung, Urine	16.1
CH_4 – Manure	0.002
Total on-farm GHG emissions from sheep	196
Farm services	4.3
Provision of feed	60.1
Avoided N fertilizer emissions	-3.5
Avoided herbicide and application	-2.2
Total on-farm GHG emissions from farm inputs	58.7
Total emissions	**255**

The GHG emissions, water and energy use and nutrient flows linked to eutrophication for and export wether from Western Australia are summarised in Table 27. Water use to produce a wether was 287,000 L green water, 1,360 L blue water on-farm and 640 L off-farm blue water. Energy use was 440 MJ/wether and nutrient flows were 0.35 kg PO_4--- e.

Table 27. GHG emissions, water use, energy use and nutrient flows linked to eutrophication for one export wether from a Western Australian mixed sheep/cropping farming system.

Functional Unit at farm gate	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**			**Energy use (MJ)**	**Eutrophication (kg PO_4---e)**
		Green water	**Blue water from on-farm sources**	**Blue water from off-farm sources**		
1 export wether at 46 kg	255	287,000	1,360	640	440 (31)	0.35
1 kg live weight export wether	5.5	6,239	30	14	9.6 (0.7)	0.008

The LCA network diagram showing the contribution of individual processes from 'cradle-to-farm gate' is given for an average wether produced in Western Australia in Figure 10, for GHG emissions. Each box in the diagram represents a process that contributes more than 0.7% of the GHG emissions. The thickness of the arrows indicates the size of the contribution from each process. Green arrows denote the avoided products that the sheep provide to the cropping enterprises (avoided use of herbicide and fertilizer). Amongst the property inputs and management practices, those that exceeded the 0.7% contribution were the provision of sheep feeds (which includes fertilizer, pesticide and fuel to grow crops and pastures) and farm services (insurance, electricity, earth works etc).

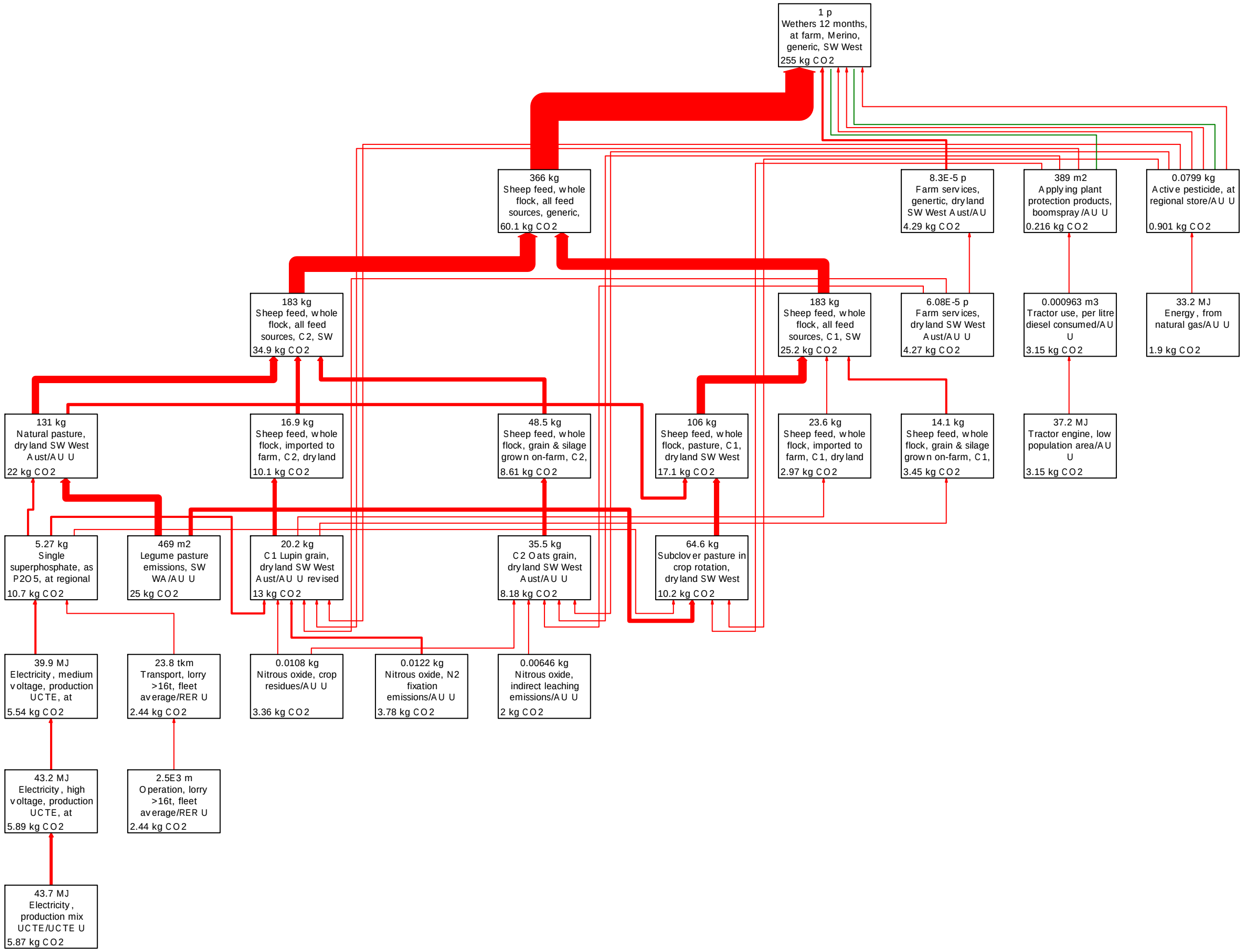


Figure 10. Network diagram showing global warming potential from ‘cradle-to-farm gate’, for sheep supply chain, for contributing process with cut-off for process impact set to 0.7% of total impact, with weight of arrows reflecting magnitude of flow.

10.1.2 Australian feed ingredients and manufacture

The GHG emissions, water and energy use and nutrient flows linked to eutrophication are listed for each of the feed ingredients for the shipping ration manufactured in Western Australian (Table 28). The values for ingredients are at the farm gate.

Table 28. GHG emissions, water and energy use and nutrient flows linked to eutrophication for each of the feed ingredients, for feed used in export yards and shipping feed, manufactured in Western Australia.

Product at farm gate (t)	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**			**Energy use (MJ)**	**Eutrophication (kg PO_4---*e*)**
		Green water	**Blue water from off-farm sources**	**Blue water irrigation**		
Cereal stubble	46	134,500	500	0	523	0.2
Wheat	264	738,000	1,500	0	3000	1.1
Lupins	646	1,030,000	13,000	0	5,190	3.1

Additional inputs for feed come from the milling and pelleting process plus transport of ingredients to the mill. The GHG emissions, water and energy use and nutrient flows linked to eutrophication are listed for these processes in Table 29.

Table 29. GHG emissions, water and energy use and nutrient flows linked to eutrophication for milling and pelleting process and ingredient transport of sheep feed for shipment to export yards and ships.

Process per t	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**			**Energy use (MJ)**	**Eutrophication (kg PO_4--*e*)**
		Green water	**Blue water from off-farm sources**	**Blue water irrigation**		
WA – milling process	46	0	144	0	601	0.02
Transport of ingredients to mill	16	0	2	0	234	
WA pellets at mill gate	**300**	**479,000**	**4,000**	**0**	**3,200**	**1.13**

10.1.3 Sheep export yards

The total GHG emissions associated with the preparation of one 46 kg export wether in the export yard were estimated to be 6.6 kg CO_2-*e* (

Table 30). This figure does not include emissions associated with the on-farm production of the wether.

Enteric methane was the largest individual source of GHG emissions, estimated to be 2.4 kg CO_2-*e*/wether. Methane and nitrous oxide from manure, urine and waste management was 0.3 kg CO_2-*e*/wether.

The next major contributor was the provision of feed ingredients at 2.2 kg CO_2-*e*/wether.

The transport of sheep to the export yards contributed 1.6 kg CO_2-*e*/wether, while the use of diesel for machinery operation in the yards added 0.1 kg CO_2-*e*/wether.

The water use at the export yard to produce one 46 kg live weight wether ready for shipping was estimated to be 3,450 L green water, 0 L of irrigation blue water and 60 L of other blue water per wether. Energy use to produce one export wether was estimated to be 48 MJ/wether and nutrient flow was estimated to be 0.03 kg PO_4--- e.. Once again this does not include water and energy use prior to the wether arriving at the export yards. These results are summarised on a per head and per kilogram of live weight basis in Table 31.

Table 30. GHG emissions associated with business inputs, transport, livestock and manure management emissions per export wether transiting through the export yard.

Emission source	**GHG emissions (kg CO_2-*e*/wether)**
Feed ingredients plus transport	2.2
Electricity and diesel	0.1
Transport sheep farm to export yard	1.6
Enteric methane	2.4
Nitrous oxide – dung & urine	0.3
Overall GHG emissions	**6.6**

Table 31. GHG emissions, water use, energy use and nutrient flows linked to eutrophication for post-farm gate to export yard gate for one 46 kg wether on per head and per kilogram live weight basis.

Product at export yard gate	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**			**Energy use (MJ)**	**Eutrophication (kg PO_4---*e*)**
		Green water	**Blue water from off-farm sources**	**Blue water irrigation**		
One 46 kg wether ready for export	6.6	3,450	60	0	48	0.03
1 kg live weight wether ready for export	0.14	75	1.3	0	1.04	0.001

10.1.4 Sheep shipping

The estimated GHG emissions for the shipping phase are given in detail in

Table 32, for one 48 kg wether delivered from Fremantle to the Middle East, and total 81 kg CO_2-*e*/wether. The provision and combustion of shipping fuel contributed the majority of the emissions (70 kg CO_2-*e*/wether), while enteric methane contributed 6 kg CO_2-*e*/wether and sheep feed contributed 5 kg CO_2-*e*/wether.

Table 32. GHG emissions associated with fuel, feed and livestock per wether transported by ship from Fremantle to the Middle East.

Emission source	**GHG emissions (kg CO_2-*e*/wether)**
Provision of feed	5
Provision of shipping fuel	12.5
Combustion of shipping fuel	57.9
Enteric methane	5.7
Overall GHG emissions	**81**

The GHG emissions, water and energy use and nutrient flows linked to eutrophication for the shipping process are given in Table 33. This includes the inputs of ship fuel, cattle feed and water, and GHG emissions from one 48 kg wether for the shipping phase.

Table 33. The GHG emissions, water and energy use and nutrient flows linked to eutrophication for the shipping process for sheep from Fremantle to the Middle East.

Product delivered to Middle Eastern port	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**			**Energy use (MJ)**	**Eutrophication (kg PO_4--*e*)**
		Green water	**Blue water**	**Blue water desalination**		
One 46 kg wether shipped to Middle East	81	8,050	31	49	1,110	0.62
1 kg live weight wether shipped to Middle East	1.8	175	0.7	1.1	24	0.01

10.1.5 Middle East feed ingredients and manufacture

The GHG emissions, water and energy use and nutrient flows linked to eutrophication are listed for each of the feedlot feed ingredients used in the Middle East, and for transport of ingredients to the Middle East (

Table 34). Results for the generic feedlot ration were estimated to be GHG emissions of 189 kg CO_2-*e*/t, green water use of 392,000 L/t, no irrigation water use, off-farm blue water use of 2,000 L/t, energy use of 2,260 MJ/t and nutrient flows of 0.49 kg PO_4--- e.

Table 34. GHG emissions, water and energy use and nutrient flows linked to eutrophication for each of the feedlot feed ingredients used in the Middle East, transport to the feedlot and the average feedlot ration based on these ingredients.

Product at farm/mill gate (t)	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**			**Energy use (MJ)**	**Eutrophication (kg PO_4---*e*)**
		Green water	**Blue water from off-farm sources**	**Blue water irrigation**		
Cereal stubble	46	134,500	500	0	523	0.2
Wheat milling by-products	225	581,000	2,000	0	2,600	0.53
Shipping pellets from Australia	300	479,000	4,000	0	3,200	1.13
Transport to the Middle East	14	0	1.5	0	202	
Average feedlot ration	**189**	**392,000**	**2,000**	**0**	**2,260**	**0.49**

10.1.6 Middle East feedlot finishing

The total GHG emissions associated with the finishing of one 48 kg wether, from delivery at port to finished weight at the feedlot gate, were estimated to be 10 kg CO_2-*e* (Table 35). This figure does not include emissions associated with the production of the wether in Australia or its shipping to the Middle East.

Enteric methane was the largest individual source of GHG emissions, estimated to be 5.5 kg CO_2-*e*/wether. Methane and nitrous oxide from manure, urine and waste management was 0.8 kg CO_2-*e*/wether.

The next major contributor was the provision of feed ingredients at 3.4 kg CO_2-*e*/wether; of this 0.1 kg CO_2-*e*/wether was associated the transport of feed ingredients to the feedlot. Minor contributions were made by diesel use at the feedlot and transport of sheep from the port to the feedlot (0.16 kg CO_2-*e*/wether).

The water use to produce one 48 kg live weight export wether from port to finished live weight at feedlot gate was estimated to be 6,870 L green water, 80 L of blue water per wether. Energy use to produce one export wether was estimated to be 46 MJ/wether and nutrient flows were 0.05 kg PO_4--- e. Once again this does not include water and energy use prior to the wether arriving at port in the Middle East. These results are summarised on a per head and per kilogram of live weight basis in Table 36.

Table 35. GHG emissions associated with business inputs, transport and livestock emissions per export wether from port to finished weight at feedlot gate.

Emission source	**GHG emissions (kg CO_2-*e*/steer)**
Feed ingredients	3.3
Transport of feed ingredients	0.1
Diesel	0.16
Transport sheep port to feedlot	0.16
Enteric methane	5.5
Nitrous oxide – dung & urine	0.8
Overall GHG emissions	**10**

Table 36. GHG emissions, water use, energy use and eutrophication for the port to feedlot gate finishing process for one 48 kg finished wether in the Middle East, on per head and per kilogram live weight basis.

Product at feedlot gate	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**			**Energy use (MJ)**	**Eutrophication (kg PO_4---*e*)**
		Green water	**Blue water from off-farm sources**	**Blue water irrigation**		
One 48 kg finished wether	10	6,870	80	0	46	0.05
1 kg live weight finished wether	0.2	143	1.7	0	0.96	0.001

10.1.7 Overall sheep supply chain to the Middle East

The GHG emissions, water and energy use and nutrient flows linked to eutrophication are listed for whole sheep supply chain to the abattoir door in the Middle East in Table 37. The distribution of GHG emissions, water and energy use and nutrient flows linked to eutrophication across the sectors of the supply chain are given in Table 38.

Table 37. GHG emissions, water use, energy use and eutrophication for the whole sheep supply chain to the abattoir gate in the Middle East for one 48 kg finished wether in the Middle East, on per head and per kilogram live weight basis.

Product delivered to abattoir in Middle East	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**				**Energy use (MJ)**	**Eutrophication (kg PO_4---*e*)**
		Green water	**Blue water on-farm**	**Blue water off-farm**	**Blue water irrigation**		
One 48 kg finished wether	353	305,400	1,360	860	0	1,640	1.05
1 kg live weight finished wether	7.4	6,363	28	18	0	34	0.02

Table 38. The distribution of GHG emissions, water and energy use and nutrient flows linked to eutrophication across the components of the supply chain for the supply of live export sheep from Western Australia to the Middle East.

Product delivered to abattoir in the Middle East	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**				**Energy use ((MJ)**	**Eutrophication (kg PO_4---*e*)**
		Green water	**Blue water on-farm**	**Blue water off-farm**	**Blue water irrigation**		
One 48 kg wether delivered to abattoir in the Middle East							
Production to farm-gate	255	287,000	1,360	640	0	440	0.35
Preparation to export yard-gate	6.6	3,450	0	60	0	48	0.03
Shipping foreign port-gate	81	8,050	0	80	0	1,110	0.62
Finishing to feedlot-gate	10	6,870	0	80	0	46	0.05
Total for one wether	**353**	**305,400**	**1,360**	**860**	**0**	**1,640**	**1.05**
Total for 1 kg live weight	**7.4**	**6,400**	**28**	**18**	**0**	**34**	**0.02**

Results for the overall sheep supply chain from farm to abattoir gate were estimated to be GHG emissions of 353 kg CO_2-*e*/wether, green water use of 305,400 L/wether, no irrigation water use, total blue water use of 2,220 L/wether, energy use of 1,640 MJ/wether and nutrient flows of 1.05 kg PO_4--- e/wether.

The LCA network diagram showing the contribution of individual processes from 'cradle-to-abattoir gate' is given for an average wether produced in Western Australia in Figure 11, for GHG emissions. Each box in the diagram represents a process that contributes more than 2% of the GHG emissions. The thickness of the arrows indicates the size of the contribution from each process. Amongst the property inputs and management practices, those that exceeded the 2% contribution were the provision of sheep feeds (which includes fertilizer, pesticide and fuel to grow crops and pastures), fuel oil and sheep feed for the shipping sector and the feed lotting sector (including feed and diesel use) in the Middle East.

The relative contribution over each sector of the supply chain for GHG emissions, water and energy use and nutrient flows linked to eutrophication for each of the environmental categories is shown graphically in Figure 12.

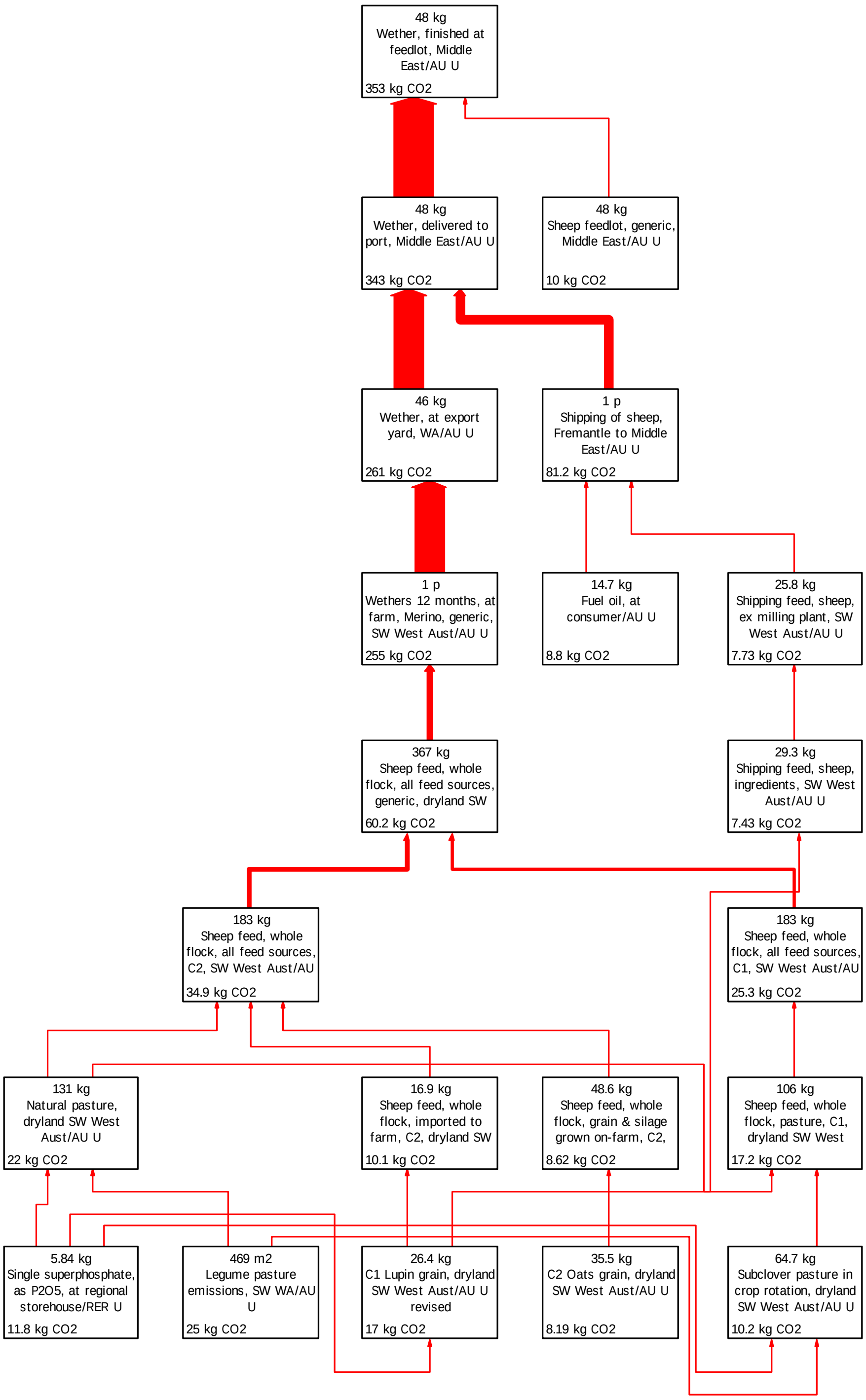


Figure 11. Network diagram showing global warming potential from ‘cradle-to-abattoir gate’, for sheep supply chain, for contributing process with cut-off for process impact set to 2% of total impact, with weight of arrows reflecting magnitude of flow.

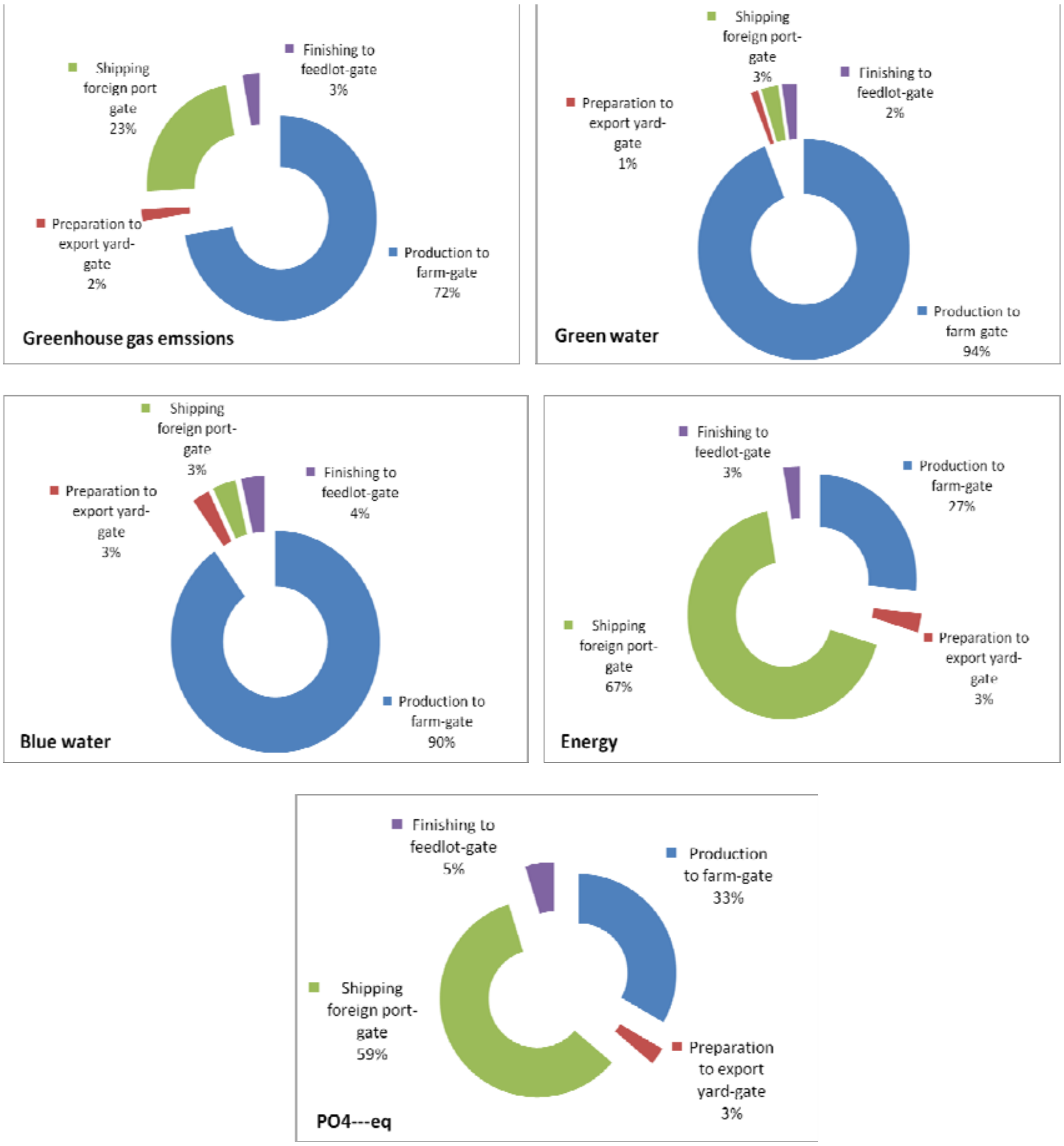


Figure 12. Relative contribution over each sector of the sheep supply chain for GHG emissions, water and energy use, and nutrient flow linked to eutrophication.

10.2 Cattle live export supply chain

10.2.1 On-farm sector

Region 713

The mean on-farm annual GHG emissions for Region 713 were estimated to be 1,362,848 t CO_2-*e* which equates to 2.64 t CO_2-*e*/adult equivalent. Table 39 shows the detailed contributions from enteric methane (CH_4) of cattle, combined nitrous oxide (N_2O) emissions from dung and urine, CH_4 emissions from manure, non-CO_2 emissions from savanna burning and N_2O emissions from legume pasture residues. The contribution of these categories is plotted in Figure 13.

Overwhelmingly GHG emission sources are directly from livestock, with a significant contribution (19%) from savanna burning, a small amount from land clearing (0.5%) and a negligible contribution from manure and legume residues (Figure 13). The contribution of the breeding animals (bulls and cows), which could be considered as the 'overhead' emissions cost of producing sale animals, was 53% of livestock emissions.

Table 39. Region 713 mean GHG emissions from direct livestock emissions (enteric methane: CH_4, and nitrous oxide from dung and urine: N_2O), indirect emissions associated with dung and urine, CH_4 emissions from manure, non-CO_2 emissions from savanna burning and N_2O emissions from legume residues.

Emission source	**Emission quantity (t CO_2-*e* /year)**	**Emissions per livestock unit – AE (t CO_2-*e* /year)**	**Enterprise parameters**
CH_4 – Enteric	1,049,626	2.03	340,986 cow herd (1st calf heifers + mature cows) and followers, totalling 659,755 head, equiv. to 517,300 AE.
N_2O – Indirect	27,917	0.05	
N_2O - Dung, Urine	13,249	0.03	
CH_4 – Manure	757	0.002	Manure deposited under grazing conditions
N_2O – Legume residues	79		1860 ha; 20% legume content and 5% residue
Non-CO_2 GHG gases- Savanna burning			
Region 713 late burn	175,000		604,802 ha/year
Region 713 early burn	89,400		560,086 ha/year
Total savanna burning	264,400	0.51	
Tree clearing	6,820	0.01	70 ha/year over last 20 years
Total on-farm GHG emissions	**1,362,848**	**2.64**	

However, the on-farm GHG emissions of 1,362,848 t CO_2-*e* represent only part of the total GHG emissions associated with the production of beef. The LCA estimates the total emissions for the 'cradle-to-farm gate' supply chain to be 1,396,400 t CO_2-*e*. Table 15 details of the origin of the additional 33,550 t of emissions.

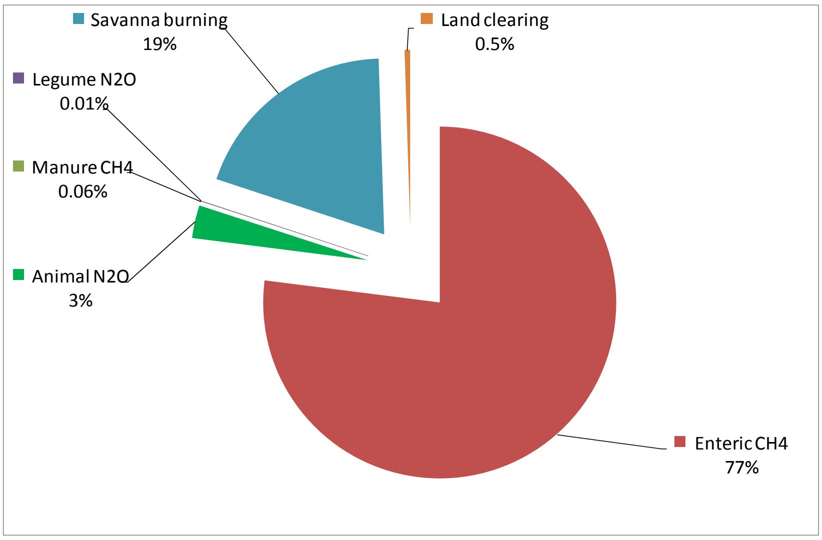


Figure 13. On-farm GHG emissions from beef enterprise showing livestock, savanna burning and legume pasture emissions for Region 713.

The resulting GHG emissions, water use, energy use and nutrient flows linked to eutrophication for enterprise products for Region 713 are presented in Table 40.

Table 40. GHG emissions, water use, energy use and nutrient flows linked to eutrophication for the range of classes of sale stock from the beef enterprise (using economic allocation) for Region 713.

Functional Unit at farm gate	**GHG emissions (kg CO_2-*e*)**	**Water use/kg live weight (L)**				**Energy use (MJ)**	**Eutrophication (kg PO_4---e)**
		Green water	**Blue water from on-farm sources**	**Blue water from off-farm sources**	**Blue water irrigation**		
1 kg live weight steer	30	63,300	113	3	0.004	7.8	0.004
1 kg live weight surplus heifer	28	58,300	106	3	0.003	7.3	0.004
1 kg live weight cull cow	22	45,300	82	2	0.003	5.7	0.003
1 kg live weight spayed cow	22	45,500	83	2	0.003	5.7	0.003
1 kg live weight cull bull	20	41,900	75	2	0.002	5.1	0.003

Region 714

The mean on-farm annual GHG emissions for Region 714 were estimated to be 301,400 t CO_2-*e* which equates to 2.85 t CO_2-*e*/adult equivalent. Table 41 shows the detailed contributions from enteric methane (CH_4) of cattle, combined nitrous oxide (N_2O) emissions from dung and urine, CH_4 emissions from manure, non-CO_2 emissions from savanna burning and N_2O emissions from legume pasture residues. The contribution of these categories is plotted in Figure 14.

Overwhelmingly GHG emission sources are directly from livestock, with a significant contribution (14%) from savanna burning and land clearing (11%) and a negligible contribution from manure and legume residues. The contribution of the breeding animals (bulls and cows), which could be considered as the ‘overhead’ emissions cost of producing sale animals, was 51% of livestock emissions.

However, the on-farm GHG emissions of 301,400 t CO_2-*e* represent only part of the total GHG emissions associated with the production of beef. The LCA estimates the total emissions for the ‘cradle-to-farm gate’ supply chain to be 307,763 t CO_2-e. Table 16 details the origin of the additional 6,363 t of emissions.

The resulting GHG emissions, water use, energy use and eutrophication for enterprise products for Region 714 are presented in Table 42.

Table 41. Region 714 mean GHG emissions from direct livestock emissions (enteric methane: CH_4, and nitrous oxide from dung and urine: N_2O), indirect emissions associated with dung and urine, CH_4 emissions from manure, non-CO_2 emissions from savanna burning and N_2O emissions from legume residues.

Emission source	**Emission quantity (t CO_2-e /year)**	**Emissions per livestock unit – AE (t CO_2-e /year)**	**Enterprise parameters**
CH_4 – Enteric	217,018	2.05	72,502 cow herd (1st calf heifers + mature cows) and followers, totalling 138,730 head; equiv. to 105,900 AE.
N_2O – Indirect	5,571	0.05	
N_2O - Dung, Urine	2,440	0.02	
CH_4 – Manure	158	0.002	Manure deposited under grazing conditions
N_2O – Legume residues	13		301 ha; 20% legume content and 5% residue
Non-CO_2 GHG gases- Savanna burning			
Region 713 late burn	28,400		97,920 ha
Region 713 early burn	14,500		90,680 ha
Total savanna burning	42,900	0.41	
Tree clearing	33,300		991 ha/year over last 20 years
Total on-farm GHG emissions	**301,400**	**2.85**	

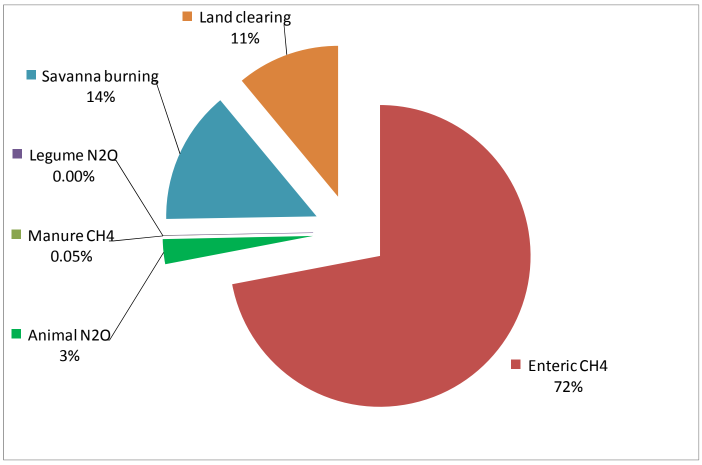


Figure 14. On-farm GHG emissions from beef enterprise showing livestock, savanna burning and legume pasture emissions for Region 714.

Table 42. GHG emissions, water use, energy use and nutrient flows linked to eutrophication for the range of classes of sale stock from the beef enterprise (using economic allocation) for Region 714.

Functional Unit at farm gate	**GHG emissions (kg CO_2-*e*)**	**Water use/kg live weight (L)**				**Energy use (MJ)**	**Eutrophication (kg PO_4---e)**
		Green water	**Blue water from on-farm sources**	**Blue water from off-farm sources**	**Blue water irrigation**		
1 kg live weight steer	41	113,200	147	4	0.003	8.3	0.004
1 kg live weight surplus heifer	36	99,900	129	3	0.003	7.3	0.004
1 kg live weight cull cow	29	80,500	101	2	0.003	5.9	0.003
1 kg live weight spayed cow	29	80,500	104	2	0.003	5.9	0.003
1 kg live weight cull bull	26	72,500	94	2	0.002	5.3	0.003

The results for feeder steer production combined across the two regions are given for a 333 kg steer in Table 43. At the farm-gate the GHG emissions to produce a feeder steer are estimated to be 10,500 kg CO_2-*e*, green water is 23,349,000 L, on-farm blue water is 39,400 L, off-farm blue water is 1,000 L, irrigation water is 1,200 L, energy use is 2,620 MJ and nutrient flows are 1.45 kg PO_4--- e.

Table 43. The GHG emissions, water and energy use and nutrient flows linked to eutrophication for average Northern Territory feeder steer at the farm-gate.

Functional Unit at farm gate	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**				**Energy use (MJ)**	**Eutrophication (kg PO_4---e)**
		Green water	**Blue water from on-farm sources**	**Blue water from off-farm sources**	**Blue water irrigation**		
333 kg live weight steer	10,500	23,349,000	39,400	1,000	1,200	2,620 (214)	1.45
1 kg live weight feeder steer	31.5	70,100	118	3	4	7.9 (0.64)	0.004

The LCA network diagram showing the contribution of individual processes from 'cradle-to-farm gate' is given an average steer produced in the Northern Territory in Figure 15 for GHG emissions. Each box in the diagram represents a process that contributes more than 0.2% of the GHG emissions. The thickness of the arrows indicates the size of the contribution from each process. Region 713 produces more steers than Region 714, and amongst property inputs and management practices, those that exceed the 0.2% contribution are savanna burning, land clearing, purchased bulls, diesel use and wet season lick.

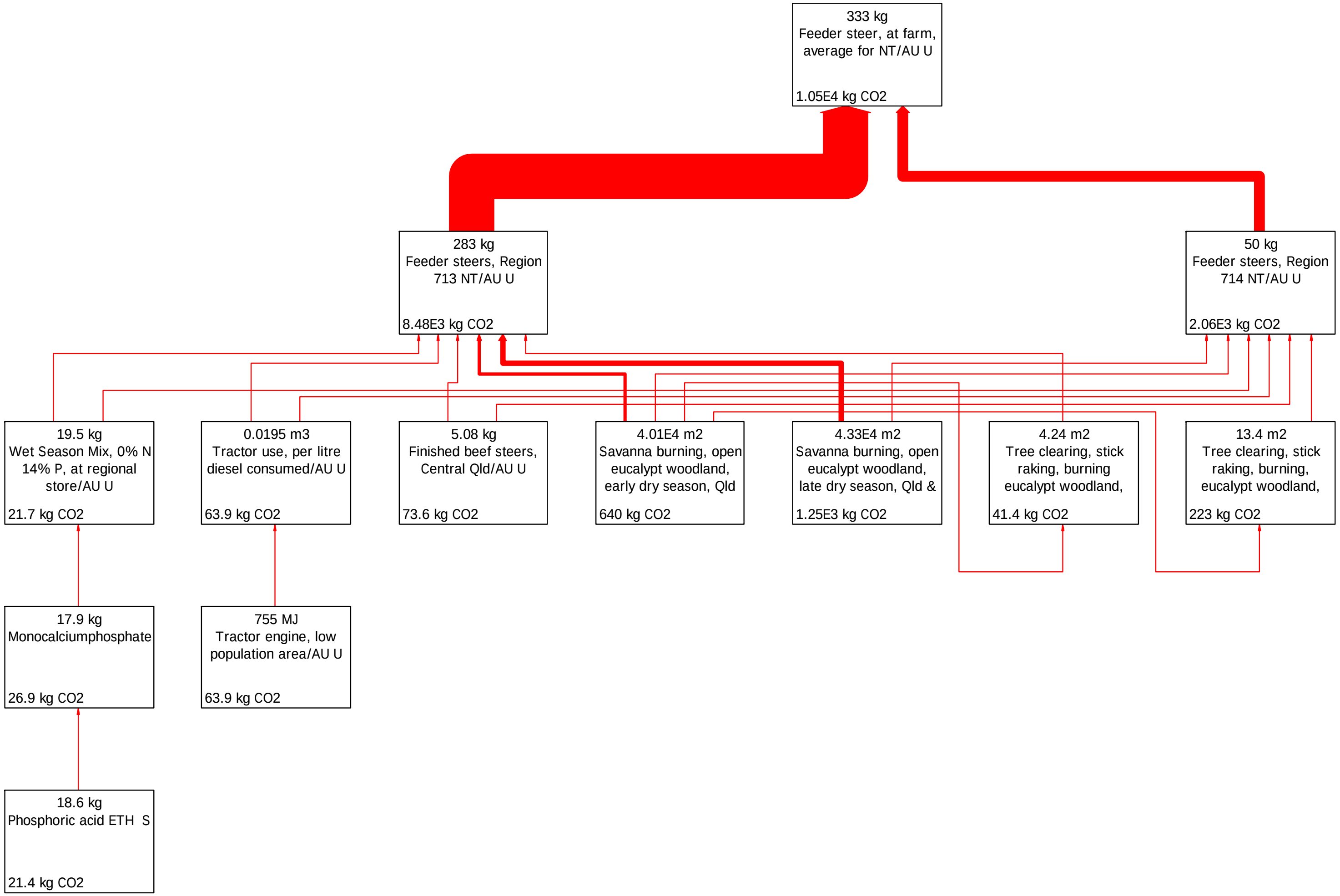


Figure 15. Network diagram showing global warming potential from ‘cradle-to-farm gate’, for cattle supply chain, for contributing process with cut-off for process impact set to 0.2% of total impact, with weight of arrows reflecting magnitude of flow.

10.2.2 Australian feed ingredients and manufacture

The GHG emissions, water and energy use and nutrient flows linked to eutrophication are listed for each of the feed ingredients for both the ration manufactured in the Northern Territory and manufactured in southern Australia (

Table 44 and Table 45). The values for ingredients are at the farm gate. Transport of ingredients to the feed mill is also given in the tables.

Additional inputs for feed come from the milling and pelleting process and packaging for shipment to export yards and ships. The GHG emissions, water and energy use and nutrient flows linked to eutrophication are listed for these processes in

Table 46.

The feed produced in the NT has higher GHG emissions and water use than feed produced in southern Australia (at the mill gate) and this difference is maintained after transport to Darwin for use in export yards or on-board ships. The energy use is similar at mill gate but higher for the Northern Territory manufactured feed once transport to Darwin is added. Nutrient flows linked to eutrophication were higher for the northern feed.

Table 44. GHG emissions, water and energy use and nutrient flows linked to eutrophication for each of the feedlot feed ingredients, transport to mill and packaging for feed used in export yards and shipping feed manufactured in the Northern Territory, and the average shipping feed based on these ingredients.

Product at farm gate (t)	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**			**Energy use (MJ)**	**Eutrophication (kg PO_4--*e*)**
		Green water	**Blue water from off-farm sources**	**Blue water irrigation**		
Forage sorghum	229	75,000	940	213,000	1,300	1.8
Perennial grass hay	133	294,500	500	0	743	0.27
Legume hay	229	1,550,000	160	0	757	0.38
Grain	270	747,000	2,730	0	2,820	0.74
Cottonseed meal	369	1,670,000	5,000	0	5,480	1.37
Molasses from Townsville	86	na	100	34,400	1,150	0.05[a]
Salt	145	0	10,500	0	2,660	0.40
Lime	1,090	0	100	0	6,830	0.41
Bentonite	413	0	40,600	0	11,700	1.2
Other plant by-products	1,090	Na	1,560	na	13,600	0.80
Transport to mill per tonne	35	0	4	0	507	
Combined ingredients plus transport	**236**	**553,000**	**2,500**	**42,500**	**1,890**	**0.68**

[a] Data not available for key process such as growing or milling.

Table 45. GHG emissions, water and energy use and nutrient flows linked to eutrophication for each of the feedlot feed ingredients used export yard and shipping feed manufactured in southern Australia, and the average shipping feed based on these ingredients.

Product at farm gate (t)	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**			**Energy use (MJ)**	**Eutrophication (kg PO_4--*e*)**
		Green water	**Blue water from off-farm sources**	**Blue water irrigation**		
Cereal straw	64	158,800	180	0	804	0.2
Legume straw	138	216,000	2,700	0	1,300	0.67
Cereal by-products	221	581,000	2,000	0	2,600	0.52
Various horticulture by-products	221	581,000	2,000	0	2,600	0.52
Molasses from Townsville	86	na	100	34,400	1,150	0.05[a]
Lime	1,090	0	100	0	6,830	0.41
Urea	841	0	33,500	0	25,300	1.36
Transport to mill per tonne	21	0	3	0	352	
Combined ingredients plus transport	**170**	**270,000**	**2,000**	**1,040**	**2,060**	**0.71**

[a] Data not available for key process such as growing or milling.

Table 46. GHG emissions, water and energy use and nutrient flows linked to eutrophication for milling and pelleting process and packaging of feed for shipment to export yards and ships.

Process/product units per t	**GHG emissions (kg CO_2-*e*)**	**Water use/kg live weight (L)**			**Energy use (MJ)**	**Eutrophication (kg PO_4--*e*)**
		Green water	**Blue water from off-farm sources**	**Blue water irrigation**		
NT – milling process	43	0	37	0	675	0.02
NT – feed packaging	6	0	5	0	193	
NT – pellets at mill gate	285	553,000	1,130	43,870	2,760	0.71
NT pellets delivered to Darwin	**316**	**553,000**	**1,130**	**43,870**	**3,210**	**0.72**
SA – milling process	46	0	144	0	601	0.02
SA – pellets at mill gate	216	270,000	3,000	0	2,670	0.41
Southern Australia pellets delivered to Darwin	**228**	**270,000**	**3,000**	**0**	**2,850**	**0.42**

10.2.3 Cattle export yards

The total GHG emissions associated with the preparation of one 333 kg feeder steer in the export yard were estimated to be 46 kg CO_2-*e* (Table 47). This figure does not include emissions associated with the on-farm production of the steer.

Enteric methane was the largest individual source of GHG emissions, estimated to be 18 kg CO_2-*e*/steer. Methane and nitrous oxide from manure, urine and waste management was 7.2 kg CO_2-*e*/steer.

The next major contributor was the provision of feed ingredients at 11.3 kg CO_2-*e*/steer. Of this 11.3 kg CO_2-*e*/steer, 3 kg CO_2-*e*/steer were associated with the clearing of land for agricultural production.

The transport of cattle to the export yards contributed 8.3 kg CO_2-*e*/steer, while the use of diesel for machinery operation in the yards added 1.2 kg CO_2-*e*/steer.

The water use at the export yard to produce one 333 kg live weight feeder steer ready for shipping was estimated to be 18,700 L green water, 800 L of irrigation blue water and 300 L of other blue water per steer. Energy use to produce one feeder steer was estimated to be 244 MJ/steer and nutrient flows were estimated to be 0.08 kg PO_4--- e. Once again this does not include water and energy use prior to the steer arriving at the export yards. These results are summarised on a per head and per kilogram of live weight basis in Table 48.

Table 47. GHG emissions associated with business inputs, transport, livestock and manure management emissions per feeder steer transiting through the export yard.

Emission source	**GHG emissions (kg CO_2-*e*/steer)**
Feed ingredients plus transport	8.3
Clearing of land to grow feed	3
Diesel	1.2
Transport cattle farm to export yard	8.3
Enteric methane	18
Manure methane	0.7
Nitrous oxide – dung & urine	6.5
Overall GHG emissions	**46**

Table 48. GHG emissions, water use, energy use and eutrophication for post-farm gate to export yard gate for one 333 kg steer on per head and per kilogram live weight basis.

Product at export yard gate	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**			**Energy use (MJ)**	**Eutrophication (kg PO_4---*e*)**
		Green water	**Blue water from off-farm sources**	**Blue water irrigation**		
One 333 kg steer ready for export	46	18,700	300	800	244	0.08
1 kg live weight steer ready for export	0.14	56	0.9	2.4	0.73	0.0002

10.2.4 Cattle shipping

The estimated GHG emissions for the shipping phase are given in detail in Table 49 for one 333 kg steer delivered from Darwin to Indonesia, and total 153 kg CO_2-*e*/steer. The provision and combustion of shipping fuel contributed the majority of the emissions (120 kg CO_2-*e*/steer), while enteric methane contributes 20 kg CO_2-*e*/steer and cattle feed contributes 10 kg CO_2-*e*/steer. Transport from the export yard to the ship contributed 3 kg CO_2-*e*/steer.

Table 49. GHG emissions associated with fuel, feed and livestock per feeder steer transported by ship from Darwin to Indonesia.

Emission source	**GHG emissions (kg CO_2-*e*/steer)**
Transport from export yard to ship	3
Feed ingredients	9.7
Provision of shipping fuel	21.4
Combustion of shipping fuel	98.2
Enteric methane	20.4
Overall GHG emissions	**153**

The GHG emissions, water and energy use and nutrient flows linked to eutrophication for the shipping process are given in Table 50. This includes the inputs of ship fuel, cattle feed and water, and GHG emissions from one 333 kg steer for the shipping phase.

Table 50. The GHG emissions, water and energy use and nutrient flows linked to eutrophication for the shipping process of one steer to Indonesia

Product delivered to Indonesian port	**GHG emissions (kg CO_2-*e*)**	**Water use/kg live weight (L)**			**Energy use (MJ)**	**Eutrophication (kg PO_4--*e*)**
		Green water	**Blue water**	**Blue water desalination**		
One 333 kg steer shipped to Indonesia	153	15,500	1,040	83	1,950	1.43
1 kg live weight steer shipped to Indonesia	0.46	47	3	0.3	5.9	0.004

10.2.5 Indonesia feed ingredients and manufacture

The GHG emissions, water and energy use and nutrient flows linked to eutrophication are listed for each of the feedlot feed ingredients used in Indonesia (Table 51). Results for the generic feedlot ration based on the average mix of ingredients were estimated to have GHG emissions of 229 kg CO_2-*e*/t, green water use of 89,000 L/t, irrigation water use of 4,900 L/t, off-farm blue water use of 3,000 L/t, energy use of 3,960 MJ/t and nutrient flow of 0.76 kg PO_4--- e.

Table 51. GHG emissions, water and energy use and nutrient flows linked to eutrophication for each of the feedlot feed ingredients used in Indonesia, and the average feedlot ration based on these ingredients.

Product at feedlot gate (t)	**GHG emissions (kg CO_2-*e*)**	**Water use/kg live weight (L)**			**Energy use (MJ)**	**Eutrophication (PO_4--- *e*)**
		Green water	**Blue water from off-farm sources**	**Blue water irrigation**		
Green forage - mechanised	492	300,000	0.2	0	20 (1.7)	0.55
Green forage - manual	504	300,000	0	0	0 (0)	0.55
Onggok	18	11,700	100	0	27.6 (2.04)	0.03[a]
Copra meal	174	na	9,520	Na	11,600 (54.7)	1.37
Palm kernel meal	65	na	6,000	37,600	7,140 (40.4)	0.48[a]
Cassava chips	442	327,000	151	0	247 (20.4)	0.68
Molasses	86	34,000	200	Na	1,150 (71)	0.05[a]
Dried distiller grain salute	867	na	7,550	Na	15,400 (1,220)	0.59
Maize	414	4,430	2,480	Na	18,100 (251)	3.96
Wheat milling by-products	221	581,000	2,000	0	2,600 (209)	0.52
Rice milling	1,470	989,800	2,200	Na	2,390	2.67

by-products					(629)	
Pineapple skins	25	na	20	2,120	395 (1.6)	0.02[a]
Rice straw	4	2,780	10	na	67 (1.8)	0.001
Soybean meal	408	na	2,550	na	17,700 (198)	4.87
Other plant by-products	174	na	9,520	na	11,600 (54.7)	1.37
Salt	145	0	10,500	0	2,660 (136)	0.40
Dicalcium phosphate	1,500	0	17,600	0	17,900 (1,400)	0.37
Urea	841	0	33,500	0	25,300 (2,180)	1.36
Mineral premix	2,640	0	128,000	0	47,600 (2,550)	62.7
Average feedlot ration	**229**	**89,200**	**3,000**	**4,900**	**3,960** **(101)**	**0.76**

[a] Data not available for key process such as growing or milling.

10.2.6 Indonesia feedlot finishing

The total GHG emissions associated with the finishing of one 470 kg feeder steer, from delivery at port to finished weight at the feedlot gate, were estimated to be 1,584 kg CO_2-*e* (Table 52). This figure does not include emissions associated with the production of the steer in Australia or its shipping to Indonesia.

Enteric methane was the largest individual source of GHG emissions, estimated to be 638 kg CO_2-*e*/steer. Methane and nitrous oxide from manure, urine and waste management was 604 kg CO_2-*e*/steer.

The next major contributor was the provision of feed ingredients at 327 kg CO_2-*e*/steer. Of this 223 kg CO_2-*e*/steer and 152 kg CO_2-*e*/steer were associated with the clearing of land for agricultural production, with the annual production of the feed ingredients themselves accounting for 153 kg CO_2-*e*/steer and transport of feed ingredients to the feedlot contributing 22 kg CO_2-*e*/steer.

The use of diesel for machinery operation contributed 7.5 kg CO_2-*e*/steer, transport of cattle from the port and for bedding material contributed 4.2 kg CO_2-*e*/steer and 0.2 kg

CO_2-*e*/steer, respectively. Electricity made a minor contribution of 2.9 kg CO_2-*e*/steer, while the contribution from health treatments and pesticides was negligible.

The water use to produce one 470 kg live weight feeder steer from port to finished live weight at feedlot gate was estimated to be 127,300 L green water, 8,600 L of blue water and 7,100 of irrigation water per steer. Energy use to produce one feeder steer was estimated to be 5,870 MJ/steer and nutrient flow to be 2.85 kg PO_4--- e. Once again this does not include water and energy use prior to the steer arriving at port in Indonesia. These results are summarised on a per head and per kilogram of live weight basis in

Table 53.

Table 52. GHG emissions associated with business inputs, transport and livestock emissions per feeder steer from port to finished weight at feedlot gate.

Emission source	**GHG emissions (kg CO_2-*e*/steer)**
Feed ingredients	153
Clearing of land to grow feed	152
Transport of feed ingredients	22
Electricity	2.9
Diesel	7.5
Health treatments	0.01
Herbicide and insecticide	0.5
Transport of bedding material	0.2
Transport cattle port to feedlot	4.2
Enteric methane	638
Manure methane	338
Nitrous oxide – dung & urine	266
Overall GHG emissions	**1,584**

Table 53. GHG emissions, water use, energy use and eutrophication for the port to feedlot gate finishing process for one 470 kg finished steer in Indonesia, on per head and per kilogram live weight basis.

Product at feedlot gate	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**			**Energy use (MJ)**	**Eutrophication (kg PO_4---*e*)**
		Green water	**Blue water from off-farm sources**	**Blue water irrigation**		
One 470 kg finished steer	1,584	127,300	8,600	7,100	5,870 (161)	2.85
1 kg live weight finished steer	3.4	271	18	15	12.5 (0.34)	0.006

10.2.7 Overall cattle supply chain to Indonesia

The GHG emissions, water and energy use and nutrient flows linked to eutrophication are listed for whole cattle supply chain to the abattoir door in Indonesia in Table 54. Results for the overall cattle supply chain from farm to abattoir gate were estimated to be GHG emissions of 12,300 kg CO_2-*e*/steer, green water use of 23,349,000 L/steer, blue water use of 50,400 L/steer, irrigation water use of 9,100 L/steer, energy use of 10,700 MJ/steer and nutrient flows of 5.82 kg PO_4--- e/steer.

Table 54. GHG emissions, water use, energy use and eutrophication for the whole supply cattle chain to the abattoir gate in Indonesia for one 470 kg finished steer in Indonesia, on per head and per kilogram live weight basis.

Product delivered to abattoir in Indonesia	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**				**Energy use (MJ)**	**Eutrophication (PO_4---*e*)**
		Green water	**Blue water on-farm**	**Blue water off-farm**	**Blue water irrigation**		
One 470 kg finished steer	12,300	23,349,000	39,400	11,000	9,100	10,700	5.82
1 kg live weight finished steer	26	49,700	84	23	19	23	0.01

The distribution of GHG emissions, water and energy use and nutrient flows linked to eutrophication across the components of the supply chain are given in Table 55.

Table 55. The distribution of GHG emissions, water and energy use and nutrient flows linked to eutrophication across the components of the supply chain for the supply of live export cattle from the Northern Territory to Indonesia.

Product delivered to abattoir in Indonesia	**GHG emissions (kg CO_2-*e*)**	**Water use (L)**				**Energy use (MJ)**	**Eutrophication (PO_4---*e*)**
		Green water	**Blue water on-farm**	**Blue water off-farm**	**Blue water irrigation**		
One 470 kg beast delivered to abattoir in Indonesia							
Production to farm-gate	10,500	23,349,000	39,400	1,000	1,200	2,620	1.45
Preparation to export yard-gate	46	18,700	0	300	800	244	0.08
Shipping foreign port-gate	153	15,500	0	1,123	0	1,950	1.43
Finishing to feedlot-gate	1,584	127,300	0	8,600	7,100	5,870	2.85
Delivered to abattoir	4	0	0	0.4	0	58	0.01
Total for one 470 kg beast	**12,300**	**23,510,500**	**39,400**	**11,000**	**9,100**	**10,700**	**5.82**
Total for 1 kg live weight	**26**	**50,000**	**84**	**23**	**19**	**23**	**0.01**

The LCA network diagram showing the contribution of individual processes from 'cradle-to-abattoir gate' for GHG emissions for an average steer produced in the Northern Territory is shown in Figure 16. Each box in the diagram represents a process that contributes more than 0.7% of the GHG emissions. The thickness of the arrows indicates the size of the contribution from each process. Region 713 produces more steers than Region 714, and amongst property inputs and management practices, those that exceed the 0.5% contribution are savanna burning and land clearing. Other sectors contributing more than 0.5% are the shipping of cattle and feed lotting in Indonesia.

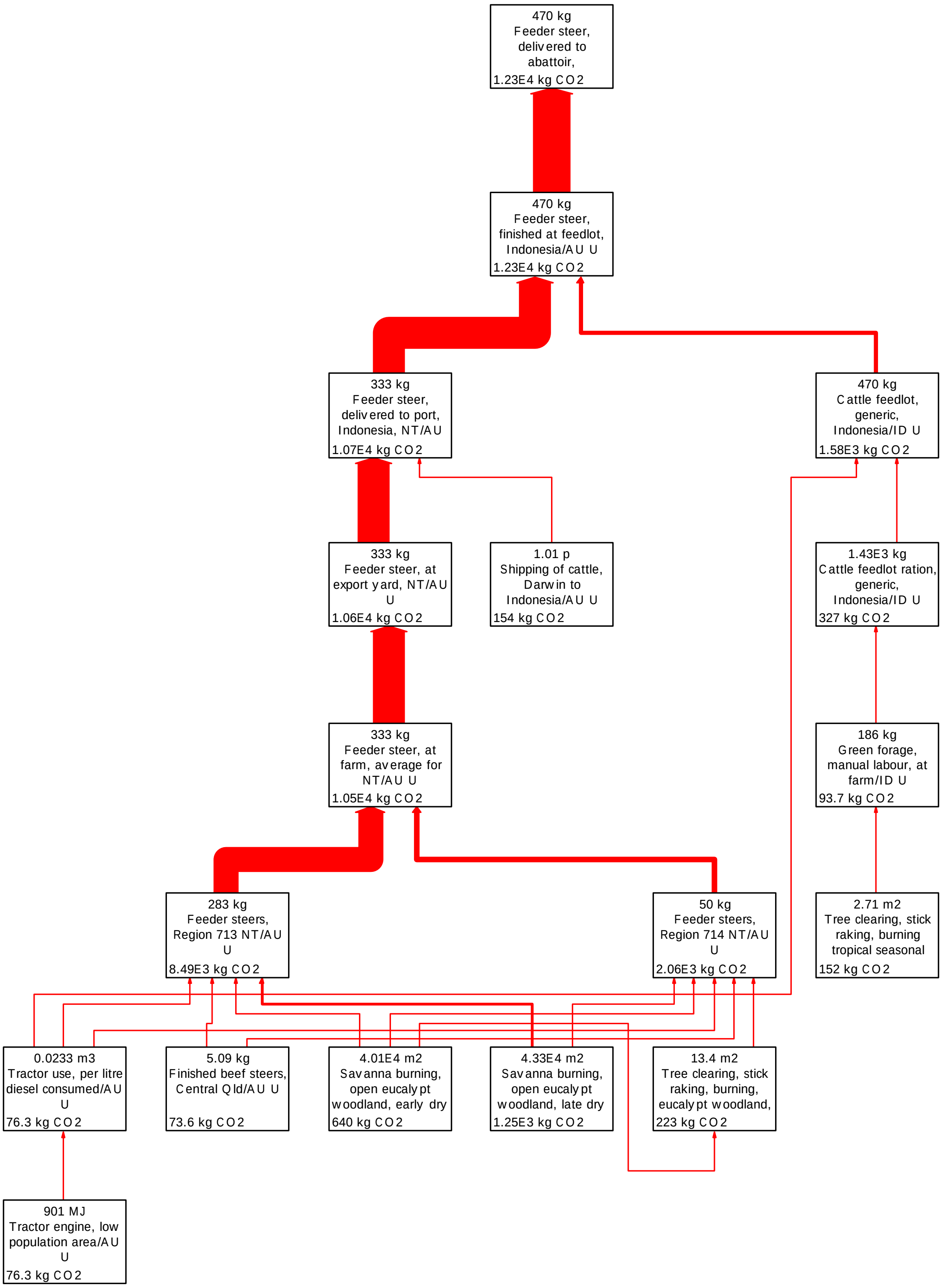


Figure 16. Network diagram showing global warming potential from ‘cradle-to-abattoir gate’, for cattle supply chain, for contributing process with cut-off for process impact set to 0.5% of total impact, with weight of arrows reflecting magnitude of flow.

The relative contribution over each component of the supply chain for GHG emissions, water and energy use and nutrient flows linked to eutrophication each of the categories is shown graphically in Figure 17.

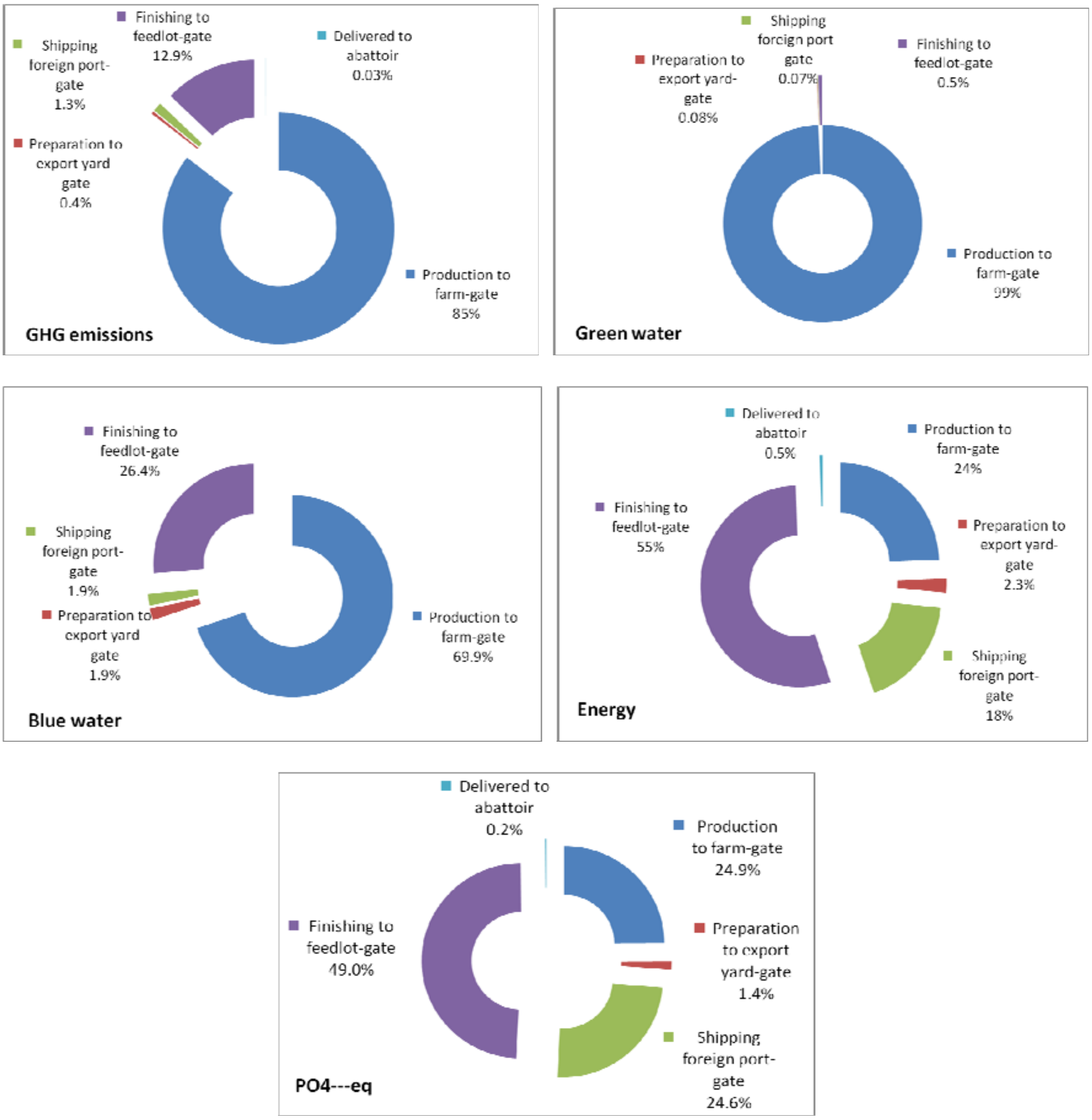


Figure 17. Relative contribution over each component of the cattle supply chain for GHG emissions, water and energy use and nutrient flows linked to eutrophication.

11. LIFE CYCLE IMPACT ASSESSMENT

11.1 Sheep supply chain

11.1.1 Global warming

The major source of GHG emissions for sheep is from the on-farm sector (72%) followed by the shipping sector (23%). On-farm emissions are largely related to enteric methane production while the shipping emissions are largely driven by fuel consumption during the voyage.

Assessing the global warming impact of the sheep supply chain is relatively straight forward – emissions of GHGs have a global impact regardless of their geographic location. However, results as reported here may have little inherent meaning to the reader unless set in some framework. In an attempt to set the case study results for on-farm GHG emissions in some context, figures for national, state and industry level emissions are given in Table 56 (DCCEE 2011).

Approximately 1,227,450 hogget and adult wethers were exported to the Middle East in 2009, similar in description to that used for the functional unit for this study. The associated whole of life GHG emissions would be in the order of 433,289 t CO_2-e, or 0.07% of national emissions, 1% of national agriculture emissions or 0.6% of Western Australian emissions (see Table 56).

Table 56. Average national, Western Australian and sheep industry GHG emissions from the National Greenhouse Gas Inventory 2008-2010.

Sector	**GHG Emissions (t CO_2-*e* /year)**
National – all sectors	572,100,000
National Agriculture – enteric fermentation, manure management, rice cultivation, agricultural soils, prescribed burning of savannas, field burning of agricultural residues	86,332,000
National sheep (enteric & manure methane, direct N_2O urine & faeces)	12,280,400
Western Australia - all sectors	70,248,400
Western Australia sheep (enteric & manure methane, direct N_2O urine & faeces)	2,600,200
Per capita (calculated as the total for the national accounts divided by the population of Australia)	25.8

The GHG emissions estimate for a 48 kg wether from Western Australia delivered to the abattoir in the Middle East (which includes emissions associated with all inputs/processes, both on and off-farm) is approximately 0.353 t CO_2-*e*, equivalent to 1.4% of the emissions attributed to each Australian per year.

In comparison with other sheep production systems, the GHG emissions of sheep meat from the sheep supply chain to the Middle East (7.4 kg CO_2-*e* /kg live weight for 48 kg wether) is higher than that of wethers produced in southern systems where published estimates of GHG emissions range from 3 to 5 kg CO_2-*e* /kg live weight for sheep (Peters *et al.* 2010; Eady *et al.* 2011). This is largely due to the additional input that shipping makes to the carbon foot print of live export sheep, contributing 1.8 kg CO_2-*e*/kg live weight. Compared to export lamb, shipped frozen to the UK from New Zealand (Ledgard *et al.* 2010), with a GHG emissions of 7.5 kg CO_2-*e* /kg (accounting for on-farm and shipping processes), Australian live export wethers had a similar GHG emissions of 7.4 kg CO_2-*e*/kg live weight, albeit the split between on-farm and shipping being quite different (75:25 for export wethers) and (94:5 for NZ lamb).

11.1.2 Water use

The major green water consumption is on-farm to produce the pasture that sheep eat prior to leaving the property. A small contribution comes from green water used to grow crops for livestock feed that is supplied during export preparation, shipping and feed lotting in the Middle East.

The major blue water consumption is also on-farm (90%) and is largely related to drinking water (classed as blue water as it is reticulated). The export yard, shipping and feedlot sector make relatively small contributions of 3-4% each. There is no (or little) irrigation water used in this supply chain.

With regards to water use, the environmental impact is dependent on location; water extracted from an environment where there is scarcity has a far different impact to its extraction in an environment of abundance. Therefore, it is difficult to ascribe an environmental impact without local parameterisation of a water impact assessment model. There is also a case for treating green and blue water differently – with the use of green water ascribed to land use, rather than considered as direct water use (Ridoutt & Pfister 2009). Impact assessment models for water and land use are under development for Australia. Hence, the figures for green and blue water use in this report are not totalled to give an overall ‘water footprint’; nor is there an equivalent national account for water use with which to make comparisons.

11.1.3 Energy use

Energy use is largest in the shipping sector (67%) followed by the on-farm sector (27%), with minor contributions made in the export yards or feedlot in the Middle East (3% each).

Due to the contribution of shipping, it is difficult to make sensible comparison with energy use from other published Australian studies for sheep meat. Shipping contributes about 23 MJ/kg live weight to the total of 34 MJ/kg live weight. Published figures of 20-23 MJ/ kg of live weight for a sheep meat supply chain in Western Australia (Peters *et al.* 2010; breed not specified) are lower than that reported here for sheep (34 MJ/ kg live weight) but also include slaughter and processing energy which is likely to be in the vicinity of 5-6 MJ/kg. Rough calculations suggest comparable figures of 11 MJ/kg live weight for live export sheep and 10-12 MJ/kg live weight for the sheep meat supply chain covered by Peters *et al.* (2010) once abattoir and shipping inputs are removed.

11.1.4 Nutrients linked to eutrophication

The estimated flow of N and P to waterways is largest for the shipping sector (59%), with the on-farm sector contributing 33%, and export yard and feedlot contributing small flows of 3% and 5%, respectively. Although the livestock are only on the ship for 14 days compared to 365 days on-farm, the nutrient flow to water is almost twice as high during shipping, this is because all of the manure is washed into the sea, while on-farm only a small proportion of the N and P (about 2-4%) added to the system as fertilizer makes its way into water ways.

Without regional characterisation of how nutrient flows drive eutrophication events (algal blooms) it is not possible to predict the effects of these flows for Australian and Middle Eastern environments. The existing impact assessment methods for eutrophication are for the northern hemisphere where the load of nutrients flowing into freshwater systems is much higher (Harris 2001). Likewise impact methods that consider marine eutrophication are most often based on the effect of nutrient flows into coastal marine conditions, whereas the cleaning of ships is done in open sea conditions (Landline Consulting 2003) and ship effluent while at port, under MARPOL regulations, is collected for later discharge (IMO 2007). Impact assessment models for nutrient flows for Australian and Indonesian conditions are required before the basic nutrient flows can be interpreted in terms of their environmental impact.

11.2 Cattle supply chain

11.2.1 Global warming

The major source of GHG emissions for cattle is from the on-farm sector (85%) followed by the feed lotting sector (13%). On-farm emissions are largely related to enteric methane production while the feedlot emissions are attributed to livestock and manure management emissions plus the provision of feed (including a significant component of land clearing).

Assessing the global warming impact of the beef supply chain is relatively straight forward – emissions of GHGs have a global impact regardless of their geographic location. However, results as reported here may have little inherent meaning to the reader unless set in some framework. In an attempt to set the case study results for on-farm GHG emissions in some context, figures for national, state and industry level emissions are given in Table 57 (DCCEE 2011).

Approximately 348,200 cattle were exported to Indonesia in 2009, if 60% of these were feeder steers of the description used for the functional unit for this study, the associated whole of life GHG emissions would be in the order of 2,569,700 t CO_2-e, or 0.5% of national emissions, 3% of national agriculture emissions or 15% of Northern Territory emissions (see Table 57).

Table 57. Average national, Northern Territory and beef industry GHG emissions from the National Greenhouse Gas Inventory 2008-20010.

Sector	**GHG Emissions (t CO_2-*e* /year)**
National – all sectors	572,076,500
National Agriculture – enteric fermentation, manure management, rice cultivation, agricultural soils, prescribed burning of savannas, field burning of agricultural residues	86,332,200
National beef cattle including feedlot cattle (enteric & manure methane, direct N_2O urine & faeces)	41,047,600
Northern Territory – all sectors excluding Land Use/Land Use Change sector	16,869,000
Northern Territory beef cattle (enteric & manure methane, direct N_2O urine & faeces)	2,585,700
Per capita (calculated as the total for the national accounts divided by the population of Australia)	25.8

The GHG emissions estimate for a 470 kg steer from the Northern Territory delivered to the abattoir in Indonesia (which includes emissions associated with all inputs/processes, both on and off-farm) is approximately 12.3 t CO_2-*e*, equivalent to 48% of the emissions attributed to each Australian per year.

In comparison with other beef production systems, the GHG emissions of beef from the cattle supply chain to Indonesia (26 kg CO_2-*e* /kg live weight for 470 kg steer) is higher than beef produced in southern systems where published estimates of GHG emissions range from 5.4 to 14.5 kg CO_2-*e* /kg live weight for finished steers (Peters *et al.* 2010; Eady *et al.* submitted). This is largely due to the southern systems having a higher reproduction rate, faster turn-off, no savanna burning emissions and lower methane emissions per unit of feed intake.

11.2.2 Water use

The major green water consumption is on-farm to produce the pasture that cattle eat prior to leaving the property. A small contribution comes from green water used to grow crops for livestock feed. Although the animals live for approximately 840 days, with 13% of the time spent on harvested feed, the green water contribution from the feed is <1%. This is largely due to the small allocation to plant by-products in the Indonesian feedlot ration, due to their relatively low economic value.

The major blue water consumption is also mainly on-farm (70%) and is largely related to drinking water (classed as blue water as it is reticulated). The feedlot sector also makes a significant contribution (26%). Irrigation water makes up 15% of the total blue water used.

With regards to water use, the environmental impact is dependent on location; water extracted from an environment where there is scarcity has a far different impact to its extraction in an environment of abundance. Therefore, it is difficult to ascribe an environmental impact without local parameterisation of a water impact assessment model. There is also a case for treating green and blue water differently – with the use of green water ascribed to land use, rather than considered as direct water use (Ridoutt & Pfister 2009). Impact assessment models for water and land use are under development for Australia. Hence, the figures for green and blue water use in this report are not totalled to give an overall ‘water footprint'; nor is there an equivalent national account for water use with which to make comparisons.

11.2.3 Energy use

Energy use is largest in the feedlot sector (55%) followed by the on-farm sector (24%) and shipping (18%). Even though the provision of fodder and the running of the feedlots uses a high level of manual labour, the need to transport and mix ingredients and pump water add significantly to the energy inputs of this component of the supply chain.

Published estimates for energy use for beef production (Peters *et al.* 2010), in the range of 11-13 MJ/kg live weight (but once again probably including 4-6 MK/kg for slaughter and processing), are much lower than the figure of 23 MJ/kg live weight reported here. Shipping adds approximately 4 MJ/kg live weight to energy use. So on a comparable basis the published estimates for Australian production (Peters *et al.* 2010) which included the on-farm sector and then feedlot finishing would be 6-8 MJ/kg live weight compared to 19 MJ/kg live weight for live export steers (excluding the shipping contribution).

11.2.4 Nutrients linked to eutrophication

The estimated flow of N and P to waterways is largest for the feedlot sector (49%), with the on-farm and shipping sectors contributing similar amounts (25% each). Although the livestock are only on the ship for 5 days compared to 730 days on-farm, the nutrient flow is similar as all of the manure is washed into the sea during shipping while on-farm only a small proportion of the P added to the system in nutrient supplements makes its way into water ways and the assumption is that none of the N ends up in waterways due to volatilisation.

Without regional characterisation of how nutrient flows drive eutrophication events (algal blooms) it is not possible to predict the effects of these flows for Australian and Indonesian environments. The existing impact assessment methods for eutrophication are for the northern hemisphere where the load of nutrients flowing into freshwater systems is much higher (Harris 2001). Likewise impact methods that consider marine eutrophication are most often based on the effect of nutrient flows into coastal marine conditions, whereas the cleaning of ships is done in open sea conditions (Landline Consulting 2003) and ship effluent while at port, under MARPOL regulations, is collected for later discharge (IMO 2007). Impact assessment models for nutrient flows for Australian and Indonesian conditions are required before the basic nutrient flows can be interpreted in terms of their environmental impact.

12. STAKEHOLDER CONSULTATION

To protect business confidentiality, the results for individual case studies are not published in this report. However, where significant data was provided by a business owner, each has received an individual report for their own enterprise. This includes the case study sheep and cattle properties, feed manufacturers and feedlot operators. Extensive feedback has been received from a number of these business owners and has been incorporated into the report in the form of background information on climate change in Australia, additional information on what inputs and management practices are included in a GHG emissions and how local estimates for things like pasture yield were estimated. In some instances underlying data assumptions were varied to better reflect the business operation.

Shipping data was distributed to all of the shipping companies with vessels operating out of Fremantle and Darwin for the study period. Two companies confirmed data for their ships (covering four of the vessels).

13. POTENTIAL TO MODERATE ENVIRONMENTAL IMPACTS ALONG THE SUPPLY CHAIN

13.1 Moderate environmental impacts

Consideration has been given to options that could be explored to moderate environmental impacts (specifically global warming) along the two supply chains. This assessment focuses on GHG emissions for the following reasons.

- Without an impact assessment methodology for water use there is little guide as to the important processes along the supply chain to target. Additionally, measures to increase productivity to abate GHG emissions will also reduce energy and water use.
- GHG emissions are largely a proxy for fossil fuel energy inputs and so energy use is not addressed separately. Control over energy efficiency improvements sits largely with machinery and shipping design engineers, rather than the livestock producer.
- The impact of nutrient flows on eutrophication is not understood well enough for the systems in the supply chains where there is significant potential for moderation of environmental impact (i.e. feedlots in the Middle East and Indonesia).

The factors affecting GHG emissions for each section of the live export sheep and beef supply chains are summarised in Table 58 and Table 59. Each is accompanied by a recommendation on whether future work is warranted to explore alternate scenarios.

Table 58. Factors affecting GHG emissions for each section of the live export sheep supply chain.

Section of the supply chain	**Factors affecting GHG emissions**	**Scenarios to investigate**	**Recommended**
On-farm production of sheep	Turn off of wethers per AE stocking rate	Improving reproduction rate, survival rate and growth rate of sheep to BMP for region	Yes – potential to support CFI methodology for livestock
	Contribution of legume pasture emissions of N_2O	Shift from annual legume based pastures to deep-rooted perennial grass pastures	Yes – potential to support a CFI methodology for soil carbon
	Enteric fermentation	Vaccinating animals with anti-methanogenic vaccine	No- the “magic bullet” scenario is still too theoretical
Live export yard	Source of feed	Varying the mix of ingredients to lower emissions intensity ingredients	No – the feed formulation is relatively simple and there would be little potential to improve the current ration.
Shipping	Fuel use by vessels Source of feed	Using fleet of more modern fuel efficient vessels As above for feed	No – not domain of MLA As above for feed
Feed lotting in Middle East	Transport distance for feed	Sourcing feeds close to Middle East to minimise transport	No – the sheep are not held in the feedlots for any length of time and exerting any influence over this input would be difficult.
	Varying of feed ingredients	Introduce GHG profile of feeds ingredients into least cost ration calculations	No - the sheep are not held in the feedlots for any length of time and exerting any influence over this input would be difficult.

Table 59. Factors affecting GHG emissions for each section of the live export beef supply chain.

Section of the supply chain	**Factors affecting GHG emissions**	**Scenarios to investigate**	**Recommended**
On-property production of cattle	Turn off of steers per AE stocking rate	Improving reproduction rate, survival rate and growth rate of cattle to BMP for region	Yes – potential to support CFI methodology for livestock
	Contribution of savanna burning – total area burnt and seasonal distribution of fires	Shifting the seasonality of fires to more frequent early season burns	Yes – potential to support a CFI methodology for savanna burning
	Enteric fermentation	Vaccinating animals with anti-methanogenic vaccine	No- the “magic bullet” scenario is still too theoretical
Live export yard	Source of feed	Northern versus southern sourced feed rations	Perhaps – main difference in GHG emissions area associated with the accounting for historic land clearing.
Shipping	Fuel use by vessels Source of feed	Using fleet of more modern fuel efficient vessels As above for feed	No – not domain of MLA As above for feed
Feed lotting in Indonesia	Land clearing for crop and fodder production	Source feed ingredients from industries that are not operating on recently cleared land. Intensify agricultural production on existing cleared land.	No – this is a problematic concept as the consequence of sourcing ingredients from land that has not been directly cleared may lead to indirect land clearing. Yes – but probably more in the domain of REDD projects under UNFCCC than MLA
	Composition of feed ingredients	Introduce GHG profile of feeds ingredients into least cost ration	Yes – although implementing a least cost nutritionally

		calculations	balanced ration is the most important imperative, there could be easily achieved gain from switching ingredients.
	Management of live stock effluent	Less ponding and more dry lot management; methane capture from anaerobic lagoons	Yes – but probably more in the domain of international projects under UNFCCC than MLA

13.2 Industry issues

Along with opportunities for mitigation of GHG emissions (and other environmental impacts) there are a number of industry-based issues that may benefit from comparing scenarios. These include:

- Comparison of frozen boxed meat (both sheep and beef) with live export of animals to target regions
- Comparison of southern Australian-based feedlot finishing for store steers with live export of feeder steers
- Comparison of disposal of culled cattle via interstate slaughter markets with live export of slaughter cattle to Asia

14. CONCLUSION

The purpose of the study was to undertake a Life Cycle Assessment for Australian live sheep and cattle export supply chains, to provide benchmarks for global warming, water and energy use, and eutrophication. The two supply chains studied were sheep exported from Fremantle to the Middle East and cattle exported from Darwin to Indonesia. All sectors of the supply chain were covered, from on-farm production, pre-shipping export yards, shipping and feed lotting in the destination country through to delivery of the live animal at the abattoir. Producing one wether ready for slaughter in the Middle East contributed an estimated 353 kg CO_2-*e* to the atmosphere, used an estimated 305,400 L rainwater, 2,220 L reticulated water, but no irrigation water, used an estimated 1,640 MJ of energy and produced estimated nutrient flows linked to eutrophication of 1.05 kg PO_4--- e. Producing one steer ready for slaughter in Indonesia contributed an estimated 12,300 kg CO_2-*e* to the atmosphere, used an estimated 23,510,500 L rainwater, 50,400 L reticulated water, and 9,100 L irrigation water, used an estimated 10,700 MJ of energy and produced estimated nutrient flows linked to eutrophication of 5.82 kg PO_4--- e. The study provides the live export industry with a comprehensive benchmark of its environmental performance. The report delivers scientifically rigorous and detailed information on the contribution of the whole supply chain, each sector of the supply chain, each feedstuff used in each sector, and the management practices applied in each sector, allowing the industry to respond in confidence to claims made by others about their environmental performance. But more powerfully, it enables the industry to explore options for improving their environmental impact, and it allows the industry to investigate the environmental outcome of alternate commercial scenarios for supplying markets.

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